NASA Astrobiology Institute

2005 Annual Report

Letter from the Director: NAI Central
Principal Investigator: Bruce Runnegar
Reporting Period: 2005 (7/04-6/05)

Astrobiology thrives. This was strikingly obvious at the NAI 2005 “all hands” meeting of the Astrobiology Institute, hosted by the University of Colorado NAI Team, in Boulder, last March. A majority of the 500 participants were young astrobiologists who are making important experimental, observational, and theoretical contributions towards understanding how life originates and evolves, here and elsewhere. The sessions were lively and comfortably multidisciplinary in a way that was not seen in the early days of the Institute.

This year, these and the other achievements of the NASA Astrobiology Institute are made available in a new interactive way, by means of a of fully-searchable annual report that is seamlessly spliced to the “team pages” on the NAI website (http://nai.nasa.gov/teams). I encourage you to browse, search, and read. The NAI Annual Reports (previous years are also available) are becoming an important ongoing resource for information about astrobiology, especially in the context of student education.

NAI is all about network science. The 16 current NAI Teams extend across the United States from Hawaii to Massachusetts . Each Team has its own internal and external investigators and collaborators. Student involvement is a vital aspect of NAI science and education, so it was particularly rewarding to participate in two outstanding student-organized events: “NAI Summer Student Seminars,” consecutive Friday videoconferences, conceived and given by summer interns at several NAI team sites; and the second Astrobiology Graduate Conference, organized by students at the Scripps Institution of Oceanography in La Jolla for astrobiology graduate students worldwide. These are events we must endeavor to keep on the annual astrobiology calendar.

As the NAI matures, cross-team collaborations become increasingly important. Core astrobiological topics such as cryomicrobiology, the limits to habitability, and planetary-scale biosignatures are being vigorously investigated by organized inter-team activities and community-wide focus groups. Recent NAI workshops aimed at developing collaborative community-wide research dealt with methane on Mars (May), protoplanetary disk evolution (October), and microbial systems in the context of astrobiological exploration (November).

Many NAI teams carry out their research in partnership with other national agencies (NSF, DOE) and laboratories (Argonne NL, Joint Genome Institute, Lawrence Livermore NL). For example, major funding for the University of Rhode Island 's investigations of the deep subsurface biosphere come from the NSF-supported International Ocean Drilling Program (IODP). NAI is exploring ways to extend these kinds of synergies.

International partnerships are aimed at collaborative research at Mars analog sites and common scientific, educational, and training goals. NAI has formal partnership agreements with astrobiological organizations in Australia, Europe, France, Russia, Spain, and the U.K. and connections with many other national organizations through the European Astrobiology Network Association (EANA), the International Federation of Astrobiology Organizations (FAO), Bioastronomy (Commission 51 of the International Astronomical Union), and the International Society for the Study of the Origin of Life (ISSOL).

NAI has a long-standing partnership with the Spanish Centro de Astrobiología (CAB) for an annual summer school in astrobiology. Resources provided by both organizations provide opportunities for about 40 students per year from both sides of the Atlantic . This year's school covered “Titan, Prebiotic Chemistry and the Origin of Life” (nai.nasa.gov/UIMP/Titan) with contributions from American and European scientists intimately involved in the Cassini-Huygens mission.

Last, but not least, NAI's achievements also depend on maintaining the distributed organization, deploying the funding, organizing and implementing collective activities such as NAI 2005, the NAI

Fellows Program, the NAI website, and, of course, producing the NAI Annual Report. These, and other largely “background” tasks, are handled with great care and dedication by my talented and devoted colleagues at NAI Central. Please thank them for their considerable efforts whenever and wherever you can.

Bruce Runnegar

Executive Summary: NASA Ames Research Center

Executive Summary: NASA Ames Research Center
Principal Investigator: David Des Marais
Reporting Period: 2005 (7/04-6/05)

The Ames Research Center Team of the NASA Astrobiology Institute conducts complementary lines of research to understand the context for habitable environments and life, the origins of life and its impact on the planetary environment, and the future of life in changing environments. These investigations address all seven goals of NASA's 2003 Astrobiology Roadmap and they pursue near-term roadmap objectives in ways that help to unify astrobiology and strengthen its linkages to flight missions. The Ames team conveys the content of its research program into its education and public outreach program through partnerships with NASA's education programs, the California Academy of Sciences (CAS), Yellowstone National Park (YNP), New York Hall of Science, and several K-14 educational organizations. Strong conceptual and functional links to multiple NASA missions provide context, motivation, and resource-sharing opportunities for both the research and the education and public outreach efforts.

We investigated the processes that control the formation and the climates of planets. We are modeling the photoevaporation of protoplanetary disks around young stars. This year we constructed a numerical code that calculates the evaporation of disks around low mass (solar-type) stars caused by the ultraviolet and X-ray radiation field created by the young, low-mass, central stars themselves. We presented preliminary results of the heating, cooling, thermal structure, and emission spectra of disks derived from these models. We also presented the first estimates of mass loss rates and dispersal timescales for disks being evaporated by the ultraviolet and X-ray emission from their central stars. We reviewed mechanisms for dispersal of disks and described preliminary results on the photoevaporation caused by the central star.

We have nearly completed a public-domain software package, named "Systemic," that analyzes radial velocity and photometric data for planetary systems. We will release an initial version to the www.transitsearch.org amateur astronomy community for beta testing. The focus of the initial test will be an attempt to obtain a better, self-consistent orbital model for the 55 Cancri 4 system and to test stability of the fit family. We have used Systemic to obtain a joint radial-velocity-photometric solution for the newly discovered transiting planet HD 149026b. The small transit radius of this Saturn-mass planet indicates that it has an extremely massive solid core (60-80 Earth Masses). This indicates that the core accretion hypothesis, and, by extension, the common formation of terrestrial planets, is almost certainly correct.

We developed a new cumulative-planetary-mass-model that predicts a surface density that is more consistent with planetary data than that obtained from the commonly used Hayashi minimum mass distribution. We investigated the condensation/sublimation front in the early solar system to determine the phase state (gas or ice) of important species related to organic chemical processes.

We completed preliminary 3D simulations of an Earth-like climate system that is subjected to extreme orbital configurations. We presented our results at the 2005 NAI meeting. We proposed that early Earth had an atmosphere with tens of percent H_2, and an H_2/CO_2 ratio greater than 1. Perhaps the early atmosphere was indeed a key source of organic molecules for prebiotic processes. We demonstrated that the biological record of extinction after the K-T event is consistent with the thermal pulse from the re-entering debris.

We are tracing, spectroscopically and chemically, the cosmic evolution of organic molecules from the interstellar medium to protoplanetary disks, planetesimals, and finally onto habitable bodies. We also examine the abiotic mechanisms of primitive membrane formation under the primordial conditions of a habitable planet. We have measured IR spectra of aromatic nitrogen heterocycles (a.k.a. polycyclic aromatic nitrogen heterocycles (PANHs) i.e., polycyclic aromatic hydrocarbons (PAHs) with N atoms) in solid H_2O at low temperature in the laboratory. We also measured mid- and near-IR and optical spectra of ionized PAHs in solid H_2O at various temperatures. We found the unexpected result that PAH ions are stable in cosmic ices at temperatures between 100 and 120 K, a very important regime for cosmic ices. We published IR lab spectra that help to interpret observations by NASA's Spitzer Space telescope by showing that the new complex of emission features near 17 microns in many objects arises from various sizes and structures of PAHs. We observed that aromatics are more readily reduced during irradiation in solid ices

than was previously thought, indicating that cyclic aliphatics might have a protostellar origin. A team member leads the proposal efforts for two astrobiology missions: ABE (Astrobiology Explorer) and ASPIRE (Astrobiology Space Infrared Explorer) which is now a mission concept study.

Our studies of potential prebiotic membranes have shown that the addition of aromatics to fatty acids cause changes in vesicle morphology corresponding to changes in surface tension measured on the Langmuir trough. We are also studying photochemical reactions that are facilitated by quinones that cross a bi-layer.

We are exploring the origin of metabolism in the earliest ancestors of cells by testing the hypothesis that proteins might have arisen and initially evolved in the absence of a genome. In order to generate laboratory models of protocellular protein catalysts, we have designed a novel, partially random protein library based on the DNA-binding domain of the human retinoid-X-receptor. We chose this domain because of its small size, stable fold, and two closely juxtaposed recognition loops. In the first selection, variants that specifically recognize adenosine triphosphate (ATP) were isolated. This work demonstrated that it is possible to significantly alter the function of a natural protein from DNA binding to ATP recognition while retaining the protein fold. In a second selection, we used the same library to isolate a novel protein that catalyzes a template-directed oligonucleotide ligation reaction. We continue to characterize our previously isolated ATP binding protein, which was obtained from a random sequence protein library. This protein exhibits a folding pattern not previously seen in biological proteins. Using nuclear magnetic resonance (NMR) spectroscopy, we showed that a new variant of this protein, which was selected for higher thermodynamic stability, retains the same overall structure.

We performed extensive computer simulation studies of model membrane peptides in order to explain the emergence of proteins that mediate transfer of ions, nutrients waste products and environmental signals across proto-cellular walls. We demonstrated that the insertion of α-helices into a membrane is energetically unfavorable, but that stability can be regained through their specific recognition and association into larger assemblies within the membrane. We further showed that, despite their simple structure, the emerging trans-membrane structures could possess properties that appear to require markedly larger complexity. These properties can be subtly modulated by local modifications to the sequence rather than global changes in molecular architecture. This is a convenient evolutionary solution because it does not require imposing conditions on the entire amino acid sequence.

We are characterizing the major factors that govern the formation of potentially diagnostic biosignatures in microbial ecosystems. We studied the microbial population structure and biogeochemical function of microbial mat communities by combining fieldwork in Baja, California, with detailed studies of live samples returned and maintained in a greenhouse facility. We employed a series of stable isotope-tracing experiments to construct detailed budgets of carbon flow through major chemical pools in the mats. We employed molecular biological techniques *in situ* to document systematic shifts in microbial population structure with changes in salinity. These studies help to interpret the biomarkers and likely community compositions of ancient sedimentary deposits hosted in evaporite sequences. They also might help us to interpret evaporitic systems on Mars. A team member published three studies that addressed the multiple roles that microorganisms play in creating biosignatures during carbonate sedimentation and lithification associated with the formation of stromatolites. Another member published a study of the effects of environmental stressors on photosynthetic microorganisms in geothermal springs of Yellowstone National Park.

We are extending the ecosystem-level studies of photosynthetic microbial mats to a planetary scale by refining and evaluating quantitative models that simulate energy relationships, biogeochemical cycling, trace gas exchange, and biodiversity in these systems. We published our first extensive computational model of elemental cycling in hypersaline microbial mats. Subsequently, we "added" to the model a guild of methanogens that rely on noncompetitive substrates such as trimethylamines for their methane metabolism. We also are better defining the roles of photorespiration and fermentation in the model. We have devised a method to model gas flux from the mat surface through the water and out into the atmosphere.

Co-I David Blake's CheMin instrument was selected to fly on the Mars Science Laboratory (MSL) 2009 mission. This closely links our team's work with the Mars program. CheMin will be deployed to study

mineralogy in our field studies (ophiolite and Spitzbergen sites) so that our work can provide directly applicable context for interpretation of MSL science. We completed a mineralogical, geochemical, and microbial community analysis of Complexion Spring, California, which indicates extensive serpentization (with potential to support biology via hydrogen release). Team members continued studies of microbial activity associated with carbonate-cemented lava breccias from Spitzbergen, which are relevant analogs of some martian rocks. We initiated a consortium study on the newly found Martian meteorite NWA2737, which contains abundant brown olivine that has been ascribed to high ferric iron content. Interpretation of this meteorite will contribute to our understanding of the alteration of ultramafic rocks on Mars.

We are examining the effects of climate variability on a vegetation-rich biosphere over intermediate time scales, using South American ecosystems as a model. We have identified modern analogs that serve as functional scenarios for past environments inferred from proxy records. We found that (1) pollen stratigraphy offers rich, diverse information to hindcast ecosystems at coarse time scale, (2) tree rings provide the best time resolution, and (3) neural networks are powerful tools to extract climate-related signals from tree rings. Using South America as our ecosphere analog, we are working to hindcast Net Primary Production over the last 750 years. We are currently enlarging our databases to enable hindcasting of the last 2,500 years, which spans the duration of the Subatlantic phase of the Holocene. Our contributions to the investigation, by M. L. Absy in Northeastern Brazil, show changes in the modern ecosystem that can be captured by quantitative models.

We are assessing the potential for life to move beyond its planet of origin and to survive in potentially lethal radiation environments. We conducted fieldwork in the Bolivian Andes at altitudes (~15,000 feet) where the ozone column was substantially reduced and levels of UV radiation were high. We discovered organisms that are previously undescribed and are possibly highly radiation resistant. We developed a high-throughput assay to detect both direct and indirect DNA damage, such as that caused by radiation. To test a potential means whereby microbes might survive interplanetary travel, we are preparing to test the radiation resistance of organisms situated inside meteorites. We obtained samples of breccia that function as analogs of meteorites, and we are determining crack dimensions in collaboration with the Natural History Museum, London. We are developing methods to get microbes in and out of the breccia. We are using these observations to develop a proposal to obtain actual meteorite samples for tests of microbial survival.

The Ames team's Education and Public Outreach program continues to focus principally on its partnerships with California Academy of Sciences (CAS) and Yellowstone National Park (YNP), but it also pursued other significant activities. The team authored the chapter on thermophiles and astrobiology in the 2005 edition of the recently published Yellowstone Resources and Issues Guide. The first four permanent large "way side" (trail) ceramic signs that interpret thermophilic microorganisms and astrobiology will be installed in YNP this summer. The team submitted extensive recommendations to the "content matrix," a planning document for the new Old Faithful Visitors Center. The team contributed to astrobiology exhibits at the CAS in San Francisco. A team Co-I was recently appointed to the CAS Exhibit Planning Board. He will serve as an astrobiology specialist in designing a permanent exhibit, "Earth and its Place in the Universe", for the newly remodeled CAS campus scheduled to open in 2008. This Co-I participated in both the filming of James Cameron's "Aliens of the Deep" IMAX film and the authorship of the associated educators guide. Two team members are instructors and textbook authors for the current JASON project entitled, "Mysteries of Earth and Mars." The Ames team and the education office hosted the first "Earth to Sky" interpreters' training workshop in collaboration with the National Park Service. Ames continues to work with TERC to disseminate its new high school astrobiology course. Several team members gave numerous talks in classrooms and in informal public venues.

The Ames team maintains on ongoing substantial presence on current NASA missions. The P.I. serves as a strategic planning lead on the Science Operations Working Group of the Mars Exploration Rover mission. Another team member was selected as a P.I. of the CheMin XRD spectrometer for the Mars Science Laboratory mission. A third member serves as a co-investigator with the Kepler mission of NASA's Discovery program. Several team members are involved with the SOFIA mission. Several others are involved with missions that are scheduled or planned for the next several years.

Project Reports: NASA Ames Research Center

Interplanetary Pioneers

Project Investigator: Lynn Rothschild

Project Progress

Year 7 focused on three activities.

1. Field work to new sites in extreme environments. This consisted of field trips to the Bolivian Andes as part of the SETI NAI team led by Nathalie Cabrol of the SETI Institute. The idea was that at the altitudes where we sampled (near about 15,000 feet), the ozone column was substantially reduced, resulting in high levels of UV radiation flux. Additionally, many lagoons exist in the Altiplano with unusual chemistries. As we suspected, organisms new to science, and possibly highly radiation resistant, appear to grow there. The work on one of the lagoons, Laguna Colorado, was presented at the annual NAI meeting in Boulder. The second field site was a radioactive hotspring, Paralana Springs, in the Flinders Ranges in central Australia. Currently collaborator Anitori is working on getting samples into culture and identifying the organisms through DNA sequencing prior to testing for radiation resistance.

2. Development of high-throughput assays to detect DNA damage. Previously our lab used an HPLC method that while accurate, required highly purified DNA and was expensive and slow. Through work conducted by Erin Lashnits, formerly an undergraduate and now a graduate student at Stanford, a quicker, high throughput method for detection of direct and indirect DNA damage is available in our lab.

3. Survival of microbes in meteorites. Collaborator Consolmagno obtained breccia that functions as an analog of meteorites, and is determining crack dimensions in collaboration with the Natural History Museum, London. In our lab, Technician Rogoff has begun to test whether we can easily get microbes in and out of the breccia. This work is being conducted in preparation for tests of radiation resistance of the organisms once inside meteorites, and to have enough data to request actual meteorite samples.

Roadmap Objectives

- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
1	BioPan (ESA)	Co-Investigator
1	EXPOSE (ESA ISS Mission)	Co-Investigator

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

BioPan (ESA) - Co-I (Mancinelli), Co-I (Horneck)

EXPOSE (ESA ISS mission) - Co-I (Mancinelli), Co-I (Horneck)

Field Expeditions

Field Trip Name: Bolivian Altiplano	
Start Date: 10-27-04	**End Date:** 11-9-04
Continent: South America	**Country:** Chile and Bolivia
State/Province:	**Nearest City/Town:** San Pedro de Atacama
Latitude: 67° 46' 53	**Longitude:** 22° 49' 17
Name of site(cave, mine, e.g.): Altiplano	**Keywords:** Thermophiles, extremophiles, UV, halophiles
Description of Work: To collect organisms that might be highly radiation resistant	
Members Involved:	

Field Trip Name: Paralana Springs	
Start Date: 2-4-05	**End Date:** 2-9-05
Continent: Australia	**Country:** Australia
State/Province: South Australia	**Nearest City/Town:** Port Augusta
Latitude: E139°, 26', 26.9	**Longitude:** S30°, 10', 39.8
Name of site(cave, mine, e.g.): hotsprings	**Keywords:** Thermophiles, extremophiles, UV
Description of Work: To collect organisms that might be highly radiation resistant	
Members Involved:	

Cross Team Collaborations

Collaboration with two SETI NAI teams:

1. Mars Analog (Cabrol et al.). The collaboration involved joint field trip to Bolivian Altiplano

2. Iron as a UV protectant on early earth (Bishop). The collaboration involved testing resistance of selected microbes to ambient solar radiation using nanophase iron oxides as protectants. Paper submitted.

Biosignatures in chemosynthetic and photosynthetic systems

Project Investigator: Tori Hoehler

Project Progress

Photosynthetic Systems:

The microbial population structure and biogeochemical function of microbial mat communities was studied through a combination of fieldwork in Baja California and detailed studies of live samples returned and maintained in a greenhouse facility. Detailed budgets of carbon flow through major chemical pools were constructed via a series of stable isotope-tracing experiments. Incorporation of stable isotope into lipid biomarkers and nucleic acids during these experiments is currently being quantified. Molecular biological techniques were deployed in situ to document systematic shifts in microbial population structure with changes in salinity. These studies are relevant to interpretation of biomarkers and likely community composition in ancient sedimentary deposits hosted in evaporite sequences. They are similarly relevant to potential interpretation of evaporitic systems on Mars.

Chemosynthetic Systems:

Co-I David Blake's CheMin Instrument was selected to fly on the MSL 2009. This provides a very close link between our team's work and the Mars program. In parallel with its development for flight, CheMin will be deployed to study mineralogy in our field studies (ophiolite and Spitzbergen sites), so that our work can provide directly applicable context for interpretation of MSL science.

A survey of aqueous geochemistry in Northern California ophiolite-hosted springs was continued. We completed a mineralogical, geochemical, and microbial community analysis of Complexion Spring, which suggests extensive serpentization (with potential to support biology via hydrogen release). We began biomarker analysis on chimney samples from the seafloor serpentinizing ultramafic "Lost City" complex, and published work to establish the "energetic habitability" concept as a constraint on subsurface life.

Conducted studies on formation mechanisms of Fe-rich carbonate deposits in basaltic rocks from Spitzbergen and several other locales. This work directly supports an ability to interpret mineralogical and morphological features in Mars meteorites, as related to olivine weathering. A consortium study was initiated on the newly found Martian meteorite NWA2737, which contains abundant brown olivine that has been ascribed to high ferric iron content. Interpretation of this meteorite will contribute to our understanding of ultramafic alteration on Mars.

Roadmap Objectives

- **Objective No. 2.1:** Mars exploration
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
0	MER 2003	
0	MRO 2005; CRISM Spectrometer	
0	MSL 2009	
0	Copernicus (discovery mission)	

0	Comet Odyssey (discovery mission)
0	Venus/SAGE (New Frontiers mission)
0	Astrobiology and Solar System Exploration

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Overall, this investigation is designed to provide science background and interpretive capacity for Mars in situ and sample return missions, as well as for telescopic life detection (e.g., TPF). By focusing on the production of mineral biosignatures in environments analogous to possible early Martian systems, and on the production of volatile biosignatures in photosynthetic ecosystems, these studies will provide an enhanced scientific context for the eventual return of data from Mars and TPF missions.

MER 2003 - (PI Des Marais): serves on the Science Operations Working Group as a chair of the Long Term Planning Science Theme Group. (Co-I Treiman): is applying (has applied) to be a participating scientist with the MER team, per the ROSES announcement opportunity NNH05ZDA001N-MERPS.

MRO 2005; CRISM spectrometer- (PI Des Marais): serves as Interdisciplinary Scientist for Astrobiology on the CRISM team.

MSL 2009- (Lead Co-I Blake): PI of CheMin XRD/XRF instrument included in the Analytical Laboratory of MSL 2009. (PI Des Marais): Member of MSL '09 CheMin instrument science team. (Co-I, Allan Treiman): Member of MSL '09 CheMin instrument science team

Copernicus (discovery mission)- (Lead Co-I Blake): Co-I, instrument provider for CheMin XRD/XRF.

Comet Odyssey (discovery mission) - (Lead Co-I Blake): Co-I, instrument provider for CheMin XRD/XRF

Venus/SAGE (New Frontiers mission) - (Lead Co-I Blake): Co-I, instrument provider for CheMin XRD/XRF.

Astrobiology and Solar System Exploration - (PI Des Marais): Member of the writing team for a HQ-mandated white paper on this topic.

Field Expeditions

Field Trip Name: Baja Spring 2005
Start Date: 2-10-05 **End Date:** 2-17-05
Continent: North America **Country:** Mexico
State/Province: Baja California Sur **Nearest City/Town:** Guerrero Negro
Latitude: N 27 degrees 40 minutes **Longitude:** W 113 degrees 55 minutes
Name of site(cave, mine, e.g.): ESSA Salt Ponds **Keywords:** Microbial Mats
Description of Work: Sampling microbial mats for maintenance in rooftop greenhouse facilities.
Members Involved:

Field Trip Name: Artic Mars Analog Svalbard Expedition (AMASE) II
Start Date: 8-11-04 **End Date:** 8-25-04
Continent: Europe **Country:** Norway (Norwegian artic)
State/Province: Svalbard **Nearest City/Town:** Longyearbyen

Latitude: 78.5 N

Longitude: 5E

Name of site(cave, mine, e.g.): Sverrefjelle Volcano

Keywords: ALH84001, siderite, carbonate globules, abiotic organic matter

Description of Work: Collection of basalt and carbonate rock from the volcano, chemical and mineralogical analyses. In support of understanding how basaltic rocks alter to form siderite, as is seen in the Martian meteorites ALH84001, Nakhla, and Lafayette.

Members Involved:

Field Trip Name: Bay Area Ophiolites

Start Date: 3-17-05

End Date: 3-17-05

Continent: North America

Country: USA

State/Province: California

Nearest City/Town: San Jose

Latitude:

Longitude:

Name of site(cave, mine, e.g.):

Keywords: Ophiolites, serpentinization

Description of Work: Geochemical analysis of fluids from ophiolite-hosted wells

Members Involved:

Cross Team Collaborations

Work on both the photosynthetic and chemosynthetic systems aspects of this work have been conducted in conjunction with members of the Colorado NAI team. Research on microbial mats in Baja California is being coordinated with a phylogenetic mapping effort on the part of ARC collaborator and CU team member John Spear. Fieldwork and thermodynamic modelling relevant to the geochemistry of ophiolite springs is being conducted in conjunction with Tom McCollom, of the CU team. Additionally, McCollom and ARC team members Hoehler and Schulte were co-organizers of a special session on microbial energetics in extreme environments, at the 2005 Goldschmidt meeting.

Early Metabolic Pathways

Project Investigator: Andrew Pohorille

Project Progress

In order to generate laboratory models of protocellular protein catalysts, we have designed a novel, partially random protein library based on the DNA-binding domain of the human retinoid-X-receptor. We chose this domain because of its small size, stable fold, and two closely juxtaposed recognition loops. We replaced the two loops with segments of random amino acids, and used mRNA-display to isolate new proteins with different functional properties.

In the first selection, variants that specifically recognize adenosine triphosphate (ATP) were isolated. This work demonstrated that it is possible to significantly alter the function of a natural protein from DNA binding to ATP recognition while retaining the protein fold. In a second selection, we used the same library to isolate a novel protein that catalyzes a template-directed oligonucleotide ligation reaction. The chemistry of the reaction is the same as that catalyzed by protein polymerases, i.e. the attack of a 3’-hydroxyl on a 5’-triphosphate. We are currently characterizing the properties of this new catalyst.

Using experimental and computer simulation methods, we continue to characterize our previously isolated ATP binding protein, which was obtained from a random sequence protein library. This protein exhibits a folding pattern, not previously seen in biological proteins. Using NMR spectroscopy, we showed that a new variant of this protein, which was selected for higher thermodynamic stability, retains the same overall structure. We expect to interpret the role of each mutation that arose during the evolutionary optimization of this protein.

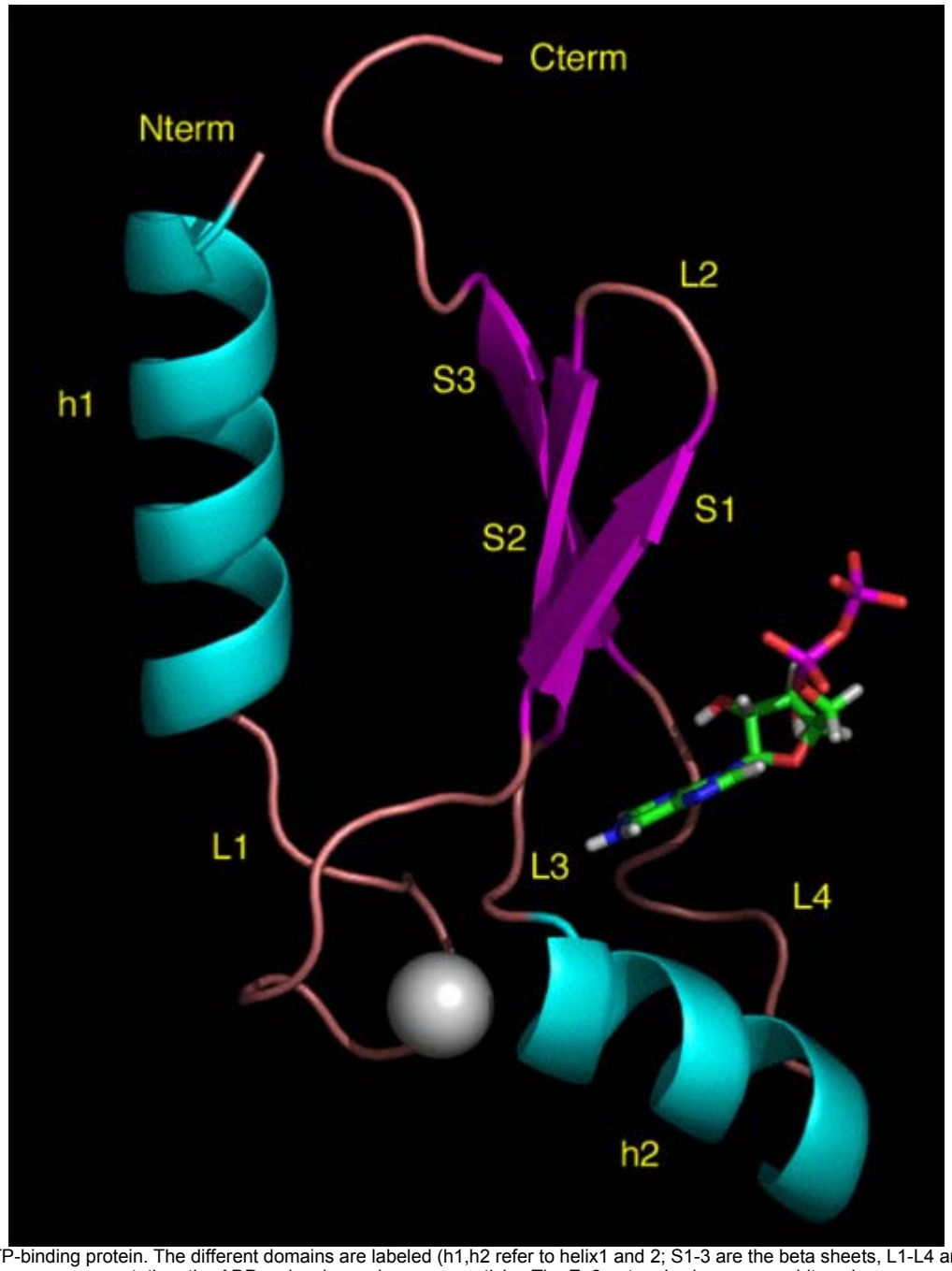

Figure 1. The novel ATP-binding protein. The different domains are labeled (h1,h2 refer to helix1 and 2; S1-3 are the beta sheets, L1-L4 are loop regions). In this representation, the ADP molecule can be seen as sticks. The Zn2+ atom is shown as a white sphere.

In order to explain the emergence of proteins that mediate transfer of ions, nutrients waste products and environmental signals across protocellular walls we performed extensive computer simulation studies of model membrane peptides. These studies rely on an observation that, although contemporary membrane proteins are large and complex, their structural motifs are simple, with α-helices being most common. This suggests that membrane proteins might have evolved from simple building blocks. We demonstrated that the insertion of α-helices into a membrane is unfavorable, but stability can be regained through their specific recognition and association into larger assemblies. We further showed that, despite their simple structure, the emerging transmembrane structures could possess properties that appear to require markedly larger complexity. These properties can be subtly modulated by local modifications to the sequence rather than global changes in molecular architecture. This is a convenient evolutionary solution because it does not require imposing conditions on the whole amino acid sequence.

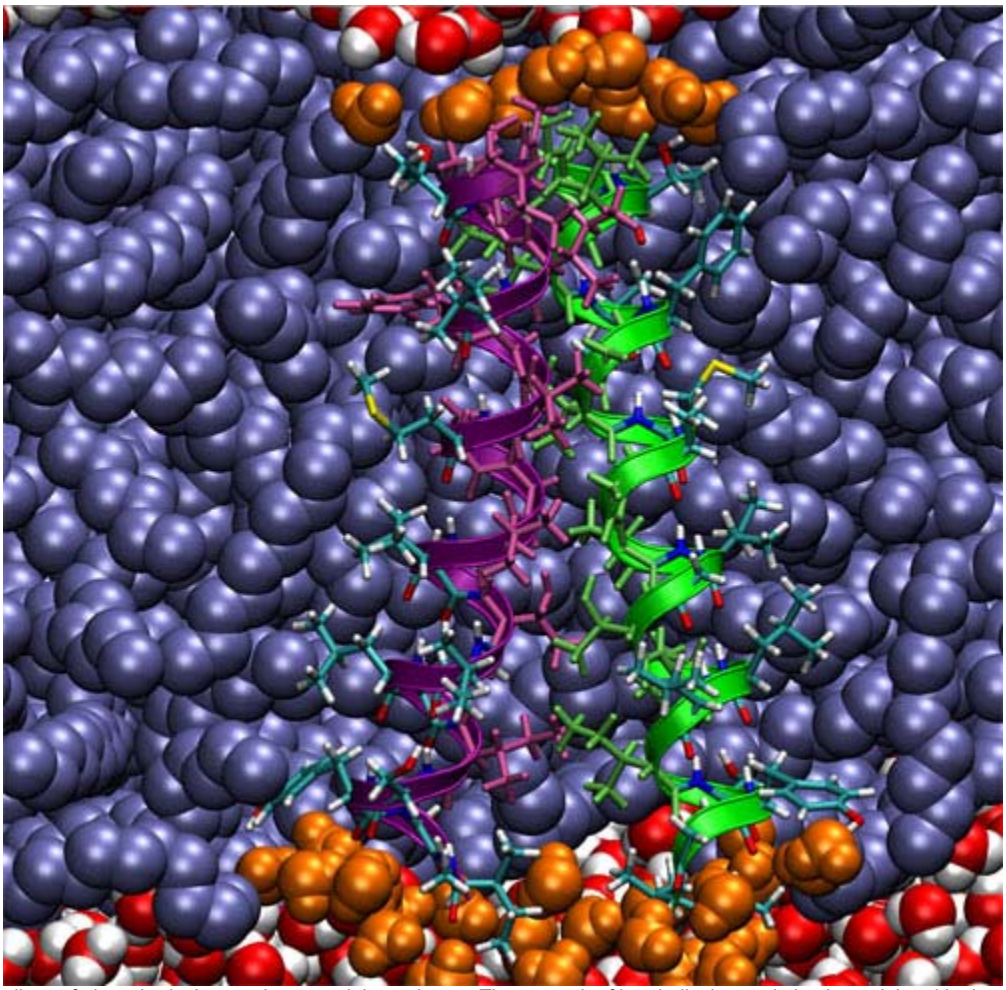

Figure 2. Two interacting α-helices of glycophorin A spanning a model membrane. The strength of interhelical association is modulated by interaction between amino acids directly in contact and can be affected by single-point mutations.

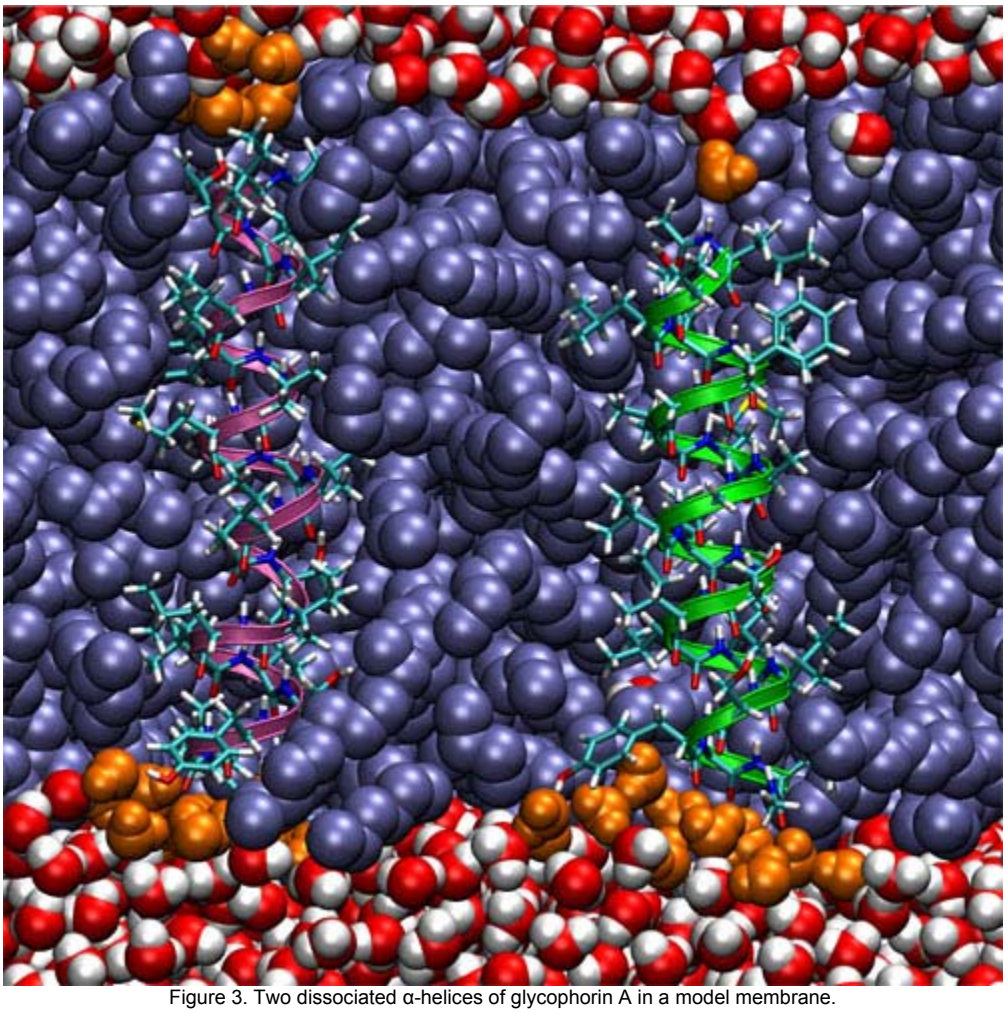

Figure 3. Two dissociated α-helices of glycophorin A in a model membrane.

Roadmap Objectives

- **Objective No. 3.2:** Origins and evolution of functional biomolecules
- **Objective No. 3.4:** Origins of cellularity and protobiological systems

Ecosystem to Biosphere Modeling

Project Investigator: Christopher Potter

Project Progress

Our first paper of the model of hypersaline mats MBGC (Microbial BioGeoChemistry) was published. We worked to add a guild of methanogens to the model that relied on noncompetitive substrates such as trimethylamines for their methane metabolism. This work is currently being prepared for publication. We have also been continuing our work of completing the carbon cycle within the mat which is to prominently include the role of photorespitration and fermentation. Finally, we have devised a means of modeling gas flux from the mat surface through the water and out into the atmosphere. This includes several steps 1) moving gases across the diffusive boundry layer where diffusive flux dominates, but the boundry layer thickness varies wit flow rate of the water; 2) moving gases through the open water via eddy diffusion, and 3) moving gases across the air-water interface (a process involving an aqueous boundry layer and temperature- and salinity-dependent coefficients, as well as the windspeed over the water). We expect this work to be submitted for publication in December 2005.

Roadmap Objectives

- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Habitable Planets

Project Investigator: Richard Young

Project Progress

Co-I O.B. Toon and colleagues at the University of Colorado published several papers with partial support from the Ames Astrobiology Institute, (as described in this and the following 4 paragraphs). A hydrodynamic escape model was applied to an extrasolar planet (Tian,F., et al., Astrophys. J. 621 (2): 1049-1060 Part 1 Mar 10 2005) and was also applied to Earth (Tian F., Toon O.B., Pavlov A.A., DeSterck H.) Science, 308, 1014 (2005); published online 7 April 2005 (DOI: 10.1126/science.1106983). It was shown that early Earth had an atmosphere with tens of percent H_2, and an H_2/CO_2 ratio greater than 1. This means the rebiotic atmosphere was a good source of organic molecules and the past 25 years of searching for extraterrestrial delivery of organics, or inspecting hydrothermal systems is not necessary. Life likely originated in the oceans using the atmospherically generated organics.

The probable results of the solar system passage through interstellar dust clouds was shown to likely cause particles to build up in the stratosphere and block enough sunlight to plunge Earth into a snowball state, and how this might be shown from the geologic record using various elements and isotopes (Alexander A. Pavlov, et al., Geophys. Res. Lett., 32, L03705,doi 10.1029/2004GL021890 (2005); A. A. Pavlov et al., Geophys. Res. Lett., 32, doi 10.10229/2004GL021601, (2005)).

It was shown that mass independent fractionation of sulfur isotopes , the key to quantifying oxygen levels prior to 2.3 bya, can be understood in modern ice cores (A. A. Pavlov, M. J. Mills, O. B. Toon) Geophys. Res. Lett., in press (2005)).

It was shown that the biological record of extinction after the K-T event is consistent with the thermal pulse from the reentering debris. (D. S. Robertson, et al., Geol. Soc. Am. Bull. 116, 760-768,(2004)).

Martian gullies are likely to form under present conditions, and mark an excellent spot to search for life on mars (J. L. Heldmann, et al., J. Geophys. Res. 110, E05004, doi:10.1029/2004JE002261, (2005)).

Co-I Hollenbach working with outside collaborator U. Gorti has been modeling the photoevaporation of protoplanetary disks around young stars. During the past year a numerical code has been constructed which calculates the evaporation of disks around low mass (solar-type) stars caused by the ultraviolet and X-ray radiation field created by the young, low-mass, central stars themselves. Hollenbach & Gorti (2005a, b, book chapters in separate books, see reference worksheet) presented preliminary results of the heating, cooling, thermal structure, and emission spectra of disks derived from their models. Hollenbach & Gorti (2005b) also presented the first estimates of mass loss rates and dispersal timescales for disks being evaporated by the ultraviolet and X-ray emission from their central stars. Richling, Hollenbach, & Yorke (2005, book chapter, see reference worksheet) reviewed mechanisms for dispersal of disks, and described preliminary results on the photoevaporation caused by the central star.

Co-I Greg Laughlin and his student Aaron Wolf have nearly completed the "Systemic" public-domain radial velocity and photometric data analysis package. During Summer 2005, they plan to release an initial version of the package to the www.transitsearch.org amateur astronomy community for beta testing. The focus of the initial test will be an attempt to obtain a better, self-consistent orbital model for the 55 Cancri 4-planet system, and to test stability of the fit family. Indeed, the Systemic package has already proved to be of great utility. Laughlin and Wolf have used it to obtain a joint radial-velocity -- photometric solution for the newly discovered Saturn-mass transiting planet HD 149026b. (Laughlin and Wolf are co-authors on the discovery paper, which acknowledges the Ames NAI grant for supporting their portion of the work). The planet orbiting HD 149026b has important astrobiological consequences. Its small transit radius indicates that it has an extremely massive solid core (60-80 Earth Masses) which indicates that the core accretion hypothesis (and by extension, the common formation of terrestrial planets) is almost certain to be correct.

Co-I Davis has investigated the thermodynamic and physical environment in the early solar nebula. A new cumulative-planetary-mass-model (an integrated form of the surface density) is shown to predict a surface

density more consistent with planetary data than that obtained from the commonly used Hayashi minimum mass distribution (S.Davis, Ap. J. Letters, 2005). The condensation/sublimation front in the early solar system is investigated to determine the phase state (gas or ice) of important species relating to organic chemical processes. The two-dimensional water condensation/sublimation front is also computed and contrasted with that predicted by one-dimensional theory (S. Davis, Ap. J., 2005). With Collaborator D. Richard, a new dynamical turbulence model was developed to predict evolutionary growth of a protoplanetary nebula. This analytical model is used as the basis for the chemical-physical modeling activities. In parallel work, the physical basis of the dynamic turbulence model was investigated in light of classical finite amplitude hydrodynamic stability theory. Progress in chemical-physical modeling included: a) application of the analytical solution to the radial drift, evaporation, and diffusion of condensable substances in the nebula b) a study of the condensation front associated with condensable substances in the solar nebula and c) simulation of the deuterium fractionization in the protoplanetary nebula.

Co-I Hollingsworth in collaboration with Co-I Young modeled extreme atmospheric environments and habitable planet climates. Preliminary extreme orbital configuration simulations for the Earth's climate system have been completed using a realistic 3D climate model which is basically a recent version of the National Center for Atmospheric Research (NCAR), Community Atmospheric Model (CAM). A summary of findings for a particular experiment, wherein the planet's eccentricity was altered from its present value (epsilon = 0.017) to a highly elliptical orbit (epsilon = 0.500) was carried out for one entire Earth year. The results of these simulations were presented at the 2005 Biennial Meeting of the NASA Astrobiology Institute.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 2.1:** Mars exploration
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.3:** Effects of extraterrestrial events upon the biosphere

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
1	Kepler	Co-Investigator
1	Mars Odyssey	Background Research
2	Mars Lander 200	Background Research
2	Terrestrial Planet Finder	Background Research
1	Spitzer Space Telescope	Background Research

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Hindcasting Ecosystems

Project Investigator: Hector D' Antoni

Project Progress

Earth Science's paleobiology identifies *modern analogs* that serve as functional scenarios for past environments inferred from proxy records. This serves Astrobiology to increase its depth and scope as the science of life in the universe. Usually, astrobiologists analyze evolutionary scenarios on systems that are progressive, of growing complexity. In contrast, we analyze regressive scenarios where evolution runs backward, in a process of decreasing complexity. To explore regressive scenarios we created model (1) combining well established practices from literature with spectroscopic, geologic and astronomic data to predict the past ("paleo") ecosystem's Net Primary Production (NPP).

Paleo-NPP ={tΣT (σ*Paleo-NDVI)*ε} V.O.S. (1)

(***tΣT*** measures soil water content, ***σ*Paleo-NDVI*** measures the green biomass, ***ε*** is an energy conversion efficiency coefficient related to location and type of metabolism, and ***V.O.S*** adjusts the results to the state of the Holocene climate forcings at any given time). We use NASA-CASA model data for calibration and control. Regarding proxy records we found that (1) pollen stratigraphy offers rich, diverse information to hindcast ecosystems at coarse time scale, (2) tree rings provide the best time resolution, and (3) Neural Networks are powerful tools to extract climate-related signals from tree rings. Using South America as our ecosphere analog, we try to hindcast NPP over the last 750 years and are currently working to enlarge our databases to enable hindcasting of the last 2,500 years, the extent of the Subatlantic phase of the Holocene. Our contribution to M.L. Absy's work in Northeastern Brazil

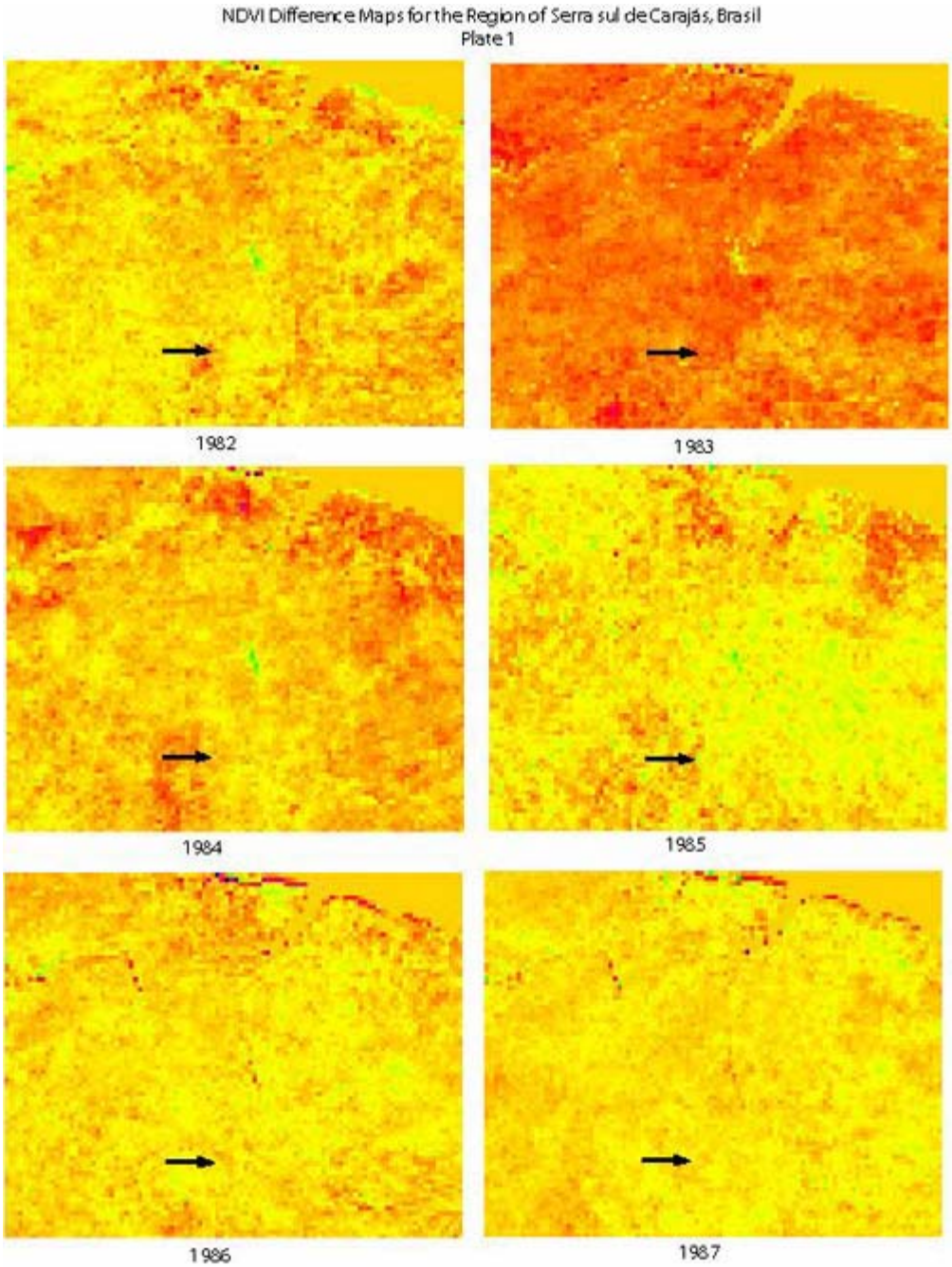

Figure 1. Serra Sul de Caraja. Deviations from 1982-1987 average NDVI map. Red is negative deviation (deficit), yellow is neutral and Green is positive. These deviations are strongly linked to the "El Niño" Southern Oscillation. (See Graph 1).

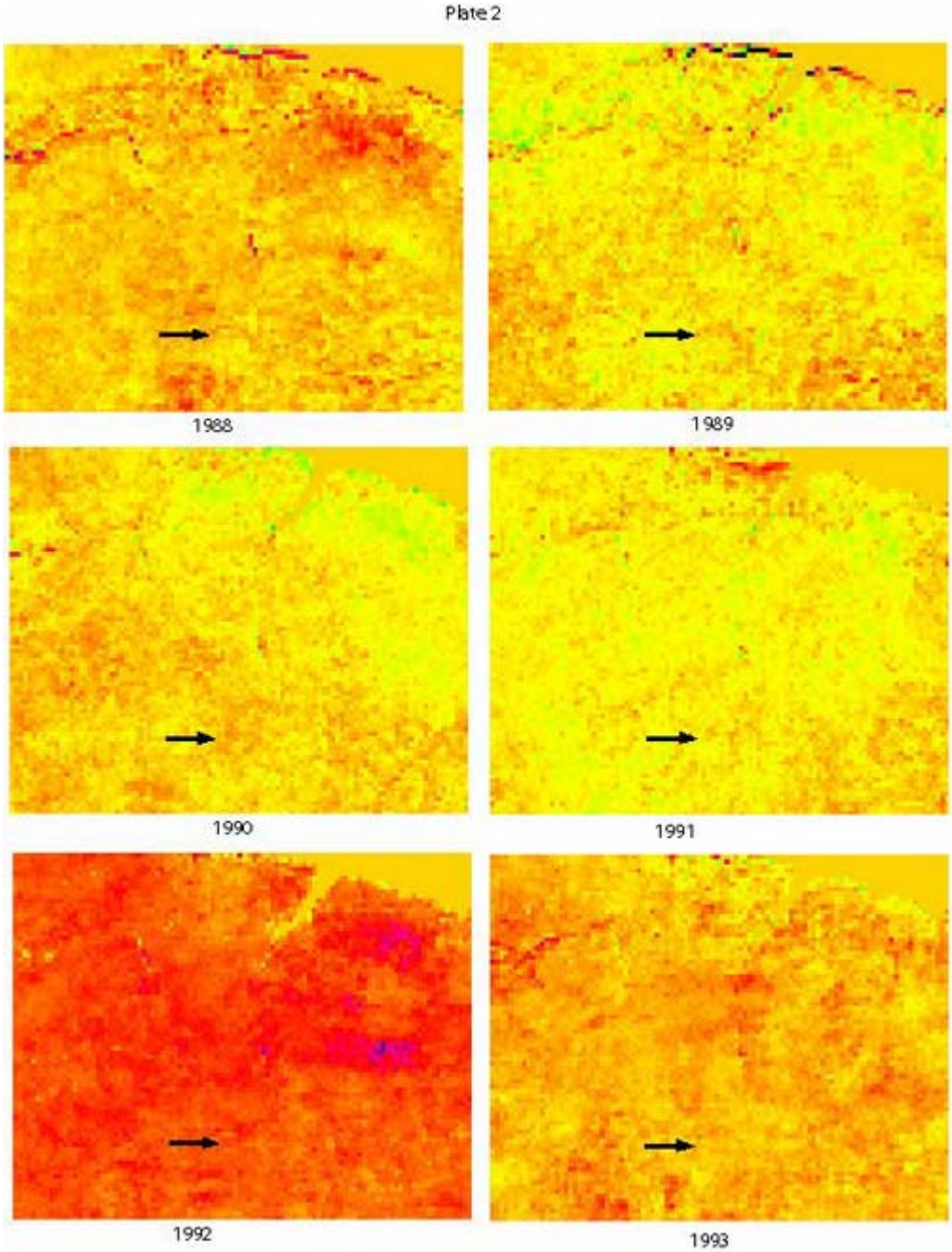

Figure 2. Serra Sul de Caraja. Deviations from 1988-1993 average NDVI map. Red is negative deviation (deficit), yellow is neutral and Green is positive. These deviations are strongly linked to the "El Niño" Southern Oscillation. (See Graph 1).

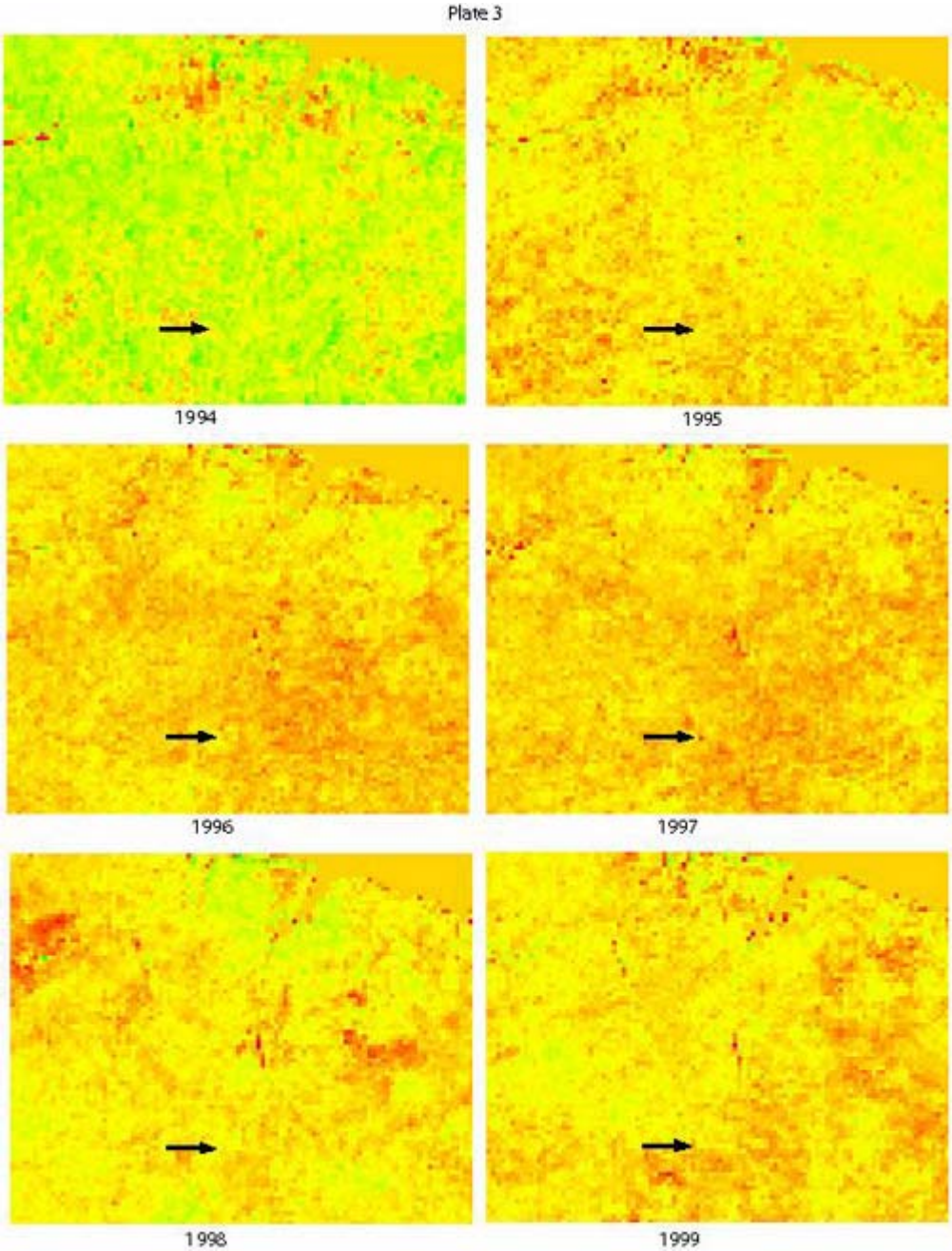

Figure 3. Serra Sul de Caraja. Deviations from 1995-1999 average NDVI map. Red is negative deviation (deficit), yellow is neutral and Green is positive. These deviations are strongly linked to the "El Niño" Southern Oscillation. (See Graph 1).

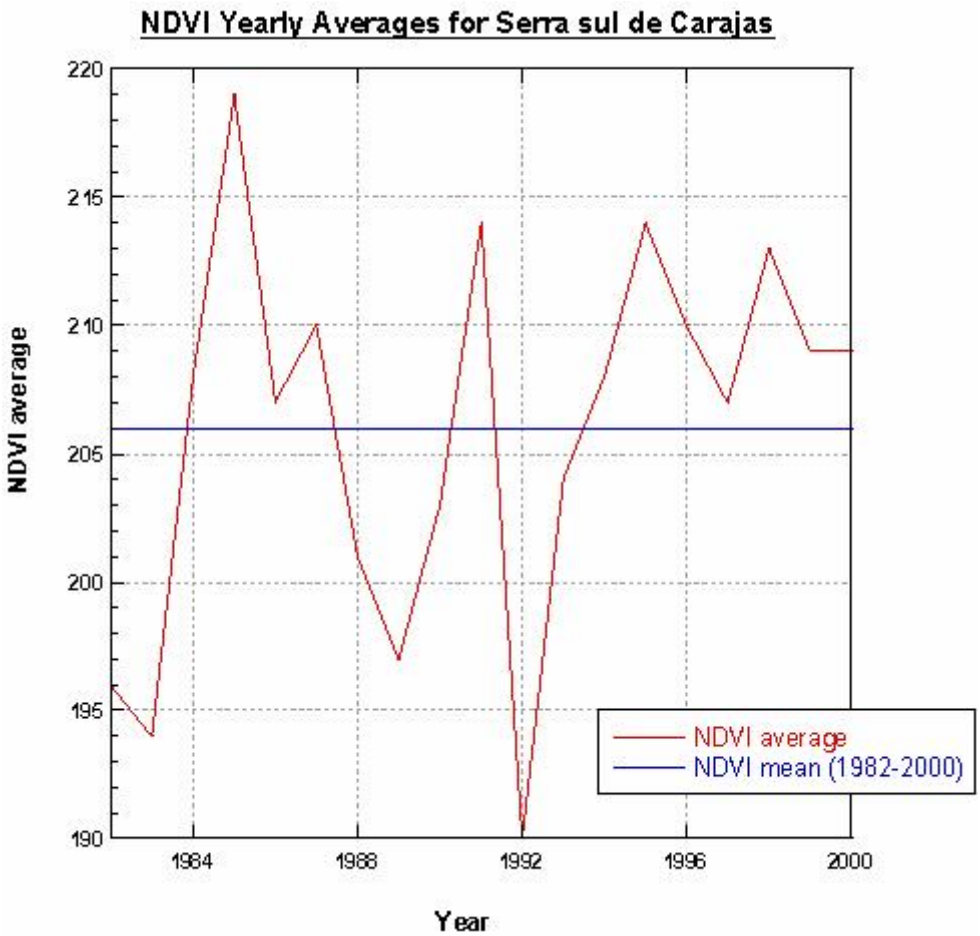

Figure 4. NDVI Deviation at 50°25' W and 6°20' S (marked with an arrow in plates 1-3), where M.L. Absy carried out stratigraphic work. Notice the large deficits of "El Niño" years 1983, 1989, and 1992, and the large positive "La Niña" years of 1985, 1991,1995 and 1997.

shows changes in the modern ecosystem that can be captured by model (1). We collaborated to study the effects of increased ultraviolet B radiation (UV-B) on skin fibroblasts by measuring exposure to the mixture of UV-A and UV-B needed to trigger the process of apoptosis. These data are useful for planning the human exploration beyond planet Earth.

Roadmap Objectives

- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems

Prebiotic Organics from Space

Project Investigator: Louis Allamandola

Project Progress

We have made substantial progress in all three focus areas pertinent to our task.

1. We have an article in-press presenting IR spectra of neutral polycyclic aromatic hydrocarbons (PAHs) in solid H_2O at low temperature. In collaboration with Andrew Mattioda of the SETI institute we have measured IR spectra of aromatic nitrogen heterocycles (a.k.a. PANHs i.e., PAHs with N atoms). We have also measured mid & near IR and optical spectra of ionized PAHs in solid H_2O at various temperatures, and are working on papers on that subject. Optical spectroscopy is a new tool to study processes occurring *within* the ice and have found the unexpected result that PAH ions are stable in cosmic ices at temperatures between 100 and 120 K, a very important regime for cosmic ices. We have applied the IR lab spectra to the analysis of new data from NASA's Spitzer Space telescope. I.e., we showed, in a letter to the Astrophysical Journal, the new complex of emission features near 17 microns in many objects arise from PAHs and the variations give unique PAH size and structure information.

2. Our studies of the radiation chemistry of PAHs in solid H_2O at low temperature are uncovering reactions that will help us better understand meteoritic organic molecules and deuterium enrichment. I.e., recent LC-MS studies done in collaboration with Zare's group at Stanford suggest that aromatics are more readily reduced than was previously thought, indicating that cyclic aliphatics may be of protostellar origin. We shall test this hypothesis with deuterium analyses of these compounds in Murchison as part of a new project this coming year.

3. Our model membrane studies have shown that the addition of aromatics to fatty acids cause changes in vesicle morphology corresponding to changes in surface tension measured on the Langmuir trough. We are also studying photochemical reactions that are facilitated by quinones that cross a bi-layer.

Furthermore, Scott Sandford, a key member of this team, continues to spearhead the proposal effort for two missions dedicated to Astrobiology, ABE the Astrobiology Explorer and ASPIRE, the Astrobiology Space Infrared Explorer which is now a mission concept study.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 3.4:** Origins of cellularity and protobiological systems
- **Objective No. 4.3:** Effects of extraterrestrial events upon the biosphere
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
1	SOFIA	Planning Support
1	SPITZER	Data Analysis
1	Stardust	Co-Investigator
2	ABE	Project Investigator
2	ASPIRE	Project Investigator

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)

3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

SOFIA - Planning support, data analysis, background research, instrument/payload development, research

SPITZER - Data analysis, background research, instrument/payload development, research. Members of team are PI and CoI on Spitzer proposals

Stardust - Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research

ABE - PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research

ASPIRE - PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research

Cross Team Collaborations

We collaborate with The Goddard Astrobiology team. Dr. Jason Dworkin is a member of that team and we exchange samples for analysis and study, as well as join together to put the results in the proper astrobiological context.

Reactions of Aromatics in Extraterrestrial Ice Analogs: Potential Chemical Precursors of Life and False Biosignatures

NAI-NRC Postdoctoral Fellow : Jamie Elsila

Project Progress

I have examined the photochemistry of the aromatic nitrogen heterocycle quinoline in interstellar ice analogs. This is the first study that we know of to examine the photochemistry of this class of molecule in interstellar ices. I have frozen quinoline (the simplest ANH, C9H7N) in water-dominated ices that also contain methane or methanol. After irradiation, I analyzed the products by high-performance liquid chromatography (HPLC) and capillary electrochromatography-mass spectrometry (CEC-MS). I have seen the addition of a variety of side groups, including hydroxy, methyl, and methoxy moieties. These results are analagous to those seen in earlier work of polycyclic aromatic hydrocarbons (PAHs) in similar ices. I have also observed the formation of reduced quinoline, an unexpected product. The discovery of these photochemistry products adds to our knowledge of potentially available chemical precursors to life. This work has been presented at two scientific conferences and is currently being written up for publication.

I have also been studying the formation of amino acids in interstellar ice analogs. Previous work in this laboratory showed that irradiation of an ice analog containing water, methanol, ammonia, and hydrogen cyanide produced a variety of amino acids. I have been working with this type of ice to confirm the previous results, and have also begun extending the previous studies by altering ice composition and formation conditions to see the effect on the distribution and yield of amino acids created. This work is presenting challenges and is ongoing.

Finally, I have been using ~5% of my time to collaborate with educators at the California Academy of Sciences and the SETI Institute on a variety of education and public outreach projects. I have created a student worksheet for a museum astrobiology exhibit, presented talks to museum staff and interns, and will be giving workshops at upcoming science teacher conventions.

Roadmap Objectives

- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 3.2:** Origins and evolution of functional biomolecules

Cross Team Collaborations

I am collaborating with the Education/Public Outreach portion of the SETI Institute's NAI team. Specifically, I am working with Edna Devore and Pamela Harman, and will be presenting two astrobiology-related workshops with Pamela at upcoming meetings ("Origins: The Big Question in Life Science" to be presented at the National Association of Biology Teachers meeting in Milwaukee on Oct. 5, and "Extreme Life Forms on Earth and Elsewhere" to be presented at the California Science Teachers Association meeting in Palm Springs on Oct. 28).

I am also collaborating with Jason Dworkin of NASA Goddard, who is assisting in the analysis of ices created in this work.

EPO Reports: NASA Ames Research Center

YELLOWSTONE NATIONAL PARK

"Yellowstone National Park Offers the Public a Portal to Astrobiology".

The Ames Astrobiology team is working with Yellowstone National Park (YNP) on a long term, public engagement program that includes exhibits, literature, field experiences, educator workshops, and "fireside chats" with astrobiologists that will reach the three million visitors of all ages who experience YNP each year.

Ames has participated in the development of the following interpretative materials on astrobiology and microbiology:

1. Chapters in the 2004 and 2005 editions of the Yellowstone Resources and Issues handbook
2. Nine wayside exhibits (large porcelain signs) presenting microbiology and astrobiology to be deployed Park-wide
3. Lectures for the formal education program of the Yellowstone Association Institute
4. Informal science talks at the Park
5. Content for the YNP web site
6. Consultation regarding the scope and content of exhibits for microbiology and astrobiology in the new Old Faithful Visitor and Education Center (OFVEC).

Understanding how life began on Earth is a natural focal point for astrobiology. Yellowstone is providing insights into the origin and evolution of life and the potential for life to exist beyond Earth. Biochemical clues hint that early life might have lived in high-temperature environments, including hot springs. The park's hot springs provide a glimpse into the nature of the early biosphere. Ancient spring alcoves on the flanks of Martian volcanoes invite comparisons with YNP, whose fossil-rich sinter spring deposits may, in turn, resemble deposits on Mars.

Yellowstone Resources and Issues Guide

The National Park Service produced and published the *Yellowstone Resources and Issues* guide to train their year-round interpreters in YNP. The NASA Ames NAI team specifically created the content for the astrobiology/microbiology chapter 4 titled, "Thermophiles." We coordinated within our team, and the Yellowstone National Park staff, to provide the images necessary to illustrate the content developed to tell the astrobiology story in the Park. Interpreters can use the content to develop specific hikes and tours for the public. NPS also publishes the manual on its web site, where it reaches millions of "remote visitors." In 2004, the Ames team entered into a funding collaboration with Lockheed Martin Space Operations, the Thermal Biology Institute, the American Society for Microbiology, and the Agouron Institute, to produce the guide in color. In 2005, The Yellowstone Park Association contributed the funding for the color publication due to the fact that for the first time this publication had been sold out at the National Park bookstores. The guide is also available to the general public in the bookstores and gift shops in Yellowstone National Park. The park presents 200 guides to the Interpreters during the YNP professional interpretive trainings. The general public purchased 1,500 guides in 2004, and the 2005 publication is currently at 2,000 copies.

Yellowstone Resources and Issues on the web. The Yellowstone web site: www.windowsintowonderland.com receives the highest number of hits of any National Park site. Over 54 additional national park interpreters have accessed the guide for use in their parks. University professors have contacted the park to purchase these guides for use in their courses or as guides for field expeditions to Yellowstone National Park. The 2005 Yellowstone Resources and Issues Guide can be found at www.nps.gov/yell/, click on "In Depth", click on "Publications", then scroll down to the section of the page titled "General Information". The 2005 Handbook is the first publication listed (with link) beneath that heading.

Way Side Sign Exhibit 2005

The Way Side Exhibit project began as a partnership between the NASA Ames Team and Yellowstone National Park. Approximately two years ago, the NASA Astrobiology Institute, Lockheed Martin Space Operations, and the Ames Team took an instrumental step in furthering this partnership by donating funds for the development of outdoor astrobiology exhibits in several locations throughout the Park. These exhibits, located park-wide at sites that best illustrate the most compelling aspects of astrobiology research in Yellowstone, describe how the Park's hydrothermal features are extreme habitats for amazing life forms that may help explain the history our biosphere and also provide clues to assist our search for life on other planets. These exhibits have been developed in accordance with YNP's Long Range Interpretive Plan. They are site specific and interpret what is immediately visible and obvious to the visitor in this spectacular setting. The Way Side Sign Exhibit opens to the Yellowstone National Park public with installation end of summer early fall 2005. Way Side titles include: "Travertine Occupants" and "Living Color" which focus on thermophiles at Mammoth Hot Springs, "Roaring Mountain: Living Landscape" and "Fumaroles" in the Roaring Mountain region, "Buried Alive" at Excelsior Geyser, "Making Mud" at Fountain Paint Pot, and "Life on the Edge" and "Prism of Light, Spectrum of Light" at Grand Prismatic Spring. Ames Team members who have major contributions include David Des Marais, David Ward, Tori Hoehler, Jack Farmer, Linda Jahnke and Catherine Tsairides. The NASA Astrobiology Institute and Lockheed Martin Corporation have contributed funding for the Way Side Exhibit. The collaborative project included the Deputy Chief of Interpretation at Yellowstone National Park and the exhibit design leads. The Yellowstone interpretative staff and the NASA Ames Astrobiology team determined the text, images and graphics. Park staff and the Ames NAI Team as agreed upon the selection of the sites that would best illustrate the astrobiology and microbiology stories. References and sources for the Thermophile Exhibits are available on-line at www.windowsintowonderland.com.

Old Faithful Visitor Education Center (OFVEC)

Millions of people visit Old Faithful every year, making a visitor education center next to the world's most famous geyser a multigenerational project that will touch the lives of young and old. It will improve the public's understanding of Yellowstone and inspire individuals to pursue further scientific learning in their personal and academic lives. A central interpretive element for Old Faithful Visitor Education Center will be to present, with remarkable thoroughness the magic, mystery, and meaning of Yellowstone's hydrothermal features and their inhabitants.

The Old Faithful Visitor and Education Center is currently scheduled for groundbreaking during the spring of 2006. Construction should be completed during the summer of 2008. The Yellowstone Park Foundation has completed the capital campaign this year that raised $15 million to fund the construction of OFVEC, which will contribute to a more scientifically literate citizenry in the following ways:

The primary resources and interpretive themes of the new exhibits will focus on the park's hydrothermal features, the fact that Yellowstone preserves the greatest assemblage of natural, undisturbed geysers, hot springs, fumaroles, and mud pots on the planet, and the story of life in these extreme environments. The NASA Ames Astrobiology Team will be invited to provide information on the astrobiology component of the thermophile story, based on their ongoing scientific research in Yellowstone. The permanent exhibits are being designed with great care and thoughtfulness because they are absolutely central to a successful and memorable visitor experience. The exhibits will have an integrated approach and be developed to complement and build upon partner expertise and facilities. The development of these exhibits offers the NAI Ames lead team an opportunity to work with the National Park Service's Division of Interpretation and an interdisciplinary team of geoscientists including geologists, volcanologists, geothermal specialists, microbiologists, sociologists, educators, exhibit specialists, and interpretive planners from an array of organizations.

The exhibits will focus on Yellowstone National Park as a living laboratory where diverse resources, natural processes, and cultural history provide important and unique opportunities for research and education. Current research on Yellowstone's thermal features will be incorporated throughout the exhibits and will be presented in an easily updateable format. The exhibits will be designed following a layered-learning model. They will be categorized in technical complexity so that all visitors, from the very young to the very old, can understand and appreciate the Yellowstone experience at their own level. Accordingly, an automated, on-

line component will be incorporated into the exhibits. World Wide Web presentations and long-distance learning materials will be well developed along with innovative and appropriate technologies that will be interesting and relevant to visitors. School groups that cannot visit Yellowstone in person will be able to access web-based Electronic Field Trips (EFTs) that will correspond to the science themes represented in the center. This on-line component will provide students from around the world, particularly from inner cities, rural areas, and nearby Indian reservations the opportunity to learn about the rich biological diversity of Yellowstone as well as the science and resource issues that concern our planet today.

Multiple points of view from the perspective of scientists, Native Americans, early explorers, artists, visitors, and others will be incorporated to make the exhibits relevant to a broader audience. The design of the exhibits will be multidisciplinary and include information about the physical sciences, math, history, humanities, Native American culture, etc. The exhibits will also focus on current and emerging research that is critical to understanding and solving environmental issues facing society today. The arts will be incorporated throughout the OFVEC in order to provide aesthetic and important historical perspectives to link Yellowstone's establishment, hydrothermal features, and worldwide recognition to the multitude of artists who have painted, photographed, composed, and written about this special place.

Seven to 20 percent of total on-site Yellowstone National Park visitors, and an even greater percentage of on-line park visitors, are from foreign countries. Exhibits will be multi-lingual and translated into the four major non-English languages spoken among Yellowstone visitors. In order to view an artist's conception of the lobby and exhibit features, visit http://www.nps.gov/yell/tours/onlinevcs/oldfaithful/sketches.htm

Special emphasis will be on activities that serve school groups. Curriculum-based programs, classroom materials, and life-long learning opportunities will correlate with national standards for science education. Programs for organized school groups on-site will expand upon the exhibits presentation and inspire new generations of young scientists and Park stewards. The curriculum will present science as a tool for exploration and facilitate learning in engaging ways that will increase the scientific literacy of many Park visitors who might otherwise be intimidated by the subject.

Opportunities for hands-on learning about science, math, and technology will be developed through the Young Scientist Program. This program will provide structured, field-based opportunities for children ages 6-13 to engage in science exploration activities with their parents and mentors during their Yellowstone visit.

The exhibits will be developed to complement and build upon partner expertise. With the NASA Astrobiology Institute $50,000 award towards astrobiology content development we can proceed with the development of these exhibits which offers NASA, specifically NASA Astrobiology lead teams, an opportunity to work with the National Park Service's Division of Interpretation and an interdisciplinary team of geoscientists including geologists, volcanologists, geothermal specialists, microbiologists, sociologists, educators, exhibit specialists, and interpretive planners from the United States Geological Survey, the University of Utah's Department of Geology and Geophysics, and Montana State University's Thermal Biology Institute, among others.

Radio Frequency Identification (RFID) will be an innovative element to enrich the visitor's experience. "RFID tags" can remotely store and retrieve data. These tags can be incorporated into wristbands, rings, and other portable devices; they will enable visitors to "bookmark" their tour of OFVEC. For example, if a visitor sees an exhibit about thermophiles the microscopic organisms living in Yellowstone's thermal springs and wants to learn more about their relationship to life on early Earth and perhaps other planets, the visitor would simply scan the RFID tag. This would enable them to "bookmark" this specific topic of interest and later access detailed information from home. RFID technology is currently being successfully used at the Tech Museum of Innovation in San Jose, California, and is being incorporated into the new D-Day Museum in New Orleans. RFID is especially useful for formal education at the Park and for visiting school groups that can continue learning about Yellowstone long after their field trip. The information that these RFID tags will disseminate must still be developed, and the Ames Team has been invited to contribute content on astrobiology and microbiology. In order to view an artist's conception of the lobby and exhibit features, go to www.nps.gov/yell/tours/onlinevcs/oldfaithful/sketches.htm

Old Faithful Education Visitor Education Center Lockheed Martin Corporate Contribution

America's fascination with Old Faithful Geyser has transformed it into a cultural icon, a place of pilgrimage, and a shared legacy. The exhibits in the Old Faithful Visitor Education Center will recognize and interpret this legacy in a meaningful way.

The NASA Ames Astrobiology team and the Yellowstone Park Foundation prepared and submitted a proposal requesting that Lockheed Martin Corporation contribute $200,000 toward the development of exhibits for the new Old Faithful Visitor Education Center in Yellowstone National Park. Mr. Kenneth Reightler, President of Lockheed Martin Space Operations authorized this generous donation to support interpretation of NASA Astrobiology and NASA space exploration. This is the first corporate donation incorporating all business units, which include the following:

- Lockheed Martin Space Operations
- Lockheed Martin Information & Technology Services
- Lockheed Martin Space Exploration Organization
- Lockheed Martin Space Systems Company
- Lockheed Martin Information Technology
- Lockheed Martin Technical Operations
- Lockheed Martin Aeronautics
- Sandia National Laboratories (Managed by Lockheed Martin)

Yellowstone National Park Planning Team / Old Faithful Visitor Education Center

Yellowstone National Park Planning Team. Dr. David Ward, Montana State University, represents the Ames Team on the YNP Planning Team. Diane Chalfant, Chief, Division of Interpretation at Yellowstone National Park invited an Ames Team member to join the Science Advisory team as part of the development team for the Old Faithful Education Center. The six-member Science Advisory Team included five geologists: Robert Fournier (ret. USGS), Robert Smith (Univ. Utah), Duncan Foley (PLU), Lisa Morgan (USGS), Hank Heasler (YNP), in addition to Dr. Ward. The Education Team consisted of various people experienced in museums and science education therein (Bonnie Sachatello-Sawyer, Native American Waters Project; Deborah Perry, Visitor Studies Assoc.; Bob Pickering, Buffalo Bill Historic Center; Jaci Tomulonis, Monterey Bay Aquarium; and Diane Chalfant). The design team from Chadbourne and Associates (Boston) was recently awarded the contract for OFEVC. A review of the front-end evaluation given by the Visitor Studies Association was part of this meeting. Overall, ultimately, our long term project goal is to be awarded significant floor space for interpreting extremophiles in the context of what causes the colors in the hot springs, and their importance to the story of evolution of life on Earth and elsewhere in the Universe. The exhibits will have an integrated approach and be developed to complement and build upon partner expertise and facilities. The development of these exhibits offers the NASA Ames Astrobiology lead team an opportunity to work with the National Park Service's Division of Interpretation and an interdisciplinary team of geoscientists including geologists, volcanologists, geothermal specialists, microbiologists, sociologists, educators, exhibit specialists, and interpretive planners from the United States Geological Survey, the University of Utah's Department of Geology and Geophysics, and Montana State University's Thermal Biology Institute, among others. The primary resources and interpretive themes of the new exhibits will focus on the park's hydrothermal features, the fact that Yellowstone preserves the greatest assemblage of natural, undisturbed geysers, hot springs, fumaroles, and mud pots on the planet, and the story of life in these extreme environments. The NASA Ames Astrobiology team has been invited to provide information on the astrobiology component of the thermophile story, based on their ongoing scientific research in Yellowstone. Dr. David Ward remains the Ames Team lead on the Old Faithful Visitor Education Planning Committee. Each month he presents the team's vision for the exhibit plan to the park and in turn provides us with the overall expectation of the park. Together the NASA Ames Astrobiology Institute team provides input to the plan. With team approval Dr. Ward presents our input to the committee and it then goes through numerous cycles for review and ultimate approval from Dr. Des Marais and the Ames Team for exhibit development.

See http://www.nps.gov/yell/tours/onlinevcs/oldfaithful/index.htm for artists conception of lobby and exhibit features on the first floor. The Selinda Research front end report is available at

http://www.selindaresearch.com/.

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100 Year Anniversary for Old Faithful Inn

The Old Faithful Visitor Center celebrated its 100th year with a four-day event in October 2004 that was hosted by the Yellowstone Park Foundation and Association. The Ames Astrobiology Team was invited to participate. The Yellowstone National Park Interpreters provided tours utilizing the interpretive process model taking us back a hundred years to interpret the historical aspects of the park. This was done through storytelling, art exhibits, music, night-time tours of the Inn, and expeditions to various sites around the park. The park Superintendent, Suzanne Lewis, gave a presentation to hundreds of corporate sponsors. On the agenda was the description of the astrobiology program and collaboration with NASA and the National Park Service. Mr. Kenneth Reightler, President of Lockheed Martin Space Operations, was honored for the $200,000 contribution to the new Old Faithful Education Visitor Center from Lockheed Martin Corporation. This contribution came forth to support the Astrobiology program specifically at NASA Ames Research Center, led by Dr. David Des Marais. Dr. David Ward of the integrated NASA Ames Astrobiology Institute team presented astrobiology/microbiology research to hundreds of visitors on the boardwalks as with the National Park Rangers. He was part of the program and provided a specific astrobiology/microbiology focused tour around the boardwalks outside of Old Faithful and into the NASA research sites describing our astrobiology Way Side Exhibit program funded by the NASA Astrobiology Institute and Lockheed Martin Space Operations.

CALIFORNIA ACADEMY OF SCIENCES

The Ames Team works with the California Academy of Sciences (CAS) to develop new astrobiology exhibits, and other products for the public. CAS has chosen to utilize astrobiology concepts to link its natural history museum, planetarium, and aquarium under the theme, Earth and its Place in the Universe. Ames personnel serve on the CAS design and exhibit development teams. Ames and CAS will also facilitate interactions between researchers and educators in order to develop inquiry-based programs and activities for K-14 students. The California Academy of Sciences (CAS) exhibit entitled "Astrobiology: Life in the Extremes" was developed and opened in downtown San Francisco during this past year. The NASA Ames Astrobiology team partnered with CAS to create the astrobiology exhibit. Dr. Carol Tang was the Co-Investigator for NASA Ames and lead on the design and development team, which included CAS curators, staff, and outside consultants (Pompei AD and Cinnabar, Inc.). This 2500 square foot exhibit focuses on extreme environments and the lessons they provide for astrobiology. Exhibit material was provided by NASA, NASA ARC, CAS, VPL, and Penn State as well as members of the scientific community consisting of scientists from UC Davis, Portland State, and Woods Hole Oceanographic Institute. NASA-ARC provided the majority of images for the hot springs exhibit component. 300,000 ticketed visitors have seen the exhibit at the California Academy of Sciences.

California Academy of sciences Collaboration Projects include the following:

Astrobiology: Life in the Extreme Exhibit ~300,000 visitor's Docent-led tours

Comet-making demonstrations by docents 4 times a month on public floor

Astrobiology: Life in the Extreme Website http://www.calacademy.org/naturalhistory/astrobiology.cfm

Astrobiology exhibit teacher support materials Online and distributed at museum http://www.calacademy.org/education/Astrobiology/astrobiology_main.htm

Docent Training Lecture by NASA ARC/NAI Postdoc on comets and deep impact, Dr. Jamie Elsila, 35 attendees

Docent and staff training Visit to Aliens Earth exhibit at Lawrence Hall of Science, 40 attendees

Docent, intern, staff training Viewing of Aliens of the Deep, 60 attendees

Outreach (introduction of film, show-and-tell of vent specimens after film) Aliens of the Deep ~600 visitors (K-12 school group participants)

Development of Earth and its Place in the Universe exhibit Content development for 2008 exhibit

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Docent Field Guide to Exhibits

The California Academy of Sciences developed a docent field guide, which provides an introduction to the exhibits featuring Astrobiology: Life in Extreme Environments. The docent manual follows the same path as the exhibit floor by outlining the content in specific exhibit areas. This collaborative manual provides the docents with the content needed to provide public talks, small group discussions, and science on the floor demonstrations within the astrobiology exhibit space. Dr. Carol Tang coordinated the development of content in the guide, which addressed the following questions: What is Astrobiology?; Astrobiology-Life in Extremes; Astrobiology is the Study of Life, its Evolution and Distribution in the Universe; How do we study life?; Earth is unique in the solar system/universe; Where is life found? Life has been found in many of Earth's extreme environments. Extreme environments exist elsewhere in the solar system on other planetary bodies. Does Life exist elsewhere in the universe? The understanding and exploration of extreme environments, both on earth and elsewhere, guides our search for life.

Engaging Researchers in Museum Exhibit Development: Lessons from NASA Ames and the California Academy of Sciences

NASA Ames Research Center's astrobiology team and the California Academy of Sciences (CAS) have implemented a partnership to develop astrobiological content for museum exhibits. Because its exhibits include astronomy, natural history and marine biology, CAS shares a broad interface with astrobiology research and exploration. The CAS-Ames collaboration has resulted in a small exhibit that opened in April 2004 and a preliminary structure for future collaborations.

One factor in the success of this partnership is the active participation of CAS in monthly Ames Team meetings. Face-to-face interactions were vital during early stages of the partnership. The PI scheduled EPO presentations alongside research talks, thus giving them equal weight and consideration. Social interactions helped cement working relationships between team members.

Secondly, by receiving updates on the pace and process of exhibit development, the scientists became better educated about the challenges of informal learning. Prior to this project, few astrobiology researchers had been involved in the evaluation, development, prototyping and design of exhibits. Ames Team members became more aware of their roles and how they could effectively contribute.

Finally, the collaboration permitted different levels of involvement. Therefore those scientists who didn't have as much time could still contribute images while those who were more extensively involved contributed to story development, fact-checking, brainstorming, and specimen preparation. Whatever their level of contribution, team members felt that they could contribute and were able to see tangible results relatively quickly. This positive feedback added to their sense of contribution and commitment to EPO efforts and future collaborations.

Bringing Astrobiology Research Alive Through Museum Exhibits. The California Academy of Sciences, a research institution, natural history museum, aquarium, and planetarium in San Francisco opened a 2000 square foot exhibit entitled, "Astrobiology: Life in the Extremes", in April 2004, developed in partnership with NAI teams (NASA Ames and SETI primarily). The exhibit currently focuses on research in hot springs and deep-sea hydrothermal vents as case studies for astrobiology.

The exhibit-development process successfully incorporated contributions from astrobiologists including

hundreds of images, captions, specimens, story ideas, and scientific background for the exhibit development team. These collaborations will continue as the Academy re-builds the museum for 2008.

The use of live organisms, physical specimens, familiar touchstones, and human facilitation is believed to enhance learning and engagement by visitors in the CAS astrobiology exhibit. Some of the most popular elements in the exhibit are the brine shrimp, bacterial/diatom community, and Death Valley pupfish tanks. While the use of hundreds of projected images, animations, and video provide a contemporary feel for the exhibit and the science of astrobiology, it can also be overwhelming and disorienting for visitors without appropriate explanations. Docents and interns have conducted public demonstrations on comets, DNA extraction, geology and microscopic life after receiving astrobiology training.

One of the major challenges for a successful small astrobiology exhibit is providing connections and integration between the disparate disciplines and concepts within the field. Given the interdisciplinary nature of astrobiology, one must use accessible content and creative graphics, lighting, text, and physical layout to allow visitors to explore connections in a non-linear fashion.

California Academy of Science Poster Presentation

Dr. Carol Tang prepared and submitted two posters that were presented at the Biennial Astrobiology Science Conference this April 2005. Authors included Dr. David Des Marais, Catherine Tsairides, Jamie Kulik. The poster session took place at the University of Colorado, Boulder.

NASA/NPS MEMORANDUM OF AGREEMENT

The Memorandum of Agreement was entered into by the National Aeronautics Administration (NASA) and the National Park Service (NPS), Department of Interior. This MOA is intended to foster a collaborative effort between NASA and the NPS to use earth science imagery and NASA exploration and science programs for the preservation, enhancement and interpretation of the natural resources of the United States.

The NASA Ames Astrobiology Institute team provided the linkage to space science and earth science throughout the document while integrating the interpretation language into the final document. Both NPS and NASA provide capabilities that educate and inspire the public through discovery and interpretation of natural environments. NASA exploration and science programs offer substantial benefits to NPS interpretation that, in turn, informs and inspires park visitors about our place in the natural world and the universe. NPS desires to establish working relationships between its interpretive staff and NASA-sponsored investigators to enrich NPS interpretive programs.

These discussions took place between Dr. Woody Turner, Dr. David Des Marais, and Dr. Chris Potter.

NASA EXPLORER INSTITUTE (NEI) "Earth to Sky" NPS/NASA

Earth to Sky NASA and NPS Explorer Institute October 18 - 22, 2004

The purpose of this Institute is to broaden exposure to and heightened interest in NASA Earth and Space Science topics; Enhance familiarity with one or two NASA content themes: Astrobiology, Comparative Planetology, Earth Systems Science, the Night Sky, and the Sun and Space Weather; Understand how to access NASA resources (people, on-line resources, programs and products); Develop further knowledge of and ability to apply the Interpretive Process Model; Network and learn with and from a community of colleagues; apply NASA content to a written product or an interpretive program -- create an Action Plan; Expose NASA scientists and E/PO personnel to interpretive concepts and techniques i.e. to understand and appreciate the power of interpretation.

Our purpose in developing this workshop was to create a sustainable partnership between NASA and the National Park Service incorporating the goals (above) into the emerging Memorandum of Agreement document. We also wanted to elevate the National Parks into the Education and Public Outreach framework for NASA in the way that science museums and centers are utilized. Reciprocal learning was a major goal of this workshop giving the NASA EPO leads the opportunity to learn the "Meaningful Interpretation" methods that the National Park Service is engaged in. During the planning phase of the science content program Dr. Isabel Hawkins from the University of California, Berkeley, and Catherine Tsairides of the NASA Ames Astrobiology Team held individual planning conferences with the invited research team members. The whole science team also participated in teleconference meetings to organize the agenda and to develop their presentation to meet the requests of the National Park participants. In turn, the National Park Interpreter facilitators trained in our first workshop held at NASA Goddard Space Fight Center now were given the opportunity to meet with each science team member by phone to discuss their NPS group expectations so that the science talk could be directly linked to the objectives of each park. The National Park Service Interpreters were given the opportunity to participate in field experiences in the research team's labs throughout the NASA Ames Astrobiology Team. Dr. Rothschild and Dana Rogoff presented Extremophiles. Dr. Hoehler, Dr. Lee-Prufert Bebout introduced the microbial Mat/Greenhouse research. Dr. Max Bernstein, Dr. Lou Allamandola introduced the NPS to the Astrochemistry Laboratory. Sandy Dueck took groups through the Life Sciences/Space Station. Each science team member in their labs provided hands-on laboratory experiences and specialized presentations for the interpreters. After each session a facilitator led discussion took place guided by the NPS interpreters. While at NASA Ames Research Center an evening event was held in the Mars Museum consisting of a reception and evening keynote talk given by Dr. David Des Marais. The keynote presentation was the "Mars Exploration Rover Mission" At the reception a Share-A-Thon was held where NASA educational materials were showcased and presented to the National Park participants. These showcased materials were introduced after each science talk and integrated into the program by education and public outreach specialists from across NASA missions. The agenda was comprised of the National Park Interpreter lead, a research scientist, and an education and public outreach representative. The NPS participants chose two or three sessions to attend and the research presented also had complimentary education material introduced during their session. The trained National Park Interpreter facilitator would then incorporate their interpretive process model into the discussion hour which then gave the NPS participants a chance to consider the research that is valuable to their park's mission and how to create programs that inform, excite, and involve the national public utilizing NASA research and educational products. According to our evaluation report on the "Earth to Sky" - A NASA and National Park Collaborative prepared by Learning Innovations at WestEd, there were many success stories in professional development from this workshop. The National Park Interpreters clearly related to the goals of informing and motivating the public that the parks share with NASA scientists and the education leads.

Ultimately, the connections that were made between the science that the NPS learned and their own parks allowed the NPS to begin planning interpretive projects to inform the general public in their parks. Some began to develop curriculum units to work with teachers as parks do have formal education programs. The NPS Interpreters found that many of the NASA formal and informal products were very relevant and useful. The interpreters also found they had a direct link to the research, and research team, so they began to invite the science team to their parks for research opportunities that were important to NASA and also fulfill the park's objectives.

Together through this integrated experience, rich science experiences were brought alive to the public from the Interpreters using the interpretive model. One such project is in place at Lassen National Park led by Dr. Lynn Rothschild at NASA Ames Research Center and Mr. Steve Zachary, Lassen Volcano National Park Deputy Chief of Interpretation. Lynn Rothschild and Rocco Mancinelli organized a program with Steve Zachary to become park volunteers. They went on a three day exploratory mission to Lassen National Park. He arranged for the science team be Park volunteers through December to facilitate sampling. Included were also three high school interns who were part of the research expedition. Mr. Zachary hiked the team to Devil's Kitchen and Boiling Springs Lake, both acidic areas, where research samples were taken. They snow-shoed to Cold Boiling Lake where the team collected water and microbial samples, as well as watermelon snow. This trip had the dual purpose of acquainting the research team with the park, as well as gathering samples that they are performing microscopy on. This partnership includes ongoing communication, two way learning experience and NASA research that provide the NPS with real outreach opportunities. The research data, graphics, and subsequent content will be given to Lassen Volcano National Park to use in exhibits underway. Steve Zachary will also create a web site and public presentation integrating the NASA Ames Astrobiology extremophile research into a variety of programs for the national public. This is one

example project that stemmed from the NASA/NPS collaborative. There are a variety of science team members holding conversations with the Interpreters who attended to begin preparing proposals that include the NPS so that the funding for this partnership can be sustained as they enter into a long term research/public outreach partnership.

DEVELOP, A NASA PROGRAM PROMOTING GIS AND REMOTE SENSING USE

DEVELOP is a NASA-sponsored student intern program with activities at four NASA Centers. DEVELOP creates pilot application demonstration projects, using remote sensing and earth science information, to show state, local and tribal governments how Earth Science technology and data can be used to assist communities as they seek solutions for local problems. DEVELOP is a unique program because it is high school student-run and student-led with advisors and mentors from the public and private sector.

During the summer of 2005, DEVELOP interns worked on three projects. The three projects are described below. Results from these studies will be presented at the seminars held at the various NASA Centers.

Project 1: Yosemite Fire Recovery. Developing methods to assess ecological change in vegetation is increasingly important to Yosemite National Park managers. Alterations in vegetation result in changes of wildfire frequency and intensity. Park managers are interested in monitoring catastrophic changes, due primarily to large fires, and subtle vegetation changes, such as an overall increase in vegetation density, over a twenty-five year period. The DEVELOP student research group at NASA Ames Research Center assisted in these efforts by conducting a change detection study utilizing Landsat imagery. Each image was atmospherically corrected to adjust for differences between years. Using various techniques, change detection was performed on the resulting maps to analyze catastrophic and subtle vegetation change. These maps will be used in a model to predict burn severity levels within the Park.

Project 2: Utah Cheatgrass. The objective of the southwest reGAP analysis has been to standardize image-processing methodology, field data and classification systems in an effort to emphasize eco-regions rather than political boundaries. The data available through the reGAP set are frequently needed to aid in natural resource decision-making and other land-related activities. By 2004, much of the preliminary new classification for the reGAP effort was completed, and is now available for pinpointing exact species presence particularly for widespread invasive plants such as Bromus tectorum, or cheatgrass. Using a customized regression model (CART), a percent coverage map for cheatgrass has been derived from presence and absence points from the new reGAP data set. The DEVELOP student research group at NASA Ames Research Center developed a method of field validation for the percent coverage map, as well as a means of estimating invasive species density using MODIS data sets.

Project 3: Waste Tire Detection. DEVELOP student interns at NASA Ames Research Center worked with California Integrated Waste Management Board's (CIWMB) Special Waste Division to create a proof-of-concept project investigating the use of high-resolution satellite imagery for locating and mapping waste tire disposal sites in the Sonoma and San Bernardino counties of California. Previous methods for locating waste tire disposal sites in California included contracting California Highway Patrol to fly-over suspected sites and take photographs, a method that was not accurate. The methodology and outputs generated from the imagery were used to reduce time and capital necessary to manage waste tire sites, which left unkempt, pose threats of combustion and run the risk of becoming breeding grounds for mosquitoes.

"ALIENS OF THE DEEP" IMAX FILM

"Aliens of the Deep" IMAX Movie/Educator Guide Walt Disney Pictures and Walden Media present an Earth Ship Production "Aliens of the Deep" directed by James Cameron.

The expedition team of astrobiologists, marine biologists, planetary scientists, and geophysists consider connections between life under water and life we may one day find in space. The research team appears in the 3-D IMAX film "Aliens of the Deep" which tells the story of an expedition to one of the Earth's deepest,

most extreme and unknown environments. They take us to the ocean floor to search for clues about the potential for life on other planets.

As an "expedition scientist", Dr. Tori Hoehler was instrumental in bringing this collaboration to the NASA Astrobiology Institute making the initial contact between Walden Media and the NAI E&PO Central office. He also presented the film's astrobiology content in a series of broadcast interviews for CBS Sunday. He provided the basic conceptual and content framework of the film's educator guide, and served as a reviewer on three rounds of its review. The Educator Guide is developed by Walden Media and the NASA Astrobiology Institute Team and is designed for students 5-8 to be used before or after viewing the film. This teacher's guide is a teaching tool that engages students in thought provoking activities about the deep-ocean and space research as an interdisciplinary content area.

The California Academy of Sciences has teamed with Disney to feature scientific discussions with the Astrobiology exhibit and the IMAX movie at the Metreon in San Francisco, California. Dr. Carol Tang has invited NASA Ames Astrobiology science team member's to speak at the IMAX showings and to interact with the public on the museum floor. The CAS docents have been trained to use the "Aliens of the Deep" teachers? guide as educators tour the Astrobiology exhibit after each IMAX movie showing. Dr. Tang has spoken to over 1715 audience members based on the initial ticket sales at the IMAX for her sessions with movie goers. The educators, students, and general public were offered discounted tickets through a marketing strategy prepared by CAS to attend the Astrobiology exhibit. At that time Dr. Tang and the trained docents at the museum presented activities from the "Aliens of the Deep" educator Guide on the museum floor prior to and after the "Aliens of the Deep" showings at the San Francisco Metreon IMAX Theater. This same strategy was also used by Dr. Martin Weiss at the New York Hall of Science to draw the IMAX audiences into the museum to see the Extremophile exhibit in New York.

JASON Expedition: Mysteries of earth and Mars

A team of scientists will take middle-school students and teachers on the trip of a lifetime... to Mars! This next year's Jason Expedition will engage students in the process of scientific inquiry. Teachers and students work with top scientists as they seek to uncover the Mysteries of Earth and Mars. Big questions that scientists consider such as what was the environment like on early Earth and Mars? How did life arise on Earth? And could there be life on Mars? These thoughts and content are correlated to major textbooks and science kits, including: Teacher's Edition text book Student Activity Book Introductory Video Expedition Broadcast (January 30 - February 4, 2006).

A wide range of scientific investigations explore the principles of space travel with NASA engineers who helped design the latest generation of Mars rovers and orbiters. They compare and contrast geology of Earth and Mars alongside NASA's chief scientist for Mars exploration and planetary geologists. Leading astrobiologists participate as they search for extreme life forms at Mars analogs-locations on Earth where environmental conditions resemble Mars. The host researchers for astrobiology include Dr. Linda Jahnke, spotlighting her research and the lesson, "Signs of Life?; also research by Dr. Jack Farmer from Yellowstone National Park appears in a field data lesson.

STANFORD UNIVERSITY ASTROBIOLOGY COURSE

The Ames Astrobiology researchers participate in the development of the course presented at Stanford University to graduate students. Dr. Lynn Rothschild is the director of this program. The NASA Ames Team collaborates each year on the design and content of the course. The researchers provide lectures, lessons, lab experiences, and projects for the duration of the semester long course. Each series of lecturers are responsible for preparing the mid term and final exams for their portion of the program.

Human Biology 107, Geology and Environmental Sciences 107 - Enrollment: 20, freshman to graduate student Guest lecturers:

Astrobiology asks, where do we come from? Are we alone? Where are we going?

This course gives an overview of the excitement of astrobiology and space exploration, from the origin of our own biofriendly universe to questions of the future of mankind both on Earth and beyond. The instructor, Dr. Lynn Rothschild (NASA), will guide you on the journey from the Big Bang to the evolution of life on Earth and possibly elsewhere to man's place in the universe. Guest lecturers are leaders in the field from NASA, UC Santa Cruz, SETI Institute, and of course, Stanford. We anticipate at least one guest astronaut.

The class will be lecture and discussion, with students contributing late-breaking astrobiology news. A term paper will allow the student to explore an area of interest in depth, and the final will be the opportunity to tie the material together. A background in two or more science courses (may include HumBio core) and a curious mind are essential.

Rothschild Introduction: Cosmology, Astrobiology, and Space Exploration

Shostak: The Big Bang, Our Universe, and All That Jazz Laughlin Stellar Evolution and Habitable Planets (switched to 1.27)

Allamandola: From Interstellar Molecules to Astrobiology

Pohorille: Origin of life and RNA world Rothschild Evolution of Life from Microbial to Multicellular

Rothschild: Pushing the Envelope for Life; Environments for life in the universe

Morrison (Switched to 2.10)

Mancinelli: Life beyond Earth/ panspermia Chyba Looking for Life in All the Right Places - Europa, Titan and Elsewhere

Des Marais: The Search for Life on Mars

Morrison: When Worlds Collide - Extraterrestrial Threats to Life

Rothschild: Replaying the tape - Darwin's birthday Cohen (moved to 2.22) Space exploration

Cohen/Holton: (moved to 2.24) Newton, Gravity, and Biology

Holton: (moved to 2.17) Gravitational Biology and Adaptation to Space

Kliss: (Webbon) Controlled Environmental Life Support

Cagle: Humans in space

Shostak: Search for Extraterrestrial Intelligence

McKay: Exploration and Colonization of Mars - Why and How?

NASA EXPLORER INSTITUTE
Seeing the Universe NEI Focus Group

SEEING THE UNIVERSE NASA Explorer Institute Focus Group

February 2-4. 2004 American Museum of Natural History, New York, NY

The vast quantity of high-quality space science data acquired by NASA's missions and scientists is providing revolutionary new understandings of our Earth and sky. At the same time, advances in computational power allow us to depict current astronomical discoveries with unprecedented fidelity, providing audiences with an opportunity to experience the universe as never before. SEEING THE UNIVERSE brought together visualization providers, users, commercial vendors, and NASA scientists and mission personnel to identify the next steps in coordinating efforts to bring superior visual experiences to NASA's audiences. Informal science education venues represented ranged from living room television sets and pages on the World Wide Web to fully immersive, real-time visualization theatres. Planetaria, screens and kiosks in museums and science centers, educational multi-media, IMAX, television, news media, the Web, games, and feature films have all made use of visual representations of NASA data in an effort to share space exploration with general audiences. Beyond informal science education, NASA visualizations have been an important and effective communications tool for formal education, the news media, congressional briefings, and other important NASA audiences. SEEING THE UNIVERSE assessed the present state of scientific visualization of NASA data and identified strategies for the future that maximize quality and efficiency of visualization production and dissemination.

NASA Explorer Institute Planning and Evaluation Meeting

NASA Explorer Institutes Planning and Evaluation Meeting, March 14-17, 2005, American Museum of Natural History, New York

NASA headquarters organized the first series of the National NASA Explorer Institute program planners to attend an evaluation and planning session. This was done to develop a summary and action plan for training the next generation through informal education. The original NEI NASA Explorer Institute teams included: "Earth to Sky" NASA/National Park Service, University of California, NASA Ames Research Center, NASA Goddard Space Flight Center, Maryland Science Center, Girl Scouts USA, Jet Propulsion Laboratories, NASA and North Carolina 4-H, Langley Research Center, NASA Langley, and Virginia Air and Space Workshop for Informal Education Kennedy Space Center. In order to build a strong relationship between NASA staff members of the informal education community this session brought together the collaborative proposal teams and individuals from the first NASA (NEI) Focus Groups to provide input from this National Meeting providing NASA with the collective "Big Ideas" from the several hundred different formal and informal education institutions that participated in the pilot phase of the NEI programs. Contributions from these collective organizations are formalized in the action report from the Informal Education office.

EDUCATIONAL FILM, RADIO, WEB AND PRINT PRODUCTIONS

The Ames Astrobiology Team is highly involved with public programming on television, radio, video, and publications. The distribution of astrobiology research, specific missions, and unique scientific events are shown nationally and internationally featuring any number of scientists on the Ames Team. Team members have been involved in numerous diverse media events.

Dr. Tori Hoehler interviewed for a series of broadcasts featured on "CBS" Sunday to present the astrobiology related content for the curriculum matching the IMAX movie "Aliens of the Deep". Dr. Lynn Rothschild participated in four TV interviews on Life in Extreme Environments on CNN, a T.V. series with Martin Reese, Astronomer Royal "What We Don't Know" which aired in the United Kingdom, December, 2004 for the BBC4. She had interviews for the NPR program Pulse of the Planet and on National Geographic.

EDUCATIONAL WORKSHOPS/LABS/CLASSROOM

The Ames Team has developed and organized educational sessions and workshops at national conventions or site locations across the country and internationally. Team members participated as keynote speakers, lecturers, and presenters of hands-on workshops targeted at students of all levels, university professors,

and educators. The team also develops and presents science lessons for local and international classroom experiences at various schools including the NASA Explorer and Challenger schools. We organize these events and venues with our NASA Ames Research Center education team. The presentations occur in places where team members are conducting research on-site or involved in science conferences. The science team makes it a priority to present their research at universities, while providing a program for the K-12 school in the areas they are visiting. Because of return field experiences or invitations as speakers, the team does have more than a "one stop" experience with the local school districts. Students and educators are invited to various centers, universities, and field sites to participate with the science team. The experiences with the science team also include field expeditions, short courses, course series, and lesson development with the educators on site. The Camp Wilderness Curriculum and Park Kids programs at Yellowstone National Park and the Museum programs at the California Academy of Sciences involve scientists with students, teachers, museum docents, and National park interpreters. Science team members make themselves available after they return home to answer questions via e-mail from the students or educators that they had met. The Ames Team has developed a rapport with our local Bay Area school districts. Our scientists are asked to complement the existing science program for California by coming into the formal education classroom to provide specific lectures or hands-on demonstration activities. The researchers incorporate their science into the content that is part of the local and national standards for the district. The science team also invites the classrooms to NASA Ames for onsite demonstrations, tours, and access to the laboratories. The team is often called upon for career day programs, science fair and poster session judging, special event programming for scientific events scheduled at the schools. This classroom involvement is initiated by the science team members themselves because of their interest in K-14 classroom partnerships.

The NASA Explorer Schools serve over 150,000 students nationwide and team members provide satellite presentations that reach audiences around the country. The three-year partnership affords many opportunities for the schools to become engaged in NASA related activities and improve student achievement in the areas of science, technology, engineering, math, and geography to inspire and inform a group of teachers and/or students, either in person during an on-site workshop, or remotely through NASA's Digital Learning Network. The Digital Learning Network gives scientists the opportunity to interact in real time with classrooms over a video conference link. The themes usually addressed are the value of scientific training, participating in space exploration, as well as the exciting details of astrobiological research.

CONFERENCES/REVIEW PANELS, PUBLIC ORGANIZATIONS, UNIVERSITY UNDERGRADUATE AND GRADUATE

The NASA Ames Astrobiology Team is involved with Undergraduate and Graduate Students in a variety of situations formally and informally at universities, conference locations, and in various laboratories around the country. The science team participates as invited speakers and panel participants while advising and managing internships, camps, workshops, mentoring, REU programs, courses, majors/minors, seminars, student societies, funding students to travel, etc. This involvement inspires and motivates students to pursue careers in science, technology, engineering, and mathematics focusing on NASA's unique missions, discoveries, and innovations.

- Dr. David Des Marais - Geobiology
- Catalina Island - 110 students/faculty
- University of Washington - 100 students
- University of Tennessee - 100 students
- University of Kentucky - 100 students
- Washington University - 100 students
- Stanford University - 30 students
- Cornell University - 100 students
- American Institute Aeronautics and Astronautics - 100 attendees
- Industrial Light and Magic - 50 attendees

Dr. Hector D'Antoni Rotary Club of Coronel Vidal Coronel Vidal, Buenos Aires, Argentina Astrobiology, Biology and Earth Science (Panel with Prof. F.V. Vega [U of Santiago de Compostela, Spain], Dr. G. Vasta [U of Maryland, Baltimore and U. John Hopkins] and H. D'Antoni [NASA Ames] 70 attendees NASA Ames

Research Center Astrobiology and Earth Science 60 attendees Biochemical Meeting of the Southeast of Buenos Aries Astrobiology, Origin of Life, and Global Change (Closing speech) 200 attendees

Dr. Gregory Laughlin - UC Santa Cruz - Astronomical Observatory Public lecture "Saturn, Titan, Astrobiology" - 110 attendees

Dr. Kelly Decker - NASA Astrobiology Institute Student Poster Competition Judge - 30 posters

Dr. Kelly Decker - Stonington Free Library, Public lecture - 125 attendees

Dr. Pieter Visscher - 5th International Geobiology Course Nassau, Bahamas, Agouron graduate, NASA Exobiology/Planetary Protection Peer Review Panel

Lou Allamandola - Stanford University, Palo Alto, California, "From Interstellar Molecules to Astrobiology" presented to the Stanford Astrobiology Lecture Series/Class - 30 students Astrochemistry LabTours with OOL emphasis

Scott Sandford - San Jose State Univ., Biological Sciences Department "Cometary Material Returned to Earth by the Stardust Mission - Testing the Role Interstellar Chemistry plays in the Origin of Life"

Linda Jahnke - Jason Foundation for Education Host scientist for 2006 'Mysteries of Earth and Mars' filmed video, developed chromatograph demonstration, proofed-edited Student Activities and Teacher's Edition Books/ curriculum. info@jason.org

NASA Explorer Schools 1 hour talk on 'Evidence for the Early Evolution of Oxygenic Photosynthesis" - 40 educators

Biennial NASA Astrobiology Institute Poster Competition Judge - 50 posters

Lunar and Planetary Institute Invited talk @ Biomarkers for early Earth and Mars analogs [Abstract]. Second Conference on Early Mars: Geologic, Hydrologic and Climatic Evolution and the Implications for Life - 150 attendees

Dr. Tori Hoehler - Biennial NASA Astrobiology Institute Meeting University of Colorado, Boulder Invited speaker: Yellowstone National Park Outreach "A Living Laboratory" - 150 attendees

Dr. Carol Tang - California Academy of Sciences Poster on Astrobiology; exhibit poster on Collaboration with the NASA Ames Research Center Science team and the CAS exhibit team.

Dr. Mitch Schulte - San Jose State University Lecture: California's ophiolites as analogs for early Earth (and Mars?) habitats

Dr. Lynn Rothschild - USS Hornet panelist for Women in Space Science, USS Hornet, July 20, 2004 as part of the Apollo 11 Anniversary celebration activities - 150 participants

Lynn Rothschild, Rocco Mancinelli - SETI Institute presentation for SETI science day on radiation and astrobiology - 80 participants

Vatican Observatory Foundation Joint presentation with Father George Coyne, Director of the Vatican Observatory on Astrobiology - 150 participants

Taught Course, "Astrobiology and Space Exploration" (Human biology 107; Geology 107) 30 students

Dr. David Ward - Microbiology/astrobiology Montana State University

Park Kids/microbiology - Yellowstone Institute 100 attendees

Publications: NASA Ames Research Center

There are **130** publication entries for the NASA Ames Research Center

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Andres, M.S., Reid, R.P., Visscher, P.T. & Sumner, D.Y. (2005). Biocomplexity of modern marine stromatolites [Abstract]. In: G. Camoin & P. Gautret (Eds.). *Microbialites and Microbial Communities in Sedimentary Systems* (pp. 11-13). Paris, France: Assocation des Sedimentologistes Francais.

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Bernstein, M.P., Cruikshank, D.P. & Sandford, S.A. (In Press, 2005). Near Infrared Laboratory Spectra of Solid CO2 in H2O and CH3OH. *Icarus*.

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Bernstein, M.P., Mattioda, A.L., Sandford, S.A. & Hudgins, D.M. (In Press, 2005). Laboratory Infrared Spectra of Polycyclic Aromatic Nitrogen Heterocycles: Quinoline, and Phenanthridine in Solid Argon and H2O. *Astrophys. J*.

Bernstein, M.P., Sandford, S.A. & Allamandola, L.J. (In Press, 2005). The Mid-Infrared Absorption Spectra of Neutral PAHs in Dense Interstellar Clouds. *Astrophys. J. Suppl. Ser*.

Bernstein, M.P., Sandford, S.A. & Walker, R. (In Press, 2005). Laboratory IR Spectra of 4-AzaChrysene in Solid H2O. *Adv. Space Research*.

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Executive Summary: Carnegie Institution of Washington

Executive Summary: Carnegie Institution of Washington
Principal Investigator: Sean Solomon
Reporting Period: 2005 (7/04-6/05)

The NAI team led by the Carnegie Institution of Washington is studying the evolution of organic compounds from prebiotic molecular synthesis and organization to cellular evolution and diversification. Our program attempts to integrate the sweeping narrative of life's history through a combination of bottom-up and top-down studies. On the one hand, we study processes related to chemical and physical evolution in plausible prebiotic environments – the interstellar medium, circumstellar disks, extrasolar planetary systems, the primitive Earth, and other Solar System objects. Complementary to these bottom-up investigations of life's origin, we carry out field and experimental top-down efforts to document the nature of microbial life at extreme conditions and the characterization of organic matter in ancient fossils. Both types of efforts inform our development of biotechnological approaches to life detection on other worlds.

Our team's research activities focuses on life's chemical and physical evolution, from the interstellar medium, through planetary systems, to the emergence and detection of life, across seven integrated areas of research:

1. We are applying theory and observations to investigate chemical evolution in the interstellar medium, in circumstellar disks, during planetary formation, and on Solar System bodies.
2. We are carrying out analytical research on extraterrestrial samples, including meteorites and interplanetary dust particles, with an emphasis on organic molecules and evidence for water.
3. We are studying prebiotic chemical and isotopic evolution on Earth, with an emphasis on the sulfur cycle and the role of sulfur in prebiotic organic synthesis.
4. We are investigating possible mechanisms of prebiotic molecular selection and macromolecular organization, including the self-organization of amphiphiles and the selective adsorption of organic molecules onto mineral surfaces.
5. We are continuing to study life in extreme environments, with field studies of hydrothermal microbial communities and laboratory studies of stress adaptation of microbes in high-pressure and high-temperature environments.
6. We are examining ancient fossils and microbes fossilized in the laboratory with a variety of analytical techniques to assess preservation mechanisms of molecular and isotopic biosignatures, and we are studying modern geothermal systems to investigate preservation of biosignatures during silicification in these environments.
7. We are applying our enhanced understanding of life's chemical and physical evolution to develop new techniques in astrobiotechnology – procedures that will be applied to the design and testing of instruments for life detection, initially in terrestrial settings and eventually on spacecraft to be sent to other Solar System bodies.

Fuller understanding of life's origin, evolution, and distribution requires major advances on all these topics, as well as the extensive challenge of integrating these topics. During the past year we achieved significant progress in each of these research areas, and we devoted increased attention to the interfaces among these theoretical, experimental, and field approaches.

Among the highlights from the past year's research in the area of the evolution **from molecular clouds to habitable planetary systems** were the following:

- Continued radial velocity measurements of the 2,000 Sun-like stars within 50 parsecs yielded a number of new extrasolar planet candidates, including the first Neptune-mass planet, the first terrestrial-planet analogue, and the second nearby bright transiting planet. Velocity measurement precision of 1 m/s has been achieved routinely at the Keck and Anglo-Australian Telescopes.
- Construction proceeded on the camera system for the Carnegie Astrometric Planet Search, to be dedicated to the long-term search for astrometric signatures of extrasolar planets around low-mass stars.
- High-contrast visible light imaging and novel spatially resolved spectra of the disk surrounding the young star TW Hydrae revealed a warp and smaller grains in the inner part of the disk. Both could result from collisions induced by a planet already formed within the disk.

- Far-ultraviolet spectroscopy of the disk around the 12-Myr-old M star AU Microscopii showed that most of the primordial gas has been removed from the disk. A giant planet orbiting this low-mass star, as others have suggested, would be difficult to form by traditional core-accretion. The low gas contents of AU Mic and its more massive cousin Beta Pictoris indicate that the gas dissipation mechanism is largely independent of the luminosity of the central star.
- A newly developed semi-analytical model for the oligarchic growth stage of planet formation predicts the formation of Earth-mass terrestrial planets in the habitable zone of a Sun-like star.
- Theoretical models of the diversity and signature of extrasolar planets led to the prediction of a new type of terrestrial planet with a substantial fraction of carbon.

Highlights in the area of **extraterrestrial materials and the origin and evolution of organic matter in the Solar System** during the past year included the following:

- Chemical and isotopic analysis of high-purity samples of insoluble organic matter (IOM) from the CR group of chondritic meteorites indicate that these meteorites contain interstellar organic matter that resembles refractory organic matter in comets and interplanetary dust particles. Little is known about how this complex and enigmatic material forms in the interstellar medium, but the relatively large amounts that can be isolated from CR chondrites will greatly facilitate its study.
- Chemical, isotopic, and nuclear magnetic resonance measurements on high-purity samples of IOM from other primitive chondritic meteorites have revealed complex but systematic trends attributable to parent body processing of a common precursor that resembled the insoluble organic matter in CR chondrites.
- The first confocal Raman images of IOM from primitive chondrites reveal variations in Raman band characteristics that correlate with the composition of the organic matter and with the extent of parent body metamorphism. Raman imaging may prove to be a useful non-destructive technique for analyzing organic matter in Stardust samples and classifying unequilibrated chondritic meteorites.
- The documentation of extreme isotopic heterogeneity of carbon in a partially differentiated meteorite raises questions concerning the extent of parent body melting needed to achieve carbon isotopic homogeneity and the origin of carbon heterogeneity on Earth.
- Trace element concentrations in clays and hydrous silicates in contact with carbonates and halites in Martian meteorites indicate that these samples were subjected to multiple episodes of aqueous alteration while on Mars.

Highlights in the area of **prebiotic chemical and isotopic evolution on Earth** during the past year included the following:

- Experimental studies of metal-sulfide-promoted prebiotic chemistry showed that pyrite can reductively demethylate certain compounds formed by catalyzed hydroformylation reactions to yield succinic acid. That an abiotic pathway links the methylated intermediates with four-carbon dicarboxylic acids strengthens the hypothesis that metal sulfide catalysis provided a critical connection between environmental chemistry and the emergence of life.
- A newly developed laser fluorination gas chromatograph mass spectrometer permits measurements of multiple isotope ratios at nanomole levels of sulfur. This tool is being applied to refine the isotopic analysis of sulfide mineralogy in Archean drill cores.
- Measurements of multiple sulfur isotopes in experiments with sulfate-reducing, sulfur-disproportionating, and thisulfate-disproportionating bacteria progressed toward the goal of deconvolving mass-dependent sulfur fractionations associated with metabolic and biogeochemical networks. Analysis of four sulfur isotopes as a tracer of post-Archean biochemical cycles promises to decouple mass-dependent and mass-independent fractionation.
- A method was developed to conduct high-precision abundance measurements of organic nitrogen isotopes on nanomole-size samples. The method is being applied to organic inclusions in Archean rocks and meteorites.

Highlights in the area of **prebiotic molecular selection and organization** during the past year included the following:

- A “PAH world” model for life’s origins was developed by which self-organized stacks of PAH molecules provide a template for the first, RNA-like, self-replicating genetic polymer.

- DNA microarray technologies were applied for the first time to the combinatoric study of interactions between organic molecules and mineral surfaces that may mimic the selection of organic molecules from the prebiotic "soup."
- A theoretical study of molecular adsorption onto mineral surfaces demonstrated that strong chiral adsorption requires three points of bonding between the molecule and mineral, a result that clarifies the contrasting behavior of the amino acids alanine and aspartic acid on calcite surfaces.
- Organic molecules, including amino acids and nucleobases, were shown to be rapidly removed from an acidic hot spring environment by adsorption on clay minerals, a phenomenon that may point to a mechanism for the prebiotic selection and organization of biomolecules.

Svalbard is the target of annual field excursions by the Arctic Mars Analog Svalbard Expedition (AMASE), which includes participation by several investigators from the Carnegie Institution.

Highlights in the area of **life in extreme environments** during the past year included the following:

- Subseafloor archaea related to the most abundant group of archaea in seawater were shown to have genes for nitrogen fixation. That these potential nitrogen-fixing archaea are found in deep seawater near mid-ocean ridges but not in deep seawater off axis suggests that this group of archaea circulates through the N-poor subseafloor as part of their life cycle.
- Characterization of a microbial community at the 3.5-Ma Baby Bare Seamount revealed a higher diversity of microorganisms than expected, including anaerobic hyperthermophiles and hydrogen-utilizing thermophiles. These diverse organisms must have novel metabolisms and physiologies that allow for growth in the absence of nutrients derived from photosynthesis.
- Study of microbial biofilms formed on minerals in subseafloor habitats at Axial Volcano on the Juan de Fuca Ridge yielded evidence for biofilm formation at temperatures considerably higher than 121°C, the highest growth temperature so far demonstrated for isolated microbes.
- Collection of new samples of Fe-oxidizing bacteria from the Loihi Seamount and new methods for obtaining and culturing DNA from these organisms led to their reclassification as a deeply branching group of proteobacteria.
- High-pressure, high-temperature experiments showed that methane readily forms by reduction of carbonate under conditions typical for terrestrial planetary mantles.
- In experiments designed to understand adaptations that allow microbial life to persist at high pressures, mRNA from *E. coli* cells subjected to pressures up to 2 GPa was isolated for DNA microarray analysis to identify genes turned off and on in response to pressure.

Highlights in the area of **molecular and isotopic biosignatures** during the past year included the following:

- Carbonate globules in mantle xenoliths from a Mars analog site in Svalbard, morphologically similar to carbonate globules in Martian meteorite AL84001, include hematite and magnetite within distinct zones and carbon in conjunction with magnetite, zonation patterns most likely formed during the precipitation of carbonate from a CO_2-rich hydrothermal fluid.
- Raman spectroscopy, energy-dispersive X-ray microanalysis, and time-of-flight secondary ion mass spectrometry of mineralized bacterial sheaths produced by Fe-oxidizers within a modern iron seep demonstrate a complexity in the distribution of molecular species that points to the difficulty of identifying biosignatures in ancient samples that have suffered some level of modification.
- Stable C, N, O, and H isotope analyses of samples from the Mars analog site in Svalbard demonstrate

a range of biogenic and abiogenic sources of carbon compounds that can potentially be sorted on the basis of coupled isotopic anomalies and geobiological context.

- New organic geochemical analyses of extracts from late Archean shale and carbonate rocks form Western Australia substantiate earlier documented relationships among lipid biomarkers, carbon isotopes, and rock types. These results support syngenicity between fossil lipids and their host rocks and indicate biological cycling of oxygen 400 My before the steep rise of atmospheric oxygen.
- Pyrolysis gas chromatography mass spectrometry and ^{13}C solid-state nuclear resonance spectroscopy have illuminated the chemical transformations that accompany the conversion of modern organic matter into plant fossils.

Highlights in the area of **astrobiotechnology** during the past year included the following:

- Life-detection instrumentation utilizing microfluidics to prepare samples for inoculation onto DNA and protein microarrays has been tested in a Mars analog environment on Svalbard. Results were confirmed with other biotechnology tests including ATP measurements, DNA amplification using degenerate species and gene-specific primers, and an enzyme-based test for cell wall components.
- A proposal to test microarrays for radiation exposure in low Earth orbit on the European Space Agency Biopan series of missions was approved. A 2006 flight will carry both protein and DNA microarrays.
- In another application of similar technology, a hand-held device will be flown on the International Space Station to detect and monitor potentially harmful bacteria and fungi in the cabin environment.

In summary, our team's recent research, including discoveries and characterization of new planetary systems, investigation of the fates of carbon and water on planetary building blocks and other worlds, elucidation of robust pathways for prebiotic organic synthesis, documentation of novel microbial metabolic strategies, evaluation of possible biosignatures, and development of new technologies for astrobiological exploration, inform the central questions of astrobiology. Taken together, these discoveries are changing our views of life's origin and its possible distribution in the universe.

Project Reports: Carnegie Institution of Washington

1. From Molecular Clouds to Habitable Planetary Systems

Project Investigators: Alan Boss, R. Paul Butler, John Chambers, Sara Seager, Sean Solomon, Alycia Weinberger

Project Progress

1. From Molecular Clouds to Habitable Planetary Systems

1. Formation of Habitable Planetary Systems

Chambers developed a new semi-analytic model for the oligarchic growth stage of planet formation. The model simulates the orbital and collisional evolution of solid bodies in a protoplanetary nebula during an important stage of planetary growth that saw bodies grow from the size of asteroids to the size of Mars in the inner Solar System and the size of giant-planet cores in the outer Solar System. Rapid growth is achieved when the largest objects acquire essentially circular and coplanar orbits due to dynamical friction. Collisional fragmentation of smaller objects also promotes growth as fragments acquire circular, coplanar orbits due to gas drag. In the late stages of oligarchic growth, accretion rates are enhanced when large bodies acquire massive atmospheres of gas captured from the protoplanetary nebula. Calculations made using the model demonstrate that Mars-sized bodies would have formed in the inner solar nebula within 0.1 million years, while 10-Earth-mass bodies formed in the outer nebula in 1 million years, for reasonable nebula parameters. These results are consistent with the formation of Earth-mass terrestrial planets in the habitable zone, and gaseous giant planets in the outer regions, of a Sun-like star.

2. Protoplanetary and Debris Disks

Weinberger continued her studies of young circumstellar disks as the sites of planet formation and evolution. In collaboration with Inseok Song of Gemini Observatory and Eric Becklin and Ben Zuckerman of UCLA, she studied a unique 300-Myr-old star, HIP 8920, which has a massive, warm debris disk. The dust exhibits a very strong silicate feature with broad peaks at 10 and 11 μm. Fits of the spectra show that small amorphous and crystalline silicate grains, < 2.5 μm, are present in the disk. While the interstellar medium, and therefore presumably proto-planetary disks, are dominated by small grains, this star is too old for the dust to be primordial. The very high line-to-continuum ratio, produced by the abundant small grains, is much larger than for even Solar System comets. Perhaps a massive asteroid collision recently pulverized a 200-km object.

With Postdoctoral Fellow Aki Roberge, Weinberger completed work on the visual spectrum of the disk around TW Hydrae. The team discovered an asymmetry in the inner part of the disk that indicates the inner disk is warped with respect to the outer part, perhaps because of perturbation by a massive planet. In addition, they showed that the disk must be dominated by relatively large grains, but collisions may be shattering these grains in the inner part of the disk.

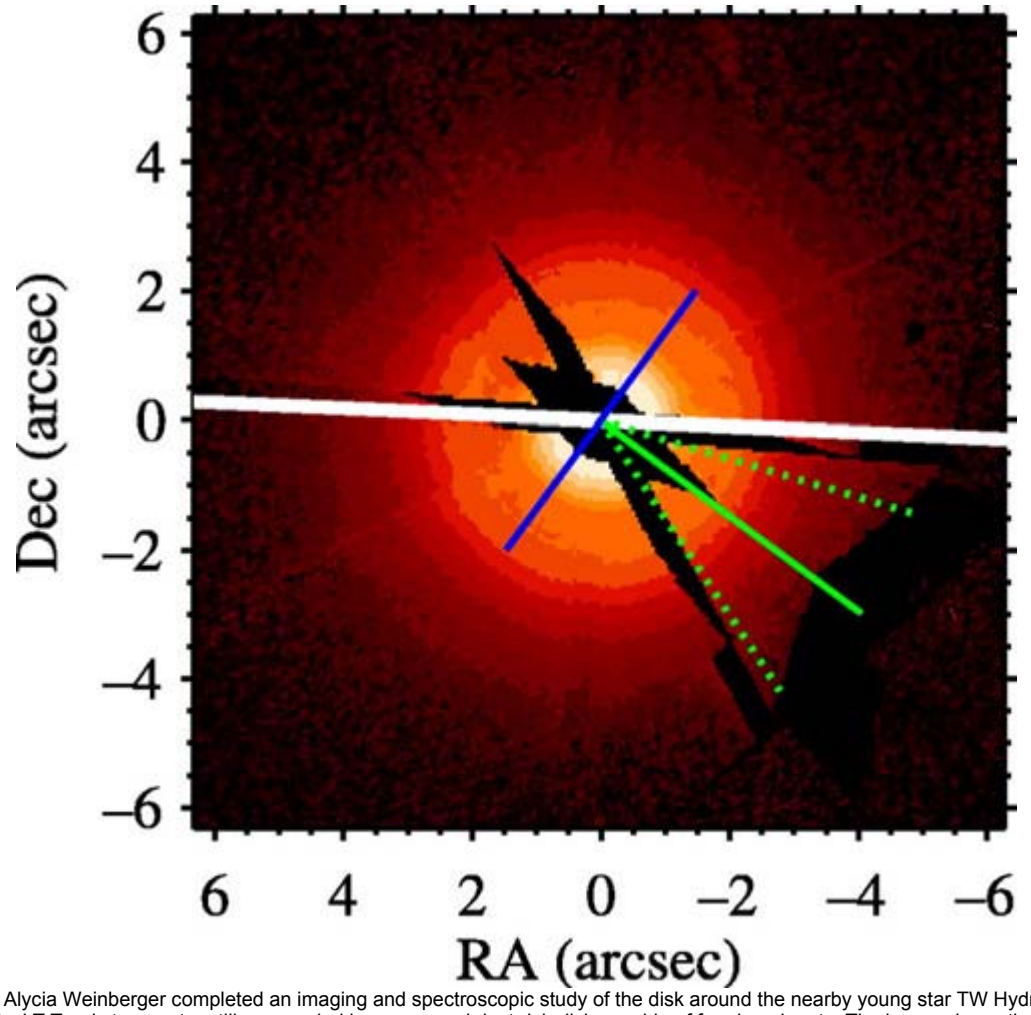


Figure 1. Aki Roberge and Alycia Weinberger completed an imaging and spectroscopic study of the disk around the nearby young star TW Hydrae. This star is the closest example to Earth of a classical T Tauri star - a star still surrounded by a gas- and dust-rich disk capable of forming planets. The image shows the disk, which extends to 280 AU from the star. Discovered in the data was a small warp in the 70-90 AU region, where that part of the disk is inclined relative to the outer part of the disk. Warps can be caused by the gravitational perturbation of a giant planet on an inclined orbit. The green line shows the direction in which the warp is brightest (most inclined toward the observer) and the blue line shows the suggested major axis of this inner disk. The white bar shows the location of the slit used for the spectroscopy of the disk.

Weinberger and Roberge probed the disk around the nearby M-type star AU Microscopii with far-ultraviolet spectroscopy. They showed that the disk's primordial gas has largely been dissipated in less than about 12 Myr, whereas some dust remains. It is extremely difficult to form a giant planet around AU Mic with current core accretion scenarios in such a short time. The dissipation timescale of the gas was just as short for this low-luminosity star's disk as for the much larger luminosity, coeval star Beta Pictoris. This result constrains the dissipation mechanism to be largely independent of luminosity.

3. Searching for Extrasolar Habitable Planetary Systems

Butler continued work on three precision Doppler surveys. The first program is a survey of the nearest 1,800 Sun-like stars (late F, G, K, and M dwarfs) using the Keck 10-m and Lick 3-m telescopes in the north and the Magellan 6.5-m telescope and 4-m Anglo-Australian Telescope (AAT) in the south. This survey represents the first reconnaissance of the nearest stars within 50 parsecs, with a limiting measurement precision of 3 m/s. These surveys have produced two-thirds of the known extrasolar planets, including all nearby planetary systems. Butler and Geoff Marcy (UC Berkeley) lead this program. An important recent discovery by the group was the detection of a 7-Earth-mass planet that may be the first rocky analogue of the terrestrial planets in orbit around another normal star, the M dwarf GJ 876.

The second program on which Butler is working is the N2K survey of metal-rich stars, led by Debra Fischer (San Francisco State University). The Keck 10-m, Subaru 8-m, and Magellan 6.5-m telescopes are surveying the nearest 2,000 metal-rich stars within 100 parsecs for short period planets. Short-period planets have a greatly enhanced chance of transiting their host stars. This program has produced four new short-period planets, including only the second nearby bright transit planet orbiting HD 149026. Remarkably this is a Saturn-mass planet with a significantly smaller radius and higher density than Saturn, implying a massive (70 Earth-mass) core.

Over the last year Butler's team has begun a new initiative to achieve 1 m/s precision on the nearest stars. They are currently surveying the nearest 200 stars with the Keck and AAT as part of this program and hope to expand this program to include the nearest 1,000 Sun-like stars within 30 parsecs, which will require a dedicated 8-m class telescope. Such a program would be the dominant planet-search program for the next 30 years.

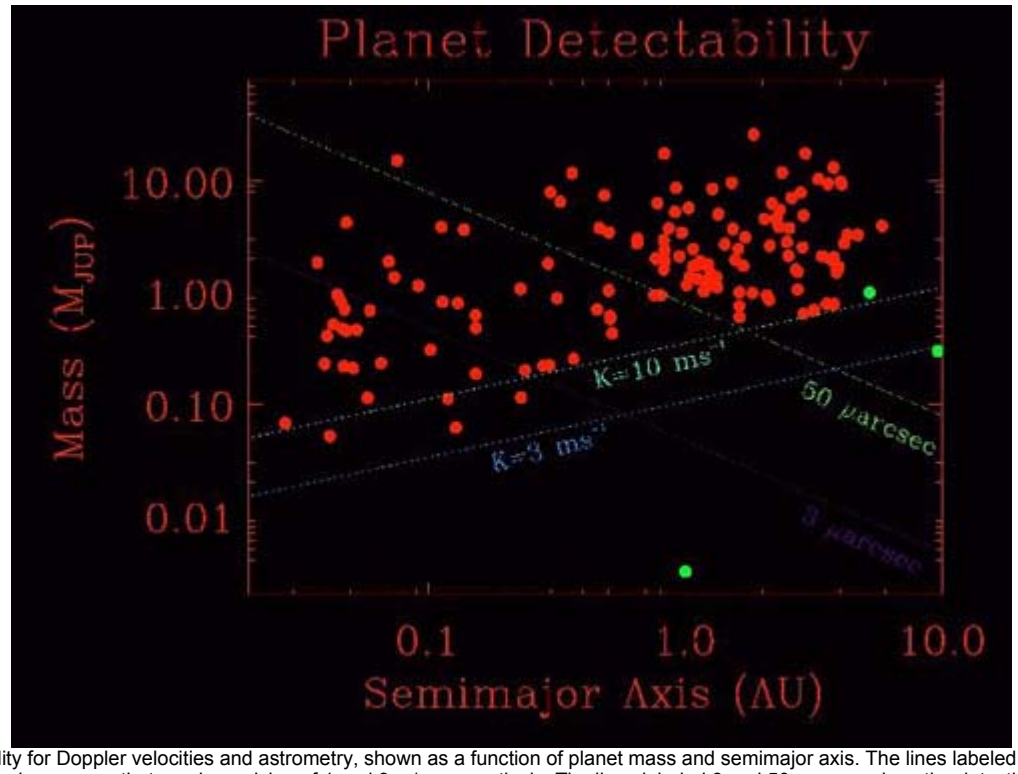


Figure 2. Planet detectability for Doppler velocities and astrometry, shown as a function of planet mass and semimajor axis. The lines labeled "3" and "10 m/s" show the detection thresholds for Doppler surveys that reach precision of 1 and 3 m/s, respectively. The lines labeled 3 and 50 μarcsec show the detection thresholds for the space-based SIM and ground-based VLTI astrometry missions for stars at 15 parsecs. The red dots are the known planets, all found from precision Doppler surveys. The green dots are Earth, Jupiter, and Saturn. Since SIM and VLTI are still several years from taking data, precision Doppler surveys will remain the dominant planet detection method into the 2020s.

Boss's contribution to Carnegie's NAI effort in the last year centered on his leadership of a new ground-based astrometric planet detection effort, to be conducted with the 2.5-m du Pont telescope at Carnegie's Las Campanas Observatory in Chile. Last summer Boss and his team were awarded funds by the National Science Foundation to build the Carnegie Astrometric Planet Search (CAPS) camera, a specialized camera that should yield astrometric accuracies of 0.25 millarcsec per epoch. This accuracy is sufficient to detect planets with masses as low as 1/10 the mass of Jupiter on 12-year orbits around nearby late M dwarf stars, with a signal-to-noise ratio of four. Boss placed the order for the $235K Rockwell Hawaii-2RG focal plane array in October 2004 and for the Barr Associates lambda/30 combination filter/window in March 2005. The camera will be completed by the fall of 2005 and will be mounted on the du Pont telescope during the December 2005 observing run. Boss observed for five nights on the du Pont in May 2005 in preparation for beginning work with the CAPS camera.

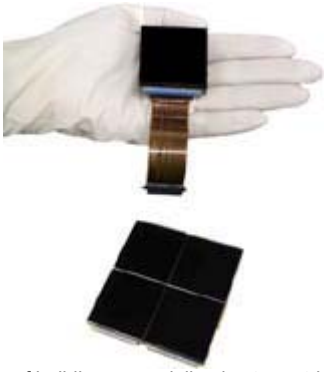


Figure 3. Boss, Weinberger, and their colleagues are in the process of building a specialized astrometric camera, the Carnegie Astrometric Planet Search (CAPS) camera. The heart of the CAPS camera will be a Rockwell Hawaii-2RG HyViSI array (shown), with the camera's design being optimized for high-accuracy astrometry of red dwarf stars. The array is designed to allow interleaved readout of the guide window and the full frame science data, allowing relatively bright target stars to be read out at a much higher cadence than the relatively faint reference stars.

4. Characterizing Extrasolar Habitable Planetary Systems

Seager and colleague's extrasolar planet atmosphere work led to the detection of thermal emission from the extrasolar planet HD209458b with the Spitzer Space Telescope. This landmark study marked the first time that photons were detected from an extrasolar planet. Atmospheric models consistent with the dayside flux measurements at thermal and near-infrared wavelengths constrain the H_2O absorption band depths and the general character of atmospheric circulation. The models point to future wavelength- and phase-dependent observations that can discriminate among current models.

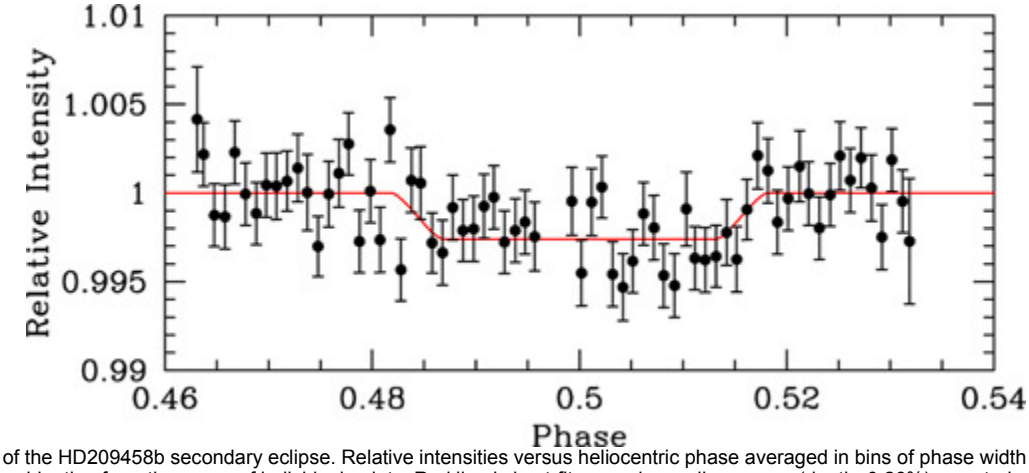


Figure 4. Observations of the HD209458b secondary eclipse. Relative intensities versus heliocentric phase averaged in bins of phase width 0.001, with 1-σ error bars computed by statistical combination from the errors of individual points. Red line is best-fit secondary eclipse curve (depth=0.26%), constrained to a central phase of 0.5. [From D. Deming, S. Seager, L. J. Richardson, and J. Harrison, *Nature*, 434, 740-743, 2005.]

5. Habitable Environments in the Solar System

One of the long-term goals of CIW NAI team is to assess the likelihood, timing, and physical and chemical characteristics of potential habitable environments on Solar System objects other than Earth. Solomon's efforts on this project during the past year have focused on hydrothermal systems on Mars as such candidate environments, primarily because of the influx of important new data from the Mars Global Surveyor (MGS), Mars Odyssey, Mars Express, and Mars Exploration Rover (MER) missions.

A first step in that evaluation was a synthesis of spacecraft observations and inferences from Martian meteorites regarding the role of water in the early geophysical, geochemical, and geochemical evolution of the planet. For its first billion years, the planet Mars was at its most active stage, and water linked interior and surface processes. Global differentiation segregated core, mantle, and crust within a few tens of millions of years of solar system formation; a magnetic dynamo in a convecting fluid core magnetized large areas of the ancient crust; and the Tharsis province became a focus for volcanism, deformation, and outgassing of water and carbon dioxide, possibly in quantities sufficient to induce episodes of global climate warming. A substantial early water budget contributed to widespread erosion, sediment transport, and chemical alteration of crustal material. A more massive early atmosphere was shielded against solar wind stripping by the global magnetic field. Deep hydrothermal circulation of water in the Martian crust acted to accelerate crustal cooling and preserve variations in crustal thickness. Such circulation chemically altered the carriers of crustal magnetization, likely rendering any residual crustal magnetization beneath the lowest areas of major drainage basins undetectable from orbit, an inference that permits a Martian dynamo to have persisted for as long as one billion years. Cessation of the dynamo, widespread reduction in the crustal field, and waning of interior outgassing allowed the early atmosphere to dissipate and the planet's surface to cool to conditions near those of the modern era, but substantial quantities of subsurface liquid water may have persisted to the present.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 2.1:** Mars exploration
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts

- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
1	MESSENGER	Project Investigator
1	Kepler	Science Team Member
1	FUSE	Project Investigator
1	HST	Project Investigator
1	Spitzer Space Telescope	Project Investigator
1	TPF	Science Team Member
0	Navigator Program	Science Team Member

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

MESSENGER: Solomon is the mission Principal Investigator. The spacecraft, launched in August 2004, will be the first to orbit the innermost Solar System planet.

Kepler: Co-I Boss is a Science Team member. Kepler's photometric observations will permit the detection of numerous Earth-like planets in Earth-like orbits around stars in the disk of our Galaxy.

FUSE: Postdoctoral Fellow Roberge is PI on a Cycle 4 Guest Observer program, Weinberger is a Co-I. Title: Circumstellar Gas in Young Planetary Debris Disks.

HST: Co-I Weinberger is PI on a Cycle 13 Guest Investigator program. Title: Observations of Ices in Circumstellar Disks.

Spitzer Space Telescope: Co-I Weinberger is PI on a Cycle 1 Guest Investigator Program. Title: MIPS Photometry of the HD 141569 Triple System: Resolving a Puzzle and Searching for Disks.

TPF: Co-I Seager is a member of the Science and Technology Definition Team (STDT) as well as a Co-I on three instrument concept studies for TPF. Her Co-I roles involve modeling both giant planet and terrestrial planet atmospheres to understand the best way of observing them with TPF instrumentation

Navigator Program: Co-I Boss is a member of NASA Headquarter's Navigator Program External Independent Readiness Board, which has oversight responsibility for all elements of the Navigator Program, including the Keck Interferometer, Large Bionocular Telescope Interferometer, Space Interferometry Mission, and Terrestrial Planet Finders (optical coronagraph and mid-infrared interferometer).

Field Expeditions

Field Trip Name: DuPont 2.5-m Telescope
Start Date: 9 May 2005 **End Date:** 18 May 2005
Continent: South America **Country:** Chile
State/Province: **Nearest City/Town:**
Latitude: **Longitude:**
Name of site(cave, mine, e.g.): Las Campanas **Keywords:**

Description of Work: Search for gas-giant planets on long-period orbits around low-mass stars - principally late M, L, and T dwarfs - planets that would permit the existence of shorter-period, habitable, Earth-like worlds around these same stars.
Members Involved:
Alan Boss

Field Trip Name: Gemini North Observatory
Start Date: 18 May 2005
End Date: 21 May 2005
Continent: North America
Country: USA
State/Province: Hawaii
Nearest City/Town: Hilo
Latitude: 19:49.7
Longitude: 155:28.7
Name of site(cave, mine, e.g.):
Gemini North Headquarters
Keywords:
Description of Work: Mid-infrared imaging of young stars to detect their dusty disks and spectroscopy to study their composition.
Members Involved:
Alycia Weinberger
Eric Becklin
Benjamin Zuckerman
Inseok Song

Field Trip Name: Magellan/Baade Telescope
Start Date: 14 June 2005
End Date: 17 June 2005
Continent: South America
Country: Chile
State/Province:
Nearest City/Town: La Serena
Latitude: -29:0.2
Longitude: 70:42.1
Name of site(cave, mine, e.g.):
Las Campanas
Keywords:
Description of Work: Molecular hydrogen imaging of young stellar outflows.
Members Involved:
Alycia Weinberger
Aki Roberge

Field Trip Name: Magellan/Clay Telescope and Magellan/Baade Telescope
Start Date: 2 July 2004; 5 September 2004; 20 October 2004; 21 December 2004
End Date: 4 July 2004; 6 September 2004; 22 October 2004; 23 December 2004
Continent: South America
Country: Chile
State/Province:
Nearest City/Town: La Serena
Latitude: -29:02
Longitude: 70:42.1
Name of site(cave, mine, e.g.):
Las Campanas
Keywords:
Description of Work: "Hot Jupiter" planet search program (radial velocity detections of extrasolar planets).
Members Involved:
R. Paul Butler
Mercedes Lopez-Morales

Field Trip Name: Keck 1 Telescope and Subaru Telescope
Start Date: 7 July 2004; 19 July 2004; 21 July 2004; 20 August 2004; 23 Augu
End Date: 13 July 2004; 20 July 2004; 23 July 2004; 22 August 2004; 23 Aug
Continent:
Country: USA
State/Province: Hawaii
Nearest City/Town: Waimea

Latitude: 19:49.7 **Longitude:** 155:28.7
Name of site(cave, mine, e.g.):
Keck Observatory and Japanese National Observatory, Mauna Kea
Keywords:
Description of Work: Keck planet search program (radial velocity detections of extrasolar planets); "Hot Jupiter" planet search program.
Members Involved:
R. Paul Butler

Field Trip Name: Anglo-Australian Telescope
Start Date: 27 July 2004; 22 April 2005 **End Date:** 31 July 2004; 28 April 2005
Continent: Australia **Country:** Australia
State/Province: New South Wales **Nearest City/Town:**
Latitude: **Longitude:**
Name of site(cave, mine, e.g.):
Anglo-Australian Observatory
Keywords:
Description of Work: Anglo-Australian planet search
Members Involved:
R. Paul Butler

Cross Team Collaborations

PI Solomon collaborated with James Head (MBL NAI team) and Bruce Jakosky (University of Colorado NAI team) on the early history of planetary water on Mars.

Co-I Boss has an ongoing collaboration with the NASA Ames Research Center scientists working on the Kepler Mission.

Co-I Chambers collaborated with Jack Lissauer and Elisa Quintana of the NASA Ames Research Center NAI team on numerical models for the origin and evolution of Earth-like planets in binary star systems.

Co-I Weinberger collaborated with Eric Becklin and Ben Zuckerman of the UCLA NAI team on observations of young circumstellar disks.

Weinberger was one of four organizers of the Aspen Center for Physics Winter Astrophsysics Conference on Extrasolar Planet Formation and Detection. This conference marked the 10th anniversary of the discovery of the first extrasolar planet around a solar-like star (51 Pegasi). In addition to being focused on a subject, planet formation, at the heart of the NAI mission, the conference had participation by members of several NAI teams including CIW, UCLA, Hawaii, Arizona, and Penn State. NAI supported the meeting with $8000 for travel to allow participation of students and postdocs, including several from CIW.

Co-I Seager collaborated with Drake Deming, on the NASA Goddard NAI team, on the first detection of photons from an extrasolar planet atmosphere. Seager also collaborated with Brad Hansen, on the UCLA NAI team, on the interpretation of the extrasolar planet atmosphere detection.

Co-I Butler collaborated with Jack Lissauer and Eugenio Rivera of the NASA Ames Research Center NAI team, Steve Vogt and Greg Laughlin of the University of California, Santa Cruz, and Geoff Marcy of the University of California, Berkeley, on the detection of the first terrestrial-mass extrasolar planet orbiting GL 876.

3. Prebiotic Chemical and Isotopic Evolution on Earth

Project Investigators: Jay Brandes, George Cody, James Farquhar, Douglas Rumble

Project Progress

3. Prebiotic Chemical and Isotopic Evolution on Earth

1. Unravelling Earth's Early Sulfur Cycle

The first focus of this project has been on the Archean sulfur cycle and understanding the significance of mass-independent sulfur isotope signals. Rumble, Farquhar, Postdoctoral Fellow Shuhei Ono, and Masters Student Margaret Baker studied Australian and South African Drill cores in collaboration with a number of international colleagues. Postdoctoral Fellows Boswell Wing and Andrey Bekker continued work on constraining the rise of atmospheric oxygen in the Huronian succession, Canada. Related progress was the development of a-state-of-the-art laser fluorination gas chromatograph mass spectrometer to measure multiple isotope ratios of nanomole levels of sulfur.

The second focus has been to deconvolve the mass-dependent sulfur isotope fractionations associated with biological metabolic and biogeochemical networks. This work has been the primary focus of Farquhar, Doctoral Student David Johnston, Wing, and Ono. Accomplishments in the past year include experiments with sulfate reducing, sulfur disproportionating, and thisulfate disproportionating bacteria and an extension of network models to biogeochemical systems. Analysis of four sulfur isotopes as a new tracer of post-Archean sulfur biogeochemical cycles promises to decouple mass-dependent and mass-independent fractionation.

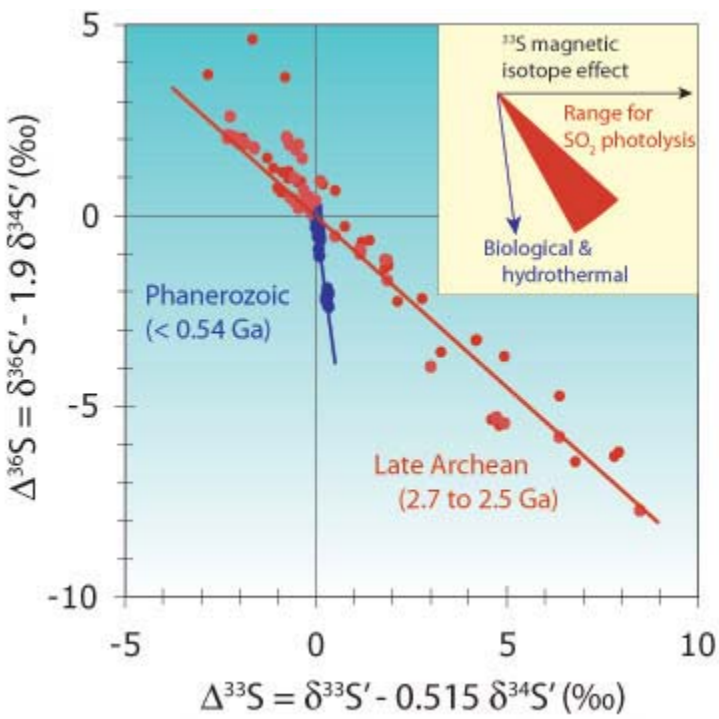


Figure 1. $\Delta^{36}S$ vs. $\Delta^{33}S$ diagram for Archean and Phanerozoic sulfur.

Related work by Andrey Bekker in collaboration with Olivier Rouxel (Woods Hole Oceanographic Institution) divided Precambrian time into three stages with different redox Fe cycles and suggested that the ocean Fe redox cycle quickly responded to the rise of atmospheric oxygen. In collaboration with Mark Barley and Bryan Krapez (University of Western Australia), Bekker attempted to integrate tectonic history with atmospheric and climatic changes during the period 2.45-2.2 Ga. Their preliminary data for the Jerome volcanic massive sulfide deposit open the possibility that the deep ocean was neither sulfidic nor fully oxygenated during 1.8-1.0 Ga.

2. The Critical Role of Sulfur in Prebiotic (Protometabolic) Organic Chemistry

Cody and Boctor continued their experimental studies of metal-sulfide-promoted prebiotic chemistry. Previous work outlined a potential entry point into a chemical reaction network that includes many compounds familiar to intermediary metabolism, e.g., citric acid and pyruvic acid. Their initial results show that transition-metal sulfides promote hydroformylation reactions that provide a suite of methylated dicarboxylic acids as intermediates, e.g., methyl fumaric (mesaconic) acid and methyl malic (citramalic) acid. They have recently discovered that by using pyrite (FeS_2) they are able to reductively demethylate these compounds to yield succinic acid. The specific mechanism is not yet known and is being explored. The fact that an abiotic pathway clearly links the methylated intermediates with the familiar four-carbon dicarboxylic acids appears to strengthen their contention that metal sulfide catalysis provided a critical connection between natural environmental chemistry and the emergence of life.

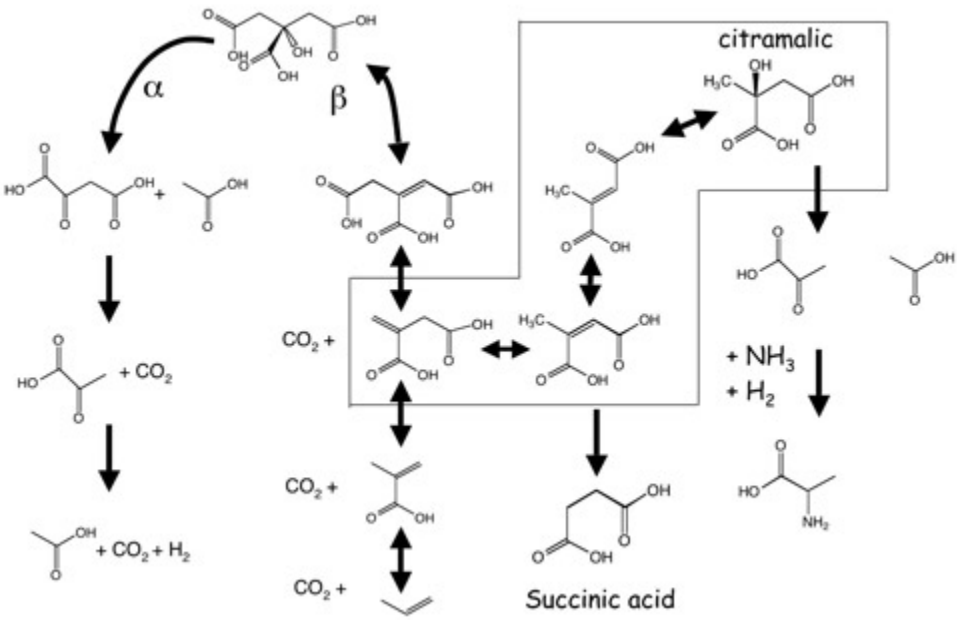


Figure 2. The reaction pathways promoted by transition-metal sulfides under hydrothermal conditions. Succinic acid is formed through a reductive demethylation reaction, but the precise mechanism is not yet known. The facile abiotic generation of molecules familiar in intermediary metabolism is clearly demonstrated.

Over the past year Cody and Boctor extended considerable effort in synthesizing a new suite of minerals to explore their catalytic qualities. In particular they synthesized tungstenite (WS_2), molybdenite (MoS_2), and awaruite (Ni_3Fe). These minerals are found in aqueously altered ultramafic rocks. They are initiating experiments to assay the catalytic performance of these phases and demonstrate hydrocarbon synthesis capability starting with CO_2 and H_2 directly. They aim ultimately to obtain stable isotopic data in order to refine their ability to distinguish between abiotic and biotic derived hydrocarbons.

Finally, over the past year Brandes and his group finished a study of metal-sulfide-catalyzed N_2 reduction. The group continued to examine different aspects of the prebiotic nitrogen cycle. Their efforts were concentrated on three areas. The first was method development to examine very small samples of organic nitrogen with the aim of examining organic inclusions in Archaean rocks and meteorites, as well as organic N generated during prebiotic synthesis experiments. This method allows high-precision natural abundance measurements of organic nitrogen isotopes on nanomole-size samples. The second was the development of techniques to quantify and characterize organic samples using soft X-ray microscopy, and they have applied the techniques to graphitic and amorphous carbon samples. Brandes and colleagues mapped C:N:O ratios in such samples and developed a detailed model used to interpret X-ray absorbtion spectra. Finally, they continued their efforts to examine mineral-catalyzed N cycling within hydrothermal systems. Their future goals in this area are to quantify and model the isotopic shifts associated with abiotic nitrogen transformations as a possible tool for investigating signatures in returned samples from Mars and other Solar System objects.

Roadmap Objectives

- **Objective No. 3.1:** Sources of prebiotic materials and catalysts

- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials

Field Expeditions

Field Trip Name: Geological survey of the middle Archean Barberton Greenstone Belt
Start Date: 11 June 2005
End Date: 1 July 2005
Continent: Africa
Country: South Africa
State/Province:
Nearest City/Town: Barberton
Latitude: 26ºS
Longitude: 31ºE
Name of site(cave, mine, e.g.): Barberton Greenstone Belt
Keywords: Archean, sulfur isotope, chert, mass-independent fractionation, oxygen, sulfate reduction
Description of Work: Geological field trip to the Barberton Greenstone Belt, South Africa
Members Involved:
Douglas Rumble
Donald Lowe

Field Trip Name: Jasper and iron-formations associated with the 1.74-Ga Jerome volcanic massive sulfide deposit
Start Date: 8 March 2005
End Date: 19 March 2005
Continent: North America
Country: USA
State/Province: Arizona
Nearest City/Town: Jerome
Latitude: 34º40'
Longitude: 112º10'
Name of site(cave, mine, e.g.): Jerome Mine
Keywords: Paleoproterozoic, volcanic massive sulfide deposit, iron-formation, jasper, microfossils, Fe isotopes, REE
Description of Work: Sample collection
Members Involved:
Andrey Bekker

Field Trip Name: Carbonates and black shales of the Paleoproterozoic Hurwitz and Amer groups, Nunavut, Canada
Start Date: 1 July 2004
End Date: 15 July 2004
Continent: North America
Country: Canada
State/Province: Nunavut
Nearest City/Town: Baker Lake, Rankin Inlet
Latitude: 64º00'
Longitude: 93º00'
Name of site(cave, mine, e.g.): Baker Lake, Rankin Inlet
Keywords: Paleoproterozoic, sedimentary succession, rise of atmospheric oxygen, carbon isotope excursion, glacial diamictite, carbonates, black shales
Description of Work: Sample collection, logging of sections
Members Involved:
Andrey Bekker

Field Trip Name: Geochronology and sampling for C and S isotope analyses
Start Date: 18 August 2004
End Date: 18 September 2004
Continent: North America
Country: USA & Canada
Nearest City/Town: Duluth,

State/Province: MI, WI, MN, ON	Sudbury
Latitude: 46º40'	**Longitude:** 89º00'
Name of site(cave, mine, e.g.): MN, WI, MI, ON	**Keywords:** Paleoproterozoic, Huronian Supergroup, Animikie Group, Marquette Range Supergroup, carbonates, glacial diamictites, U-Pb dating
Description of Work: Sample collection	
Members Involved: Andrey Bekker	

Cross Team Collaborations

Hiroshi Ohmoto and his colleagues from the Pennsylvania State Astrobiology Research Center (PSARC) visited the Carnegie Institution and the University of Maryland in September 2004 to discuss multiple sulfur isotope analysis.

Olivier Rouxel (WHOI) visited CIW to initiate collaboration with Andrey Bekker on coupled S and Fe isotope systems. Clint Scott, a Ph.D. student of Tim Lyons (associated with PSARC), visited Bekker to select samples for the collaborative study of redox-sensitive elements in Precambrian organic-rich shales. Bekker, in collaboration with Rouxel, John Slack (USGS), and Tor Grenne (Norway Geological Survey), carried out fieldwork in the Jerome, AZ, area on Paleoproterozoic volcanic massive sulfide deposits.

Ongoing collaboration with Don Canfield (NASA Ames NAI team) at Odense University has been essential to the study of sulfur isotope fractionation effects associated with different types of sulfur metabolisms. David Johnston spent several months in 2005 working in Don Canfield's laboratory, and plans for continued collaboration through visits by James Farquhar are planned for the fall.

4. Prebiotic Molecular Selection and Organization

Project Investigators: David Deamer, Robert Hazen, Andrew Steele

Project Progress

4. Prebiotic Molecular Selection and Organization

1. Molecular Self-Organization

Studies in molecular self-organization focused on two types of amphiphilic molecules, which are molecules that possess both hydrophobic and hydrophilic regions. These molecules tend to self-organize spontaneously in an aqueous environment.

Hazen and Deamer investigated the self-organization of a suite of molecules produced when an aqueous solution of pyruvate is subjected to hydrothermal conditions (250°C at 0.2 GPa). They then observed a significant production of amphiphilic, lipid-like molecules that form vesicles in water.

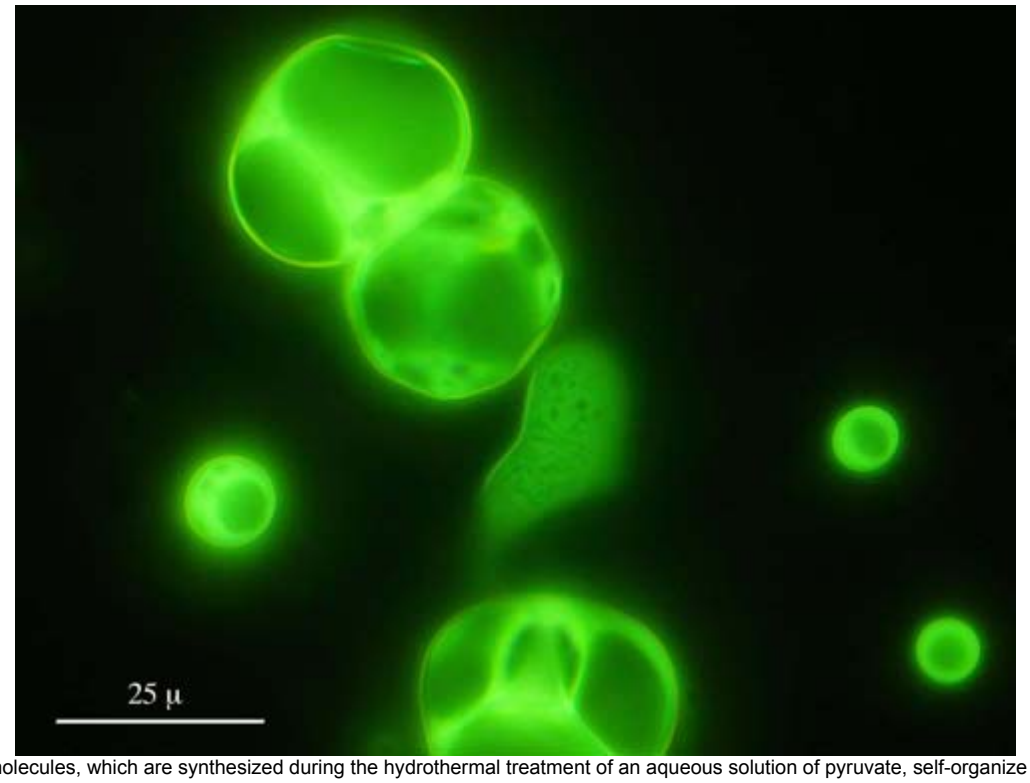


Figure 1. Amphiphilic molecules, which are synthesized during the hydrothermal treatment of an aqueous solution of pyruvate, self-organize into cell-sized vesicles.

The behavior of this molecular suite is similar to that found previously in studies of natural amphiphiles from the Murchison meteorite.

In a second study of prebiotic molecular self-organization, Postdoctoral Fellow Nicholas Platts developed the "PAH World" model of life's origins, based on the discotic self-organization of functionalized PAH molecules in an aqueous environment. In this model, a stack of PAHs becomes decorated at the edges with the bases of nucleic acids, which are linked into a genetic-type sequence. Platts proposes this model as a precursor to the RNA World.

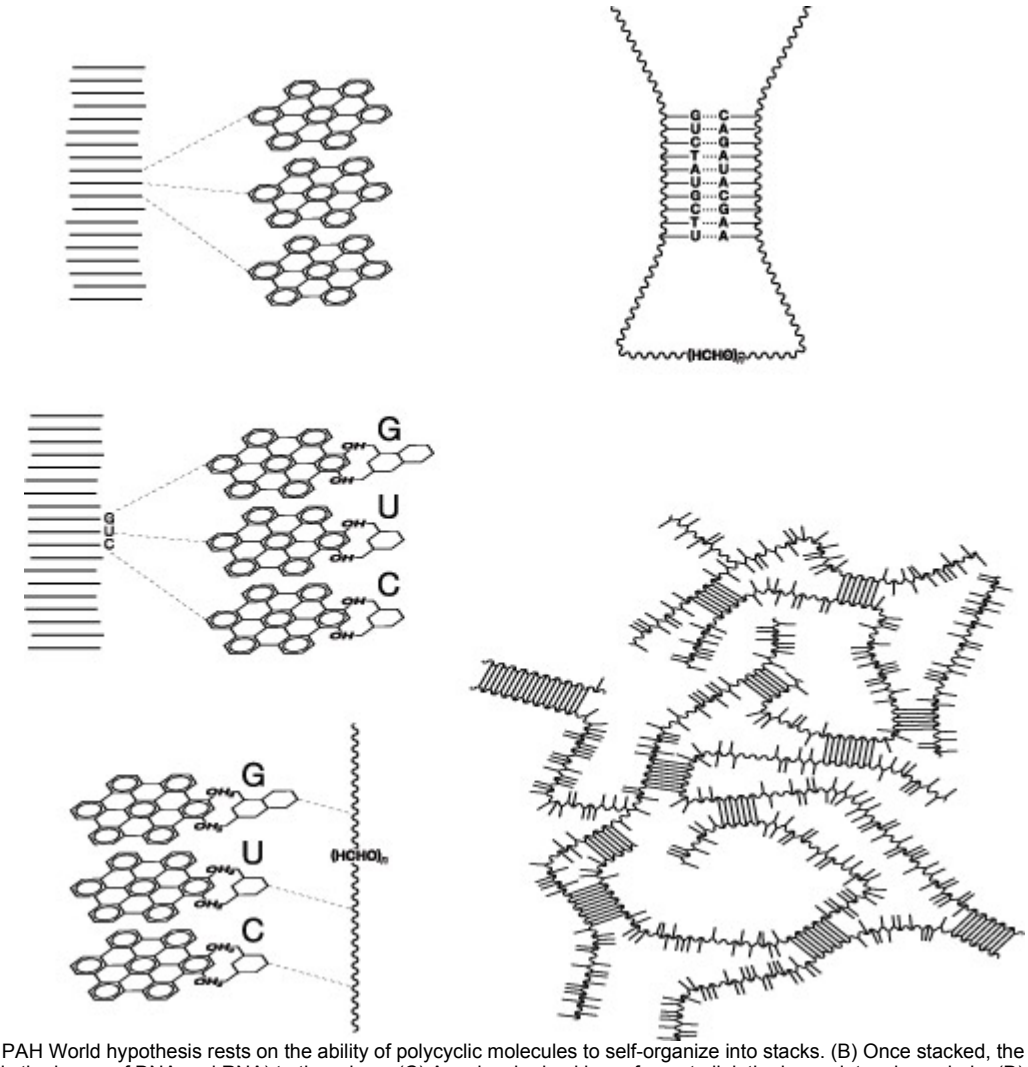


Figure 2. (A) Nick Platts' PAH World hypothesis rests on the ability of polycyclic molecules to self-organize into stacks. (B) Once stacked, the PAHs would tend to attract small flat molecules (notably the bases of DNA and RNA) to the edges. (C) A molecular backbone forms to link the bases into a long chain. (D) The RNA-like chain of bases separates from the PAHs and folds into a molecule that carries information. (E) Complex assemblages of these chains have the potential to catalyze reactions.

2. Molecular Selection and Organization on Mineral Surfaces

Several of the group's studies in molecular selection focused on the knotty problem of life's homochirality – the characteristic of life to incorporate overwhelmingly left-handed amino acids and right-handed sugars. By what processes might such molecular selectivity have occurred on the prebiotic Earth. The team's studies proceeded on two fronts – experimental and theoretical.

Two questions frame these studies. First, what molecules are adsorbed selectively onto what mineral surfaces? Given the vast numbers of different mineral surfaces and different organic molecules of interest, a combinatoric approach is needed. Therefore, Maule, Steele, and Hazen focused on the application of microarray technologies to apply small amounts of many different molecules to several different mineral surfaces in a single experiment. Preliminary results indicate that a variety of mineral surfaces are suitable for this approach, and that small amounts of adsorbed amino acids can be detected using time-of-flight secondary ion mass spectrometry (ToF-SIMS) in the macro-raster mode. These advances will allow the group to investigate a wide range of mineral-molecule interactions.

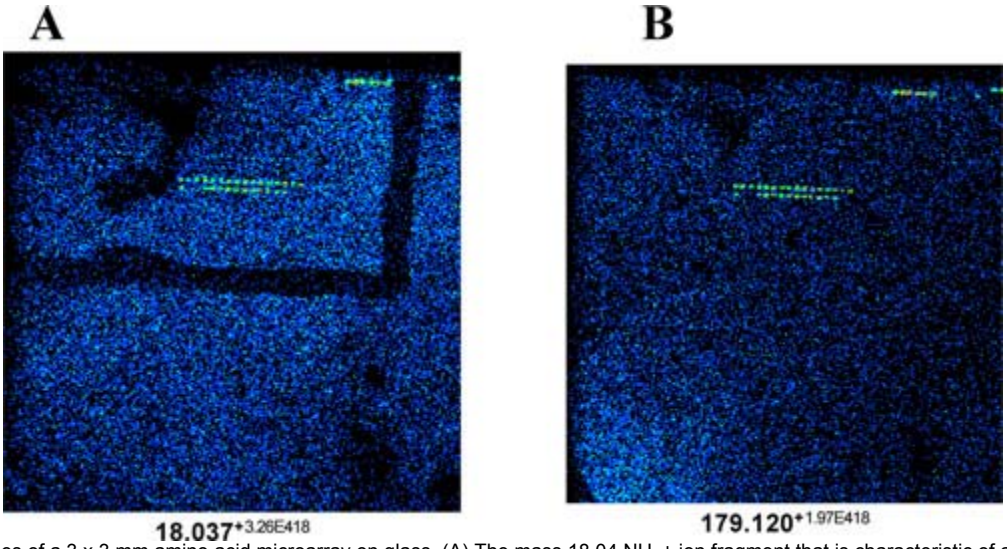


Figure 3. ToF-SIMS images of a 3 x 3 mm amino acid microarray on glass. (A) The mass 18.04 NH_4+ ion fragment that is characteristic of all amino acids; dark lines correspond to ink marks and other surface contamination. (B) The mass 179.12 Na-lysine+ whole-ion signal. Dot false colors represent amino acid concentration

In addition to the phenomenology of selective molecular adsorption, Hazen and colleagues want to know the details of mineral-molecule interactions at an atomic scale. To this end, Asthagiri and Hazen have initiated a theoretical study of molecular adsorption using density functional theory – a first principles, *ab initio* computational approach. They find that strong chiral adsorption requires three points of interaction (bonding) between the molecule and mineral surface. Such interactions occur, for example, when the amino acid, aspartic acid, bonds to the calcite (214) surface. Thus D-Asp is strongly selected in preference to L-Asp, just as observed in experiments.

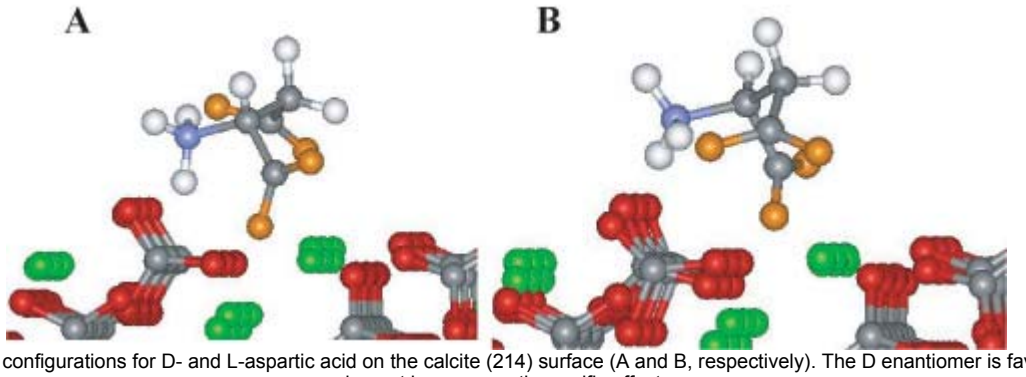


Figure 4. The most stable configurations for D- and L-aspartic acid on the calcite (214) surface (A and B, respectively). The D enantiomer is favored by 8 kcal/mol - the largest known enantiospecific effect.

However, the amino acid alanine has only two strong bonded interactions with the calcite (214) surface, so there is no chiral selection, in agreement with experiments.

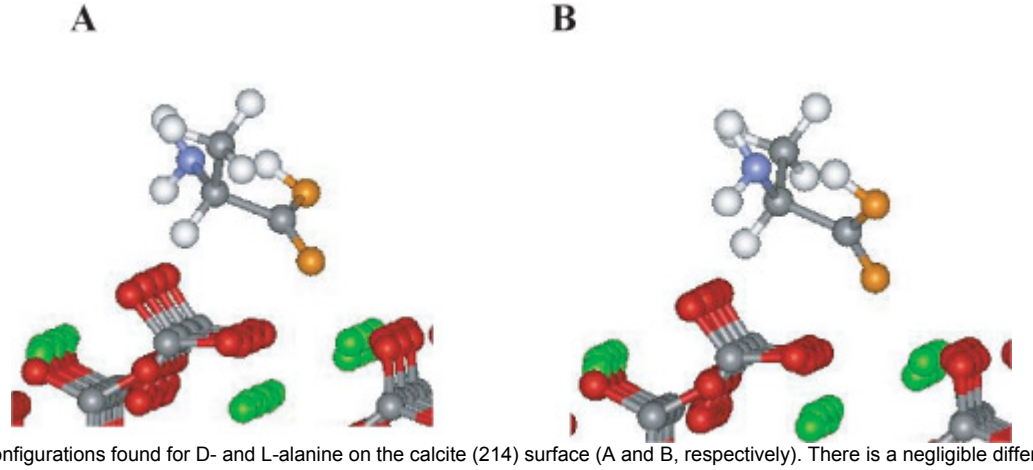


Figure 5. The most stable configurations found for D- and L-alanine on the calcite (214) surface (A and B, respectively). There is a negligible difference in adsorption energy.

In addition to these studies of chiral selection, Ertem conducted studies of the formation of RNA oligomers

on Na-montmorillonite (a clay mineral). She has demonstrated the formation of phosphodiester bonds in the presence of this clay. Furthermore, she finds that the rates of formation of different oligomers differ significantly. Thus, only a limited number of oligomers could have formed on the early Earth, rather than equal amounts of all possible isomers.

Ultimately, the objective of this project is to understand molecular selection and organization as it might have occurred in a natural prebiotic setting. To this end, Deamer and coworkers have studied the fate of a suite of organic molecules (including four different amino acids, four different nucleobases, glycerol, myristic acid, and phosphate) when poured into a natural, acidic (pH = 3.1) hot spring with a volume of approximately 10 liters. Virtually all of the solutes except myristic acid rapidly disappeared from solution with half-times ranging from 30 minutes to 2 hours. Subsequent analyses of clay minerals lining the edge of the pool revealed that the organic compounds and phosphate were adsorbed by the clay particles. Furthermore, these molecules could be released at alkaline pH ranges. The myristic acid, which was not adsorbed to the clay, nonetheless was precipitated as an iron or aluminum soap that formed an insoluble curd. They conclude that organic compounds and phosphate in an acidic hydrothermal spring exposed to mineral surfaces would not be available as soluble reactants, nor would a fatty acid amphiphile be able to produce stable membranes. These observations provide constraints on conditions that would be conducive to the origin of cellular life.

Roadmap Objectives

- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 3.2:** Origins and evolution of functional biomolecules
- **Objective No. 3.4:** Origins of cellularity and protobiological systems
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials

Cross Team Collaborations

Predoctoral Fellow Simon Nicholas Platts was a graduate student at the the NSCORT at RPI but performed much of his Ph.D. thesis work while at the Carnegie Institution of Washington. He was awarded his Ph.D. in 2004 and now holds a postdoctoral position sponsored jointly by UC Santa Cruz and CIW.

Gözen Ertem, at the NASA Goddard Space Flight Center, conducted her experiments on clay-catalyzed oligomerization of RNA as a Visiting Investigator at CIW. Hazen and collaborators have begun a cross-team collaboration with Spanish scientists at the CAB who will assist in the analysis of chiral molecules adsorbed on mineral surfaces.

5. Life in Extreme Environments

Project Investigators: John Baross, David Emerson, Russell Hemley, James Scott, Andrew Steele

Project Progress

5. Life in Extreme Environments

1. Life in Deep-Sea Hydrothermal Vents

The astrobiology research objectives of Baross and his group are focused on understanding the microbial ecology and physiology of Earth environments that share geophysical and geochemical characteristics with other planets and satellites. Baross and colleagues have targeted magma-hosted and peridotite-hosted hydrothermal systems, because they abiotically produce high concentrations of biologically important carbon and energy sources. These environments are also primordial and may be the sites for key chemical reactions that led to the origin of life on Earth and for the earliest microbial ecosystems. The group's research questions address hydrothermal vent ecosystems where hydrogen is the main energy source and the strategies used by microbes to exploit the carbon and energy sources available, extract essential nutrients from rocks, and grow and survive under the extreme conditions of these environments.

Baross's team also continued its studies of nitrogen fixation in vent environments. This work is important because other forms of nitrogen such as ammonia and nitrate are present in low concentrations or at non-detectable levels in these environments. Recent results indicate that subseafloor archaea that are related to the most abundant group of archaea in seawater have genes for nitrogen fixation (*nif*H). These potential nitrogen-fixing archaea are also found in deep seawater near mid-ocean ridges but not in deep seawater off-axis, suggesting that this group of archaea circulates through the N-poor subseafloor at mid-ocean ridges as part of their life cycle.

Baross and colleagues completed a study of the microbial community in a subseafloor environment at Baby Bare Seamount, a well-described basaltic outcrop located on 3.5-Ma oceanic crust in the northeast Pacific. The results are surprising and show a much higher diversity of microorganisms than expected, including anaerobic hyperthermophiles and hydrogen-utilizing thermophiles. Their results point to the hypothesis that the subsurface associated with hydrothermal systems in off-axis crust harbors a high diversity of microorganisms that includes archaea and bacteria that have novel metabolisms and physiologies that allow for growth in the absence of nutrients derived from photosynthesis.

Much of this work involves the isolation of microorganisms from subsurface fluids and high-temperature sulfide and rock samples. The group demonstrated that isolates of *Thermococcales* from different subseafloor habitats at Axial Volcano on the Juan de Fuca Ridge show different physiological characteristics linked to the chemistry of the subseafloor fluids. Matt Schrenk, who will be completing his Ph.D. in summer 2005, focused on microbial biofilms formed on minerals at high temperatures. He obtained evidence for microbial biofilm formation at temperatures considerably higher than 121°C, the highest growth temperature so far for isolated microbes.

Research at the Lost City Hydrothermal Field (LCHF) continued. The LCHF is located 15 km off the axis of the Mid-Atlantic Ridge and consists of a network of large carbonate chimney structures. The fluids from these structures reach temperatures greater than 90°C, have pHs from 9 to 11, and are driven by exothermic serpentization reactions that produce high concentrations of hydrogen, methane, and organic compounds. Baross and colleagues found that the most actively venting chimneys are dominated by a single phylotype of *Methanosarcinales* distinct from the two known groups. These organisms form dense biofilms on the carbonate structures. Recently, they showed the presence of 16S rDNA and methyl coenzyme-M reductase (*mcr*A) sequences related to the anaerobic methane oxidation group of *Methanosarcinales* (ANME-1) indicating that LCHF may be a high-temperature analogue to cold methane seep environments. They also completed the phylogenetic characterization of the bacterial and archaeal communities from carbonate and fluid samples and showed evidence for the widespread occurrence of methane and sulfur-oxidizing bacteria. Baross and colleagues will be participating on another cruise to LCHF in August 2005 and will attempt to measure methane production and consumption rates in situ using stable isotopes.

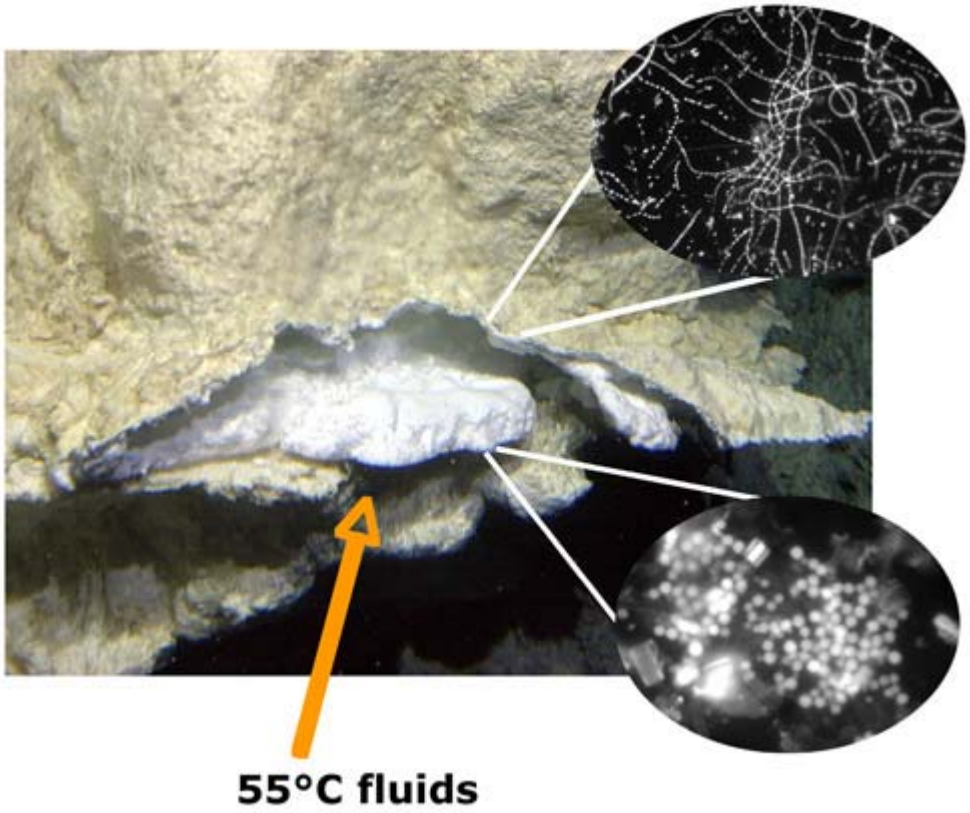


Figure 1. Methane-matabolizing Archaea (round cells) bound portions of carbonate chimney structures adjacent to volatile-rich, high-pH hydrothermal fluids in the Lost City hydrothermal vent field, Mid-Atlantic Ridge. Along the exterior of the structures filamentous bacteria (upper picture) are the predominant organisms.

2. Iron-Based Metabolic Strategies for Microbial Life

During the past year Emerson and colleagues made significant progress in their study of bacteria that oxidize iron as a source of energy at neutral pH. Emerson and Postdoctoral Research Scientist Jeremy Rentz participated in a field expedition to the Loihi Seamount in October 2004 and collected a number of new samples for analysis from the extensive microbial Fe mats that exist in association with hydrothermal vents at this site. Highlights from this work include more efficient methods for obtaining and culturing DNA from these organisms, which are very difficult to manipulate in the laboratory. This work has led to the reclassification of isolates obtained from the Loihi system as a deeply branching group of proteobacteria, in contrast to previous data that had indicated they were close relatives of known bacteria. Emerson and his group developed real-time PCR assays that will allow them to track and enumerate their populations in the environment. A simple method was also developed to study the early phase of colonization of microbial mats by these bacteria in situ; study results to date indicate that the Fe-oxidizing bacteria initiate growth rapidly and are probably responsible for catalyzing most of the iron oxidation that occurs in the early phase of Fe mat development.

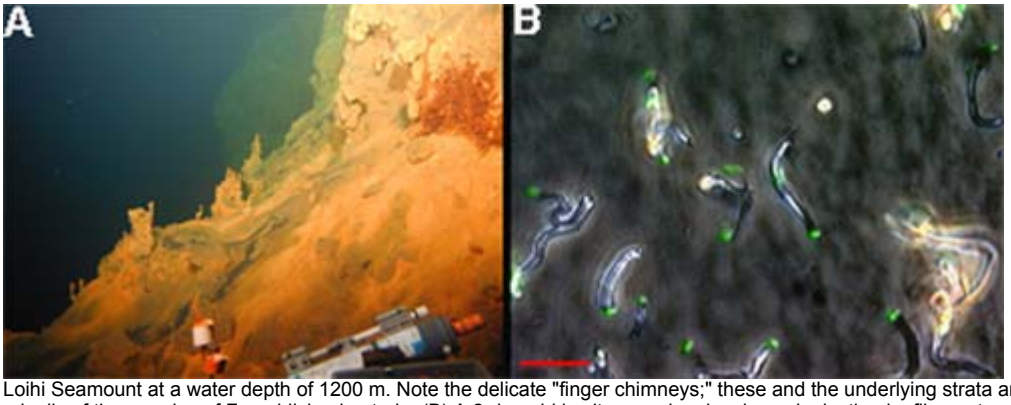


Figure 2. (A) Fe mats at the Loihi Seamount at a water depth of 1200 m. Note the delicate "finger chimneys;" these and the underlying strata are composed of centimeter-thick Fe mats composed principally of the remains of Fe-oxidizing bacteria. (B) A 2-day-old in situ sampler showing colonization by filamentous Fe-oxidizing bacteria. The bacteria are stained green and grow at the apical ends of the filaments, which are composed principally of Fe-oxyhydroxides, although high-resolution Raman analysis indicates there is a carbon-component as well. The bar is 10 µm.

In collaboration with Steele and Vicenzi, Emerson and colleagues initiated a project aimed at high-resolution imaging of some of the unique morphological structures produced by Fe-oxidizing bacteria using Raman spectroscopy coupled to light microscopy and TOF-SIMs coupled to electron microscopy. Initial results with field samples indicate that Fe-mineralogies can be distinguished and elemental maps resolved at the sub-micrometer scale. Emerson and his group are in the process of designing and conducting experiments using both pure cultures of Fe-oxidizing bacteria and natural samples to understand how diagenetic processes affect these structures. This work will allow them to interpret signatures for similar structures that are commonly found in the rock record dating back billions of years on Earth.

In another project that was partially supported by NAI, Emerson, Masters Student Melissa Floyd, and others completed a survey of environmental prokaryotes held at the ATCC. This work quantified anecdotal evidence that there is a wide gulf between the microbes that are typically used in the laboratory and those that have been surveyed in the environment using cultivation-independent methods. This work also pointed out the large discrepancy in discovery and culture of microbes from the developed nations compared with the less-developed nations (which are also home to the bulk of animal and plant diversity).

3. The Effect of Pressure on Carbon Compounds, Water, and Microbial Physiology

The chemistry of carbon and carbonaceous materials over a broad range of pressures and temperatures characteristic of those found within planets defines the limits of life (as we know it) in extreme environments and must guide all thinking about life's origins. It is well known that terrestrial carbon exists in several forms: native, oxidized, and reduced in a wide variety of hydrocarbons. This complexity is demonstrated by many examples: diamonds in kimberlite formations, graphite in metamorphic rocks, volcanic CO_2 emissions, ubiquitous carbonate minerals in the crust, methane hydrates on the ocean floor, and petroleum reservoirs in sedimentary basins. The stability and formation of reduced species such as methane and higher hydrocarbons are of particular interest from the standpoint of prebiotic chemistry and astrobiology. Indeed, information about these species in other bodies of the solar system has expanded greatly with recent planetary probes.

Hemley, NAI Postdoctoral Research Associate Henry Scott, and colleagues reported the first in situ high-pressure and high-temperature experiments to show that methane readily forms by reduction of carbonate under conditions typical for terrestrial planetary mantles. Starting materials were natural $CaCO_3$ calcite, FeO wüstite, and distilled H_2O. Experiments were conducted using new diamond anvil cell (DAC) techniques; simultaneous high-pressure and high-temperature conditions were produced by both resistive (<600°C) and laser heating (>1,000°C) methods. Additional calculations of hydrocarbon stability have been pursued with a group at the Lawrence Livermore National Laboratory, and new experiments are underway to examine the formation of higher hydrocarbons and carbon isotope fractionation.

Studies were also carried out in other organic-rich systems under a wide range of conditions with the aim of directly monitoring processes such as structural phase transformations, organic synthesis reactions, fluid-phase immiscibility, reactions kinetics, and pathways. These experiments included investigations of the stability and properties of various clathrate hydrates in a broad range of planetary environments. New data were obtained by Raman spectroscopy and by neutron scattering in a variety of systems (e.g., H_2O-H_2). One focus was the so-called novel clathrates or van der Waals compounds that may be stable in the satellites of the outer planets. One of these, $CH_4(H_2)_4$, was found to be stable over a remarkably wide range of pressure and temperature. Plans were developed for inelastic neutron scattering measurements on clathrate hydrates to understand further the structure, dynamics, and reactivity of these systems, and preliminary tests were performed.

The behavior of H_2O under pressure underlies Hemley and his team's work in prebiotic chemistry and high-pressure microbiology. New, and indeed unexpected, transformations in ice were documented by X-ray diffraction and Raman spectroscopy. In this regard, observational data indicate that the water/ice in bodies such as Europa likely contains considerable dissolved salts. Thus determination of the phase relations in aqueous solutions over a broad P-T range is essential for understanding processes within these planetary bodies. Preliminary studies of KCl-H_2O solutions revealed a series of low-temperature transformations in this system under Europan interior conditions.

Scott and Collaborator Anurag Sharma (Rensselaer Polytechnic Institute) made significant progress in understanding the adaptations that allow microbial life to persist at pressures approaching 2 GPa. Using light microscopy and epiflourescent microscopy, the group showed that gram-negative bacteria have much greater resistance to pressure than gram-positive bacteria. This work provided the framework for efforts to identify key proteins and genes that are triggered in response to pressures between 0.1 and 1.5 GPa. The effort to identify pressure-sensitive genetic elements has been a collaborative effort spearheaded by Scott, Steele, and Sharma. mRNA from cells altered by pressure has been isolated by Doctoral Student Verena Starke for DNA microarray analysis to identify genes that are turned off and on in *Escherichia coli* in response to pressure. Collaborator Grigoriy Pinchuk (Microbial Dynamics Group, Pacific Northwest National Laboratory, or PNNL) has developed continuous culturing approaches to identify pressure-sensitive proteins in *E. coli* and *Shewanella oneidensis* MR1.

4. Formate Metabolism in Shewanella oneidensis

In the course of collaborative research with the Microbial Dynamics Group at PNNL, Scott identified a novel carbon assimilation pathway utilized by *S. oneidensis* MR1 during dissimilatory reduction of ferric iron. Through the utilization of microarray and genomic analysis he confirmed that *Shewanella* MR1 contains a novel formate assimilation pathway that exploits genes and proteins usually associated with organisms that grow on methane, methylamines, and methanol as their sole sources of carbon. This work should lead to a re-examination of the topic of carbon assimilation by bacteria and archaea and to the identification of other novel pathways.

Roadmap Objectives

- **Objective No. 5.3:** Biochemical adaptation to extreme environments

Field Expeditions

Field Trip Name: Endeavour vent field on the Juan de Fuca Ridge
Start Date: Since May 2005 **End Date:**
Continent: **Country:**
State/Province: **Nearest City/Town:**
Latitude: **Longitude:**
Name of site(cave, mine, e.g.): **Keywords:**
Description of Work: Participated on two cruises to submarine hydrothermal vent environments that included sampling subseafloor hydrothermal fluids for microbial analyses and in situ enrichments of microbial biofilms in situ using a sulfide incubator.
Members Involved:
John Baross

Field Trip Name: Pacific Rim of Fire cruise
Start Date: April 2005 **End Date:**
Continent: **Country:**
State/Province: **Nearest City/Town:**
Latitude: **Longitude:**
Name of site(cave, mine, e.g.): **Keywords:**
Description of Work: Participated in a cruise to a submarine hydrothermal vent environment that involved sampling fluid, rocks, and animals from the many different volcanic environments associated subduction zones and seamounts.
Members Involved:
John Baross

Field Trip Name: Loihi Seamount
Start Date: 15 October 2004 **End Date:** 29 October 2004

Continent: Pacific Ocean
Country:
State/Province: 25 miles southeast of Hawaii
Nearest City/Town:
Latitude: 155.5°W
Longitude: 19.5°N
Name of site(cave, mine, e.g.):
Keywords:
Description of Work: Sampling and experiment deployment and recovery using University of Hawaii R/V Kaimikai O Kanaloa and DSV Pisces V. Collected microbial Fe mat samples for culturing and molecular studies; deployed and collected in situ samplers.
Members Involved:
David Emerson

Cross Team Collaborations

Baross and colleagues are discussing a possible collaboration with the MBL NAI team to look at genomic and functional diversity in subsurface environments associated with hydrothermal vents.

Co-I Emerson and team members have collaborated extensively with the NAI team at UC Berkeley. Emerson and his group have assisted them in cultivation-based studies of S-oxdizing bacteria from a sulfureta in California that they are studying. This same team has collaborated extensively with George Luther from the University of Delaware using his scanning volumetric microelectrodes to measure environmental rates of iron oxidation both in field samples and in pure cultures. In addition, they collaborate extensively with Katrina Edwards who is part of the MBL NAI team on studies at Loihi. Emerson and colleagues have a separate NSF grant for studying this site with Edwards and other colleagues.

6. Molecular and Isotopic Biosignatures

Project Investigators: George Cody, David Deamer, Marilyn Fogel, Robert Hazen, Andrew Steele, Noreen Tuross, Ed Vicenzi

Project Progress

6. Molecular and Isotopic Biosignatures

1. Preservation of Molecular Biosignatures

Steele and Postdoctoral Fellow Marc Fries used the new WiTec Raman imaging system to begin the examination of in situ carbon formation in a variety of samples, including Precambrian rocks and samples from a Mars analog site in Svalbard. Carbonate globules contained within carbonate-cemented breccia are distinct from carbonate globules within olivine-rich mantle xenoliths from the same area of Svalbard. The team studied the mineralogy and morphology of these mantle xenoliths in an attempt to understand the conditions of formation of these structures and how they may relate to carbonate globules studied from this site previously as well as to the morphologically similar carbonate globules found in Martian meteorite ALH84001.

An interesting observation from these data is the detection of hematite and magnetite within distinct zones of the carbonate globules and the occurrence of C in conjunction with magnetite. Such a zonation is predicted from studies of the stability fields of hematite, magnetite, siderite, and graphite at 0.1-GPa pressure in a CO-rich mixture of CO_2 and CO over a range of temperatures and oxygen fugacities. Interestingly, the compositions of the carbonate globules seem to follow the trends expected from thermal decomposition of siderite and production of magnetite and polyaromatic hydrocarbons (PAHs) as a mechanism to explain the presence of PAHs and magnetite in ALH84001. However, no secondary shock can have occurred to influence formation of these compounds in terrestrial samples. On the basis of zonation patterns, carbon and magnetite therefore most likely formed during the precipitation of carbonate from a CO_2-rich hydrothermal fluid percolating through the mantle.

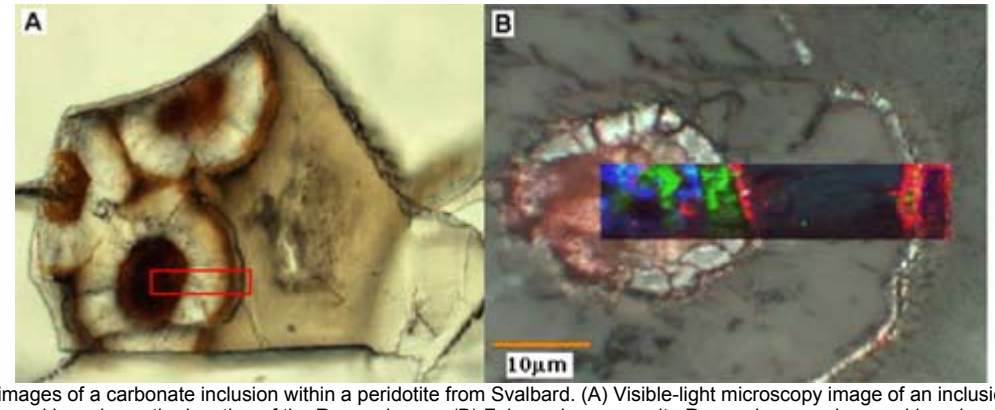


Figure 1. Confocal Raman images of a carbonate inclusion within a peridotite from Svalbard. (A) Visible-light microscopy image of an inclusion in the olivine matrix showing three carbonate rosettes. The red box shows the location of the Raman image. (B) False-color composite Raman image, where red is reduced C, green is hematite, and blue is magnetite. This data are overlain upon a confocal visible light image.

Hazen collaborated with Nora Noffke (Old Dominion University) in studies of purported microbial mat structures from the 3.2-billion-year-old Moodies Group, Barberton Greenstone Belt, South Africa, which features rocks from one of Earth's oldest known siliciclastic tidal marine environments. A combination of geological, chemical, and morphological features, including the shallow marine setting, thin mat-like distribution of carbon, negative carbon isotope values ($\delta^{13}C \sim -21$), trapping and binding of sediment grains, roll-up structures, desiccation features, and distinctive wrinkle structures are similar to those of modern microbial mats. These diagnostic biosignature features, some of which are recognizable in the field from a considerable distance, might represent potential targets in the search for life on Mars.

Understanding the role of life in the formation of early Proterozoic sedimentary manganese deposits is important for unraveling the history of the Earth during its transition from an anoxic to an oxic atmosphere. To recognize potential biomarkers in ancient deposits, Doctoral Student Rachel Schelbel is leading an

experimental study simulating the degradation of microorganisms exposed to Mn(II) and SiO_2. Degradation of *Bacillus subtilis* and *Escherichia coli* is tracked by the break-down of a short-lived biomarker (DNA) and a long-lived biomarker (phospholipid fatty acids and their derivative *n*-alkanes). Comparison samples were collected from the early Proterozoic Kalahari Manganese Field of South Africa. Study procedures include measurements of carbon isotopes and remnant organic carbon and microscopic examination of samples.

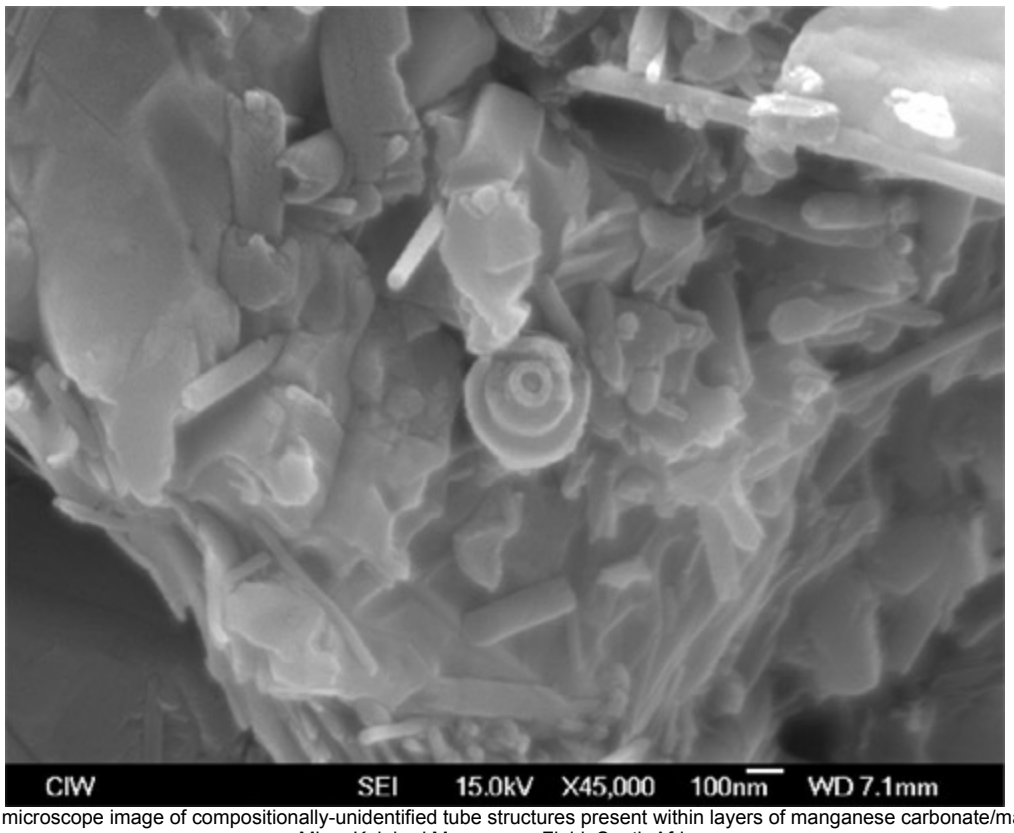


Figure 2. Scanning electron microscope image of compositionally-unidentified tube structures present within layers of manganese carbonate/manganese oxide from Gloria Mine, Kalahari Manganese Field, South Africa.

Steele and Doctoral Student Maia Schweizer studied the 400-million-year-old Rhynie Chert from Scotland, famous for its exquisite preservation of the Earth's earliest land plants in hot spring deposits. Material from this fossiliferous chert has been characterized using confocal Raman imaging. Embedded fossil plant materials were examined in transmission using thin sections as well as embedded material exposed on the surface of thick sections. For surface analysis, surface-enhanced Raman spectroscopy (SERS) was employed to amplify spectra and enhance the signatures of latent post-organic compounds. These observations will be compared with those of other chert samples, such as the 3,465-million-year-old Apex chert, as part of a study to characterize the state of biosignatures in a series of progressively older cherts.

Vicenzi worked on the problem of discerning *bona fide* fossilization products, entombed and mineralized microorganisms, from abiologically derived materials. This task can be particularly vexing in ancient sediments that have suffered some level of metamorphism and metasomatism. The difficulty in identifying the origin of such terrestrial specimens highlights the daunting task facing those who seek to determine the biogenicity of features within specimens returned from Mars and elsewhere. To address this important paleobiological issue, Vicenzi and his group examined mineralized bacterial sheaths produced by Fe-oxidizers within a modern iron seep environment. Three chemical imaging techniques were used to characterize specimens: Raman spectroscopy, energy dispersive X-ray microanalysis, and time-of-flight secondary ion mass spectrometry (ToF-SIMS). The complexity of such a "simple" specimen is particularly evident in the distribution of molecular species (Figure 3). Geochemical traces of the departed bacteria can be seen along the walls of the interior of sheaths as seen in the C_2H and C_2 images. The sheath exteriors, by contrast, are enriched in (Ca,Fe) phosphate and Cl; this coating is assumed to be related to inorganic precipitation.

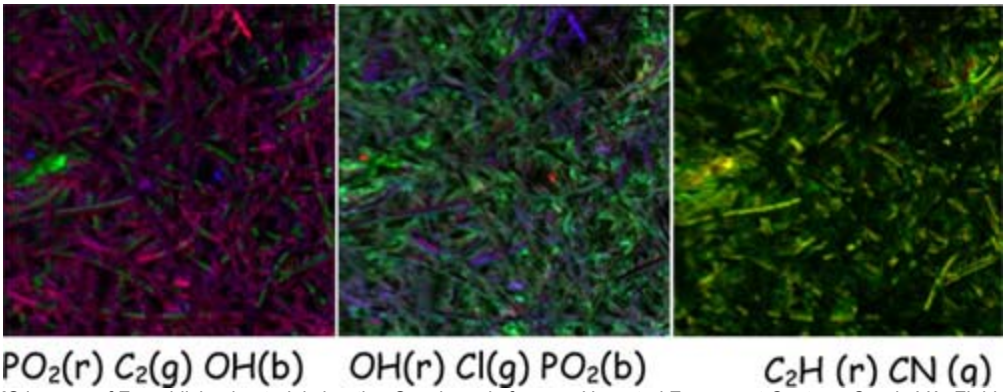


Figure 3. False-color ToF-SIMS images of Fe-oxidizing bacterial sheaths. Specimen is from a pH-neutral Fe seep at Contrary Creek, VA. Field of view = 75 μm; pixel density 256^2.

Tuross, now at Harvard University, developed an antibody for life-detection work. She also determined the N isotopic composition of various chemical fractions of the Green River Shale, a type material for organic geochemistry that has a range of molecular and anatomical fossils preserved in its matrix.

2. Stable Isotope Biosignatures

Fogel and colleagues collected a suite of samples from the Mars analog site in Svalbard for elemental and isotopic analyses with the goal of determining whether a biological signal can be detected above a background of abiogenic C in basalts, carbonates, and other surface rocks. Lichens, terrestrial higher plants, and photosynthetic microorganisms from thermal springs were also analyzed to provide signatures of the extant biological sources. The team found rocks with three potentially distinct pools of C: (1) biogenic photosynthetic organic matter, (2) high-temperature C with a mantle origin often associated with olivine crack surfaces and fluid/gas inclusions within the olivines, and (3) abiogenic C associated with cooling of volcanic gases during breccia formation. The xenolithic carbon representing the second pool of C was most likely not contaminated by biological material, because of the morphological provenance of C with specific mineral assemblages known to promote abiogenic organic C formation. Only the third pool of C has a distinct $\delta^{13}C$ signature in the organic fraction.

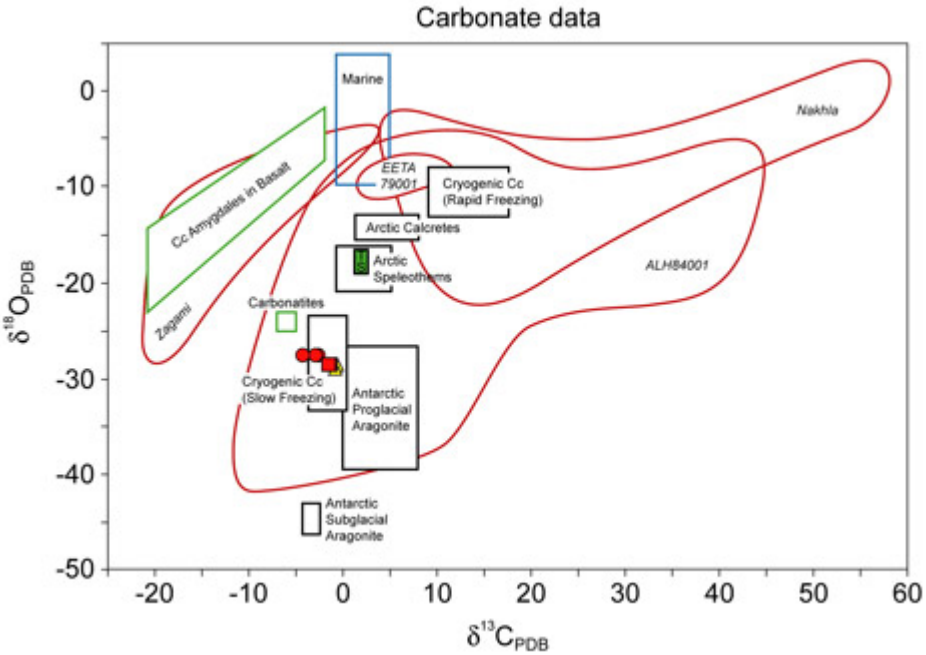


Figure 4. Oxygen and carbon isotopic compositions of carbonates from a Mars analog site in Svalbard relative to other carbonate pools.

All of the rocks analyzed showed some trace of organic C and had an average $\delta^{13}C$ value of −27.5‰, close to the value of −26.6‰ for plants and photosynthetic microbes. The most likely explanation of these results is that the majority of these rocks contained traces of modern biological C, because the soils and weathered specimens had a low C content (just above 0.2 wt %) compared with the high C content of plants (32%).

Inorganic carbonate, mostly calcium carbonate or dolomite, has $\delta^{13}C$ of +0.7‰ and is associated with thermal spring carbonate precipitation.

$\delta^{13}C$ analyses were also carried out on silicate minerals from spinel lherzolite xenoliths and carbonate globules occurring as inclusions in and on grain boundaries of xenolith minerals. Powdered xenoliths contained both inorganic carbonates ($\delta^{13}C$ = –5‰) and organic matter ($\delta^{13}C$ = –29.4‰) in the proportion of 4:1. Individual large-scale olivine crystals had less inorganic carbon ($\delta^{13}C$ = –20‰) than the xenoliths as a whole and organic carbon with $\delta^{13}C$ of –26‰ in the proportion of 2:1. Molecular biological evidence shows that the bioload in these rocks is at the limit of detection, thereby confirming an abiogenic source for this xenolith C. A third pool of C that we discovered was located in interior regions of volcanic breccia at Sverrefjell volcano. The inorganic carbon $\delta^{13}C$ = –1.1‰, whereas the organic carbon (0.2% of the total rock) inside of the breccia itself had a $\delta^{13}C$ = –12.1‰.

Fogel initiated study of interactions between the biological N cycle in plants, microbes, endolithic communities, and animals, and the geochemical N cycle in igneous and sedimentary rocks. The $\delta^{15}N$ of the plants, lichens, and microbes on Svalbard were of course the result of biological processes. Plants that were directly fertilized by animal wastes had $\delta^{15}N$ up to +14 ‰, whereas as those that obtained their N via atmospheric NH_4^+ transported 5 km downwind from massive seabird colonies had $\delta^{15}N$ as low as –14 ‰. Such extremes in isotopic composition, for the same species and types of plants, can be related directly to biological N cycling.

Ubiquitous Mg-carbonate deposits and dolomite-magnesite globules associated with the volcanic eruptive centers all show unusual ^{18}O-depletion with $\delta^{18}O$ values between –27 and –34‰ indicating precipitation from solutions of glacial origin. Combined C and O isotope signatures are matched only by reported values for cryogenic carbonates formed during slow freezing of glacial melt water. The abundant carbonates in Svalbard carbonate rocks evidently originated by cryogenic precipitation from meteoric to mantle-derived fluids following volcanic eruptions under extremely cold ambient conditions. The unusual dolomite-magnesite globules occurring in Svalbard rocks and on Mars may be typical end products of cryogenic carbonate precipitation from hydrous fluids.

Fogel, Steele, Doctoral Student Maia Schweizer, and Collaborator Jan Toporski studied the carbon and nitrogen isotopic compositions of autolithified soft tissues from 49-Ma vertebrate fossils from the Messel Formation in Germany. Messel's fossil flora and fauna are diverse and exquisitely preserved. Insects and plants are preserved with original material intact. Stable isotope results have been compared with previous trophic reconstructions based on gut contents and coprolites and also with related modern organisms. Different tissues within fish specimens are isotopically distinct, with intraorganism fractionations similar to those observed in modern organisms. Stable isotope signatures also clearly reflect the feeding patterns of fossil organisms. Primary producers are associated with low $\delta^{15}N$ values, and consumers are enriched by +2‰ or more in $\delta^{15}N$ relative to these values depending on their diets. Messel fossil organisms represent several trophic levels in each of two trophic webs, one aquatic and one terrestrial. Both trophic systems include primary producers (terrigenous and aquatic plants), primary consumers (insects), and higher consumers (carnivores such as fish, crocodiles, and frogs). $\delta^{13}C$ values for these organisms trace carbon sources and indicate widespread omnivory in both low- and high-trophic-level consumers.

Postdoctoral Fellow Jennifer Eigenbrode worked on several tasks aimed at distinguishing sources of organic molecules (i.e., geochemical vs. biological, modern vs. ancient), particularly when present at trace levels. Ultimately, her studies should provide insight into the evolution of carbon cycling on Earth and offer analytical and interpretive strategies for similar studies on other planets. In collaboration with Roger Summons (MIT), she completed new organic geochemical analyses of extracts from late Archean (2.7-2.6 Ga) shale and carbonate rocks from Western Australia. Those analyses revealed relationships among lipid biomarkers, carbon isotopes, and rock types similar to those documented earlier. The expanding isotopic and molecular dataset from these units support syngenicity between fossil lipids and their host rocks and indicates biological cycling of oxygen approximately 400 My before the steep rise of atmospheric oxygen. Because fossil designation for some of the alkane biomarkers identified in these Precambrian rocks is uncertain, samples were prepared for additional analysis (to be carried out collaboratively with Fogel) that

will target more recent biological signatures and compound-specific isotopic compositions. Isolation of DNA from these rock samples (by Eigenbrode and Steele) produced negative results. Eigenbrode also carried out organic geochemical analysis of hydrothermally altered mantle peridotite rocks, associated carbonate, and biota from Svalbard and Cedar Springs, California. In these systems, organic molecules thought to have been produced by geochemical processes provide a unique environment for geo-biological interaction. Collaborators on this last project, in addition to Fogel and Steele, include Hans Amundsen (University of Oslo) and Ken Nealson (USC).

As an early step in her analysis of biogenic and abiogenic hydrocarbon gases, Postdoctoral Fellow Penny Morrill initiated a calibration for stable carbon isotope measurements of hydrocarbon gases. Gas samples were obtained from Jug Bay, a fresh-water marsh where gas bubbles are frequently observed. The samples were analyzed for their gas compositions and carbon isotope ratios. As anticipated, the isotope signatures were typical of biological hydrocarbons. Experiments have been initiated to determine the carbon isotope fractionation between silicate minerals and a C-O-H gas phase at ranges of temperature and pressure appropriate to the mantle and crust. A preliminary experiment using silver oxalate (a source of carbon dioxide) and water heated to 1600°C and 1.5 GPa yielded a small amount of CO_2 gas, with a $\delta^{13}C$ value of −3.1 ‰. The initial $\delta^{13}C$ of the silver oxalate was approximately −2 ‰, which suggests that there was little to no isotopic fractionation between the initial substrate and CO_2. A subsequent experiment using the same starting materials heated to 1150°C suggested a large carbon isotopic fractionation. Isotopic equilibrium will be tested by conducting time studies with experiments at a given temperature, pressure, and hydrogen fugacity, over pressures between 0.5 and 2 GPa and temperatures between 1000°C and >1500°C and over durations varying between minutes and several days using starting materials having a grain size on the order of 1 mm. Experiments have been initiated to create abiogenic hydrocarbons under temperatures and pressures experienced at deep-sea hydrothermal vents. Formic acid is used as the source of dissolved CO_2, water is used as a source of hydrogen, and a variety of metals are being used as catalysts. A preliminary experiment using nickel as the catalyst yielded gaseous CO, CO_2, and CH_4. The methane had a $\delta^{13}C$ value of −39.6 ‰.

3. Scanning Transmission X-ray Microscopy and In Situ Chemical Analysis of Organic Fossils

Cody and colleagues have applied molecular spectroscopy and spectrometry to the analysis of ancient organic fossils as part of three specific tasks. First, together with Andy Czaja (UCLA), Cody utilized ^{13}C solid-state nuclear magnetic resonance (NMR) spectroscopy and pyrolysis gas chromotagraphy mass spectrometry (GC-MS) to explore the chemical transformations that accompany the conversion of modern organic matter contained within ferns into the complex organic matter detected in 50-Ma fossil ferns of identical type. Second, in collaboration with C. Kevin Boyce, a former NAI-NRC Postdoctoral Associate now at the University of Chicago, Cody applied pyrolysis GC-MS to characterize the preserved biomass of Devonian (~ 400-Ma) organisms. A comparison of pyrolysis GC-MS data (Figure 5) from a well-characterized albeit enigmatic fossil of *Prototaxites* with similarly ancient organic matter from an organic-rich sediment (Devonian coal) indicates that the distribution of molecular constituents from the fossil and the coal are quite different even as the specific types of molecular compounds detected reveal that both the *Prototaxites* and coal samples have undergone significant thermochemical evolution. The third task utilizes scanning transmission X-ray microscopy (STXM) to study ancient kerogens from the Hammersley Basin, Western Australia. Together with Postdoctoral Fellow Jennifer Eigenbrode, Cody began the process of preparing ultra-thin sections of proterozoic kerogens for in situ STXM analysis this fall.

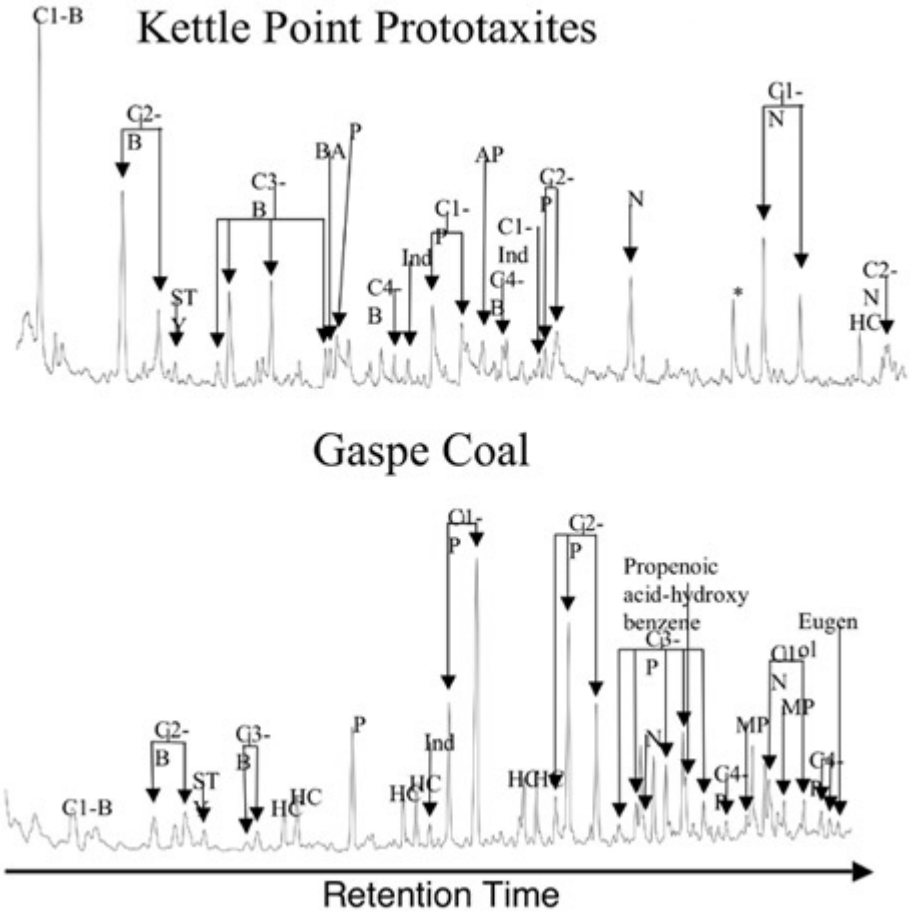


Figure 5. Chromatograms of products from pyrolysis of a Devonian Prototaxites fossil and a Devonian coal. Each peak corresponds to a specific molecular constituent, e.g., C1-B is toluene, C1-P's are methyl phenols. Although these two geochemically altered organic materials have similar molecular compounds in their pyrolysate, the relative distribution of these compounds vary substantially. This difference reflects fundamental differences in the initial biomolecular compound distributions within the organisms; that these differences are maintained even after significant diagenetic alteration demonstrates the power of pyrolysis gas chromatography/mass spectrometry.

4. Studies of Organic Compounds at the Kamchatka Hydrothermal Region

Organic species on the prebiotic Earth would serve as monomers for the synthesis of more complex molecules, such as peptides and oligonucleotides, and to form membranous boundary structures. However, for such species to accumulate in concentrations sufficient to support synthetic reactions, there must have been a source providing the material at a rate equal to or greater than they were removed by degradation, adsorption, or burial. Deamer last year initiated an experiment in the Kamchatka geothermal region with the aim of determining how a set of pertinent organic compounds behave in such a setting. Situated in the far northeastern portion of Russia, the Kamchatka Peninsula spans a region approximately 400 by 1200 kilometers. Like Yellowstone National Park in Wyoming, Kamchatka represents a modern analog for hydrothermal ecosystems that have been active throughout most of Earth's history. One such site in the region was chosen as a model system to investigate both degradative reactions and possible synthetic reactions driven by condensation. To a small (ten-liter) boiling pond Deamer's group added four amino acids and four nucleobases, and they included phosphorus as phosphate, a fatty acid as a model amphiphile, and glycerol. Specific goals included learning the fate of a mixture of organic compounds in a natural setting (i.e., assuming that there was a source of organic compounds on the prebiotic Earth, at what rate would such compounds undergo degradation and thereby be lost as potential reactants for synthetic processes?) and assessing the synthetic reactions that are possible under such conditions.

The basic observation of the experiment was that amino acids, nucleobases, and phosphate are removed as solutes with half-times measured on time scales from minutes to a few hours. Only cytosine and myristic acid could still be detected after nine days. The loss was not due simply to flow through the pond, because one of the amino acids - glycine - and one of the nucleobases - cytosine - had half times much longer than the other solutes. Nor was the loss due to simple acid-catalyzed degradation reactions, because a laboratory simulation showed that the solutes were all stable for at least two hours. The disappearance of phosphate on the same time scale offers one possible clue. Phosphate is very stable and could not undergo degradative reactions in the same way that organic compounds might. Nor could it precipitate as calcium phosphate (apatite) because there was little calcium ion in the water and the low pH of 3.1 allows calcium phosphate

to remain in solution. This inference suggests that the phosphate and organic solutes were lost from solution by adsorption to mineral surfaces of clays and then transported and deposited in the layers of clay at the borders of the puddle. When clay samples were analyzed, virtually all of the added components could be released from the clay by treatment with a dilute sodium hydroxide solution.

The conclusion of the first season of work was that the organic compounds required for the origin of life in a natural setting would have had a variety of possible fates other than those possible in a laboratory setting, in which pure compounds react in glass containers. To understand these processes, it will be necessary to repeat these experiments in a variety of natural environments that are potential models for sites associated with the origin of life. One such repetition has just been completed in a geothermal area of Iceland, and the samples are being analyzed.

Roadmap Objectives

- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.2:** Foundations of complex life
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Field Expeditions

Field Trip Name: Arctic Mars Analog Svalbard Expedition (AMASE)	
Start Date: 10 August 2004	**End Date:** 26 August 2004
Continent: Europe	**Country:** Norway/Russian protectorage
State/Province: Svalbard	**Nearest City/Town:** Longyearbyen
Latitude: 78-80° N	**Longitude:** 15° E
Name of site(cave, mine, e.g.): Bockfjorden Volcanic Complex	**Keywords:** abiogenic carbon, carbonate globules, thermal springs
Description of Work: Detailed field work to collect samples for molecular and isotopic analysis	
Members Involved:	

Field Trip Name: Belize Tangled Roots	
Start Date: 26 February 2005	**End Date:** 8 March 2005
Continent: Central America	**Country:** Belize
State/Province: Stan Creek	**Nearest City/Town:** South Water Caye
Latitude: 16° N	**Longitude:** 88° E
Name of site(cave, mine, e.g.): Twin Cayes	**Keywords:** microbial mats, extreme environments
Description of Work: Collected microbial mat material for biomarker work	
Members Involved:	

Cross Team Collaborations

Co-I Cody worked with Andrew Czaja, a Doctoral Student on the UCLA NAI team.

Co-I Fogel collaborates with Dominic Papineau and Stephen Mojzsis of the University of Colorado NAI team. Fogel serves on Papineau's Ph.D. thesis committee.

Postdoctoral Fellow Jennifer Eigenbrode collaborates with colleagues on the NAI team at Pennsylvania State University, where she was a student, as well as with Roger Summons (MIT), a member of the University of Washington NAI team.

Postdoctoral Fellow Penny Morrill collaborates with Barbara Sherwood Lollar (University of Toronto), a member of the Indiana University NAI team.

7. Astrobiotechnology

Project Investigators: Wesley Huntress, James Scott, Andrew Steele, Ed Vicenzi

Project Progress

7. Astrobiotechnology

With continued support from NASA astrobiology instrument development funding (through the Astrobiology Science and Technology Instrument Development, or ASTID, Program), as well as NAI funding, Steele and colleagues continued to develop biotechnology instrumentation for solar system exploration. This effort, Modular Assays for Solar System Exploration (MASSE), has concentrated on using microfluidics to prepare a sample for inoculation onto a microarray that contains either DNA or antibody markers for specific targets. The list of targets currently under investigation has been significantly expanded this year to include antibodies to a range of extremophile and human disease proteins. Furthermore, a significant collaboration with Affymetrix on DNA probe development for astrobiology-relevant environments has begun. This technology will allow for the simultaneous screening of hundreds of separate organisms or functional genes in a convenient platform for field science.

Field and radiation-exposure testing has been underway on protein microarrays in collaboration with Mark Sims and David Cullen (Astrobiology Society of Britain). Fieldwork has concentrated on testing protein microarrays in both Kamchatka and Svalbard. Samples analyzed during the Arctic Mars Analog Svalbard Expedition (AMASE) 2004 field season by protein microarrays were confirmed with other biotechnology tests including adenosine triphosphate measurements, DNA amplification using degenerate species and gene-specific primers, and an enzyme-based test for cell wall components (see below). A modified protocol for inoculation and reading of the protein arrays was undertaken after considerable laboratory testing. Instrumentation was transferred straight from Svalbard to Kamchatka where it was deployed to measure cell concentration in hot springs. The data obtained from these experiments remained consistent and illustrate the robust nature of protein arrays to be used in astrobiologically relevant environments

Figure 1. Andrew Steele and Maia Schweizer performing functional gene analysis in sterile conditions at Jotun Springs, Svalbard. In the background, Marilyn Fogel (in blue) performs spectrophotometric analysis of endolithic communities while Jake Maule (in black) is performing protein array analysis of microbial mats, the first time such analysis was conducted in the field.

A successful proposal to the European Space Agency (Jan Toporski, University of Kiel, Principal Investigator) to test microarrays on board the European Biopan series of low Earth orbit (LEO) missions means that testing on radiation exposure in space environments will begin. The next flight opportunity is scheduled for

2006 and will carry both protein and DNA microarrays and will mark the first time that microarrays will fly in space. Shielding will be included on some arrays to quantify the effects of launch and exposure to LEO space-radiation conditions.

Carnegie Institution of Washington, Charles River Laboratories, the Marine Biological Laboratory (MBL), and the NASA Marshall Space Flight Center (MSFC), have teamed to perform environmental microbiology on the International Space Station (ISS). A new handheld device manufactured by Charles River, known as the Lab-On-a-Chip Applications and Development Portable Test System (LOCAD PTS), will be used by the crew to detect and monitor potentially harmful bacteria and fungi in the cabin environment. The device will be launched to the ISS on Space Shuttle mission STS-116 in the spring of 2006. This will be the first biotechnology device to fly in space specifically for the sensitive detection of microorganisms.

Collaborator Jake Maule has been chosen by NASA to serve as Project Scientist for the LOCAD PTS. He will be responsible for coordination of science operations (pre-flight and on-orbit) and will be a liaison between the project's partner institutions and the NASA Johnson Space Center. Since 2002, Maule has worked with the MASSE team and Norman Wainwright of MBL to prepare the LOCAD PTS for space flight, involving tests performed in parabolic flight (see Figure 2), isolated underwater human habitats, and astrobiologically relevant Mars analogue field sites such as Svalbard and Kamchatka.

Figure 2. Collaborator Jake Maule, in zero gravity aboard NASA's KC135 aircraft testing the first biotechnology device for microbial detection to fly in space. This device is being jointly developed by MBL, Charles River Laboratories, the MSFC Center Lab-on-a-Chip Application Development group, and Carnegie Institution of Washington.

Microfluidic development for microarray handling has continued, and experiments on sample concentration are currently underway using an automated sample handling system built under ASTID funding.

The ability to monitor the expression levels of thousands of genes simultaneously offers the potential to expand the analysis of a single stress response toward a genetic network of different stress responses to each other. A study currently underway is comparing the response to “normal" stress, such as heat shock, with that to ultra-high-pressure stress in *Escherichia coli* as well as the response to the wild type response. Gene expression profiling is conducted by using the GeneChip® *E. coli* Genome 2.0 Array at the facilities of Affymetrix, in Santa Clara, California. This technique will elucidate the reaction and viability of cells under high pressures.

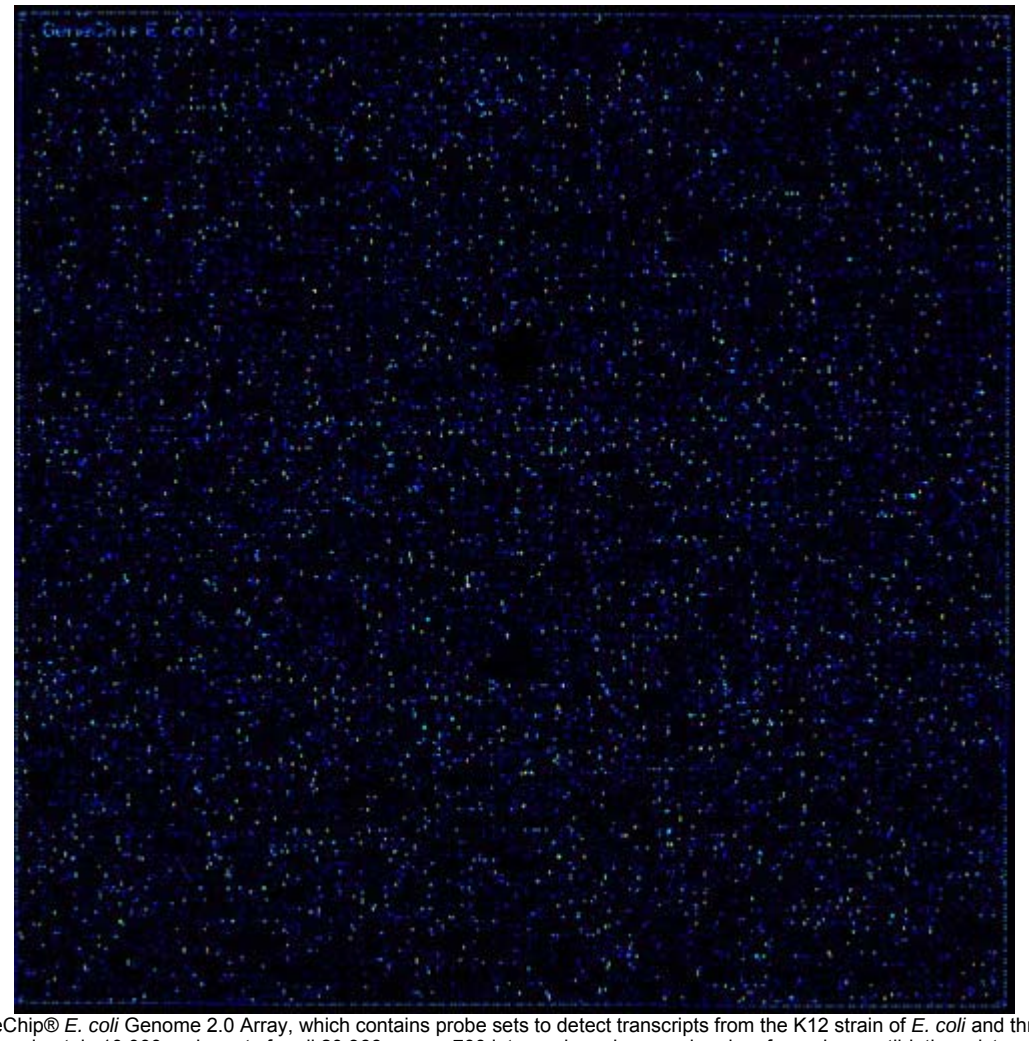


Figure 3. Image of the GeneChip® *E. coli* Genome 2.0 Array, which contains probe sets to detect transcripts from the K12 strain of *E. coli* and three pathogenic strains of *E. coli*. The array includes approximately 10,000 probe sets for all 20,366 genes, 700 intergenic regions, and probes for various antibiotic resistance markers. The size for the features on the array is 11 µm. Colored features in the picture represent bonded transcripts to the array.

Roadmap Objectives

- **Objective No. 2.1:** Mars exploration
- **Objective No. 2.2:** Outer Solar System exploration
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 3.2:** Origins and evolution of functional biomolecules
- **Objective No. 4.2:** Foundations of complex life
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
1	International Space Station Flight 12A.1 (Space Shuttle mission STS-116)	Project Scientist
1	Mars Science Laboratory	Science Team Member
1	European Space Agency (ESA) Biopan	Co-Investigator
2	ExoMars	Planning Support

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Collaborator Maule is Project Scientist. The PTS payload is a step toward safeguarding health and alerting crewmembers to potential microbial hazards on board ISS. PTS was also deployed for astrobiology field trips in Svalbard and Kamchatka by Maule, Steele, and Toporski in 2004.

Co-Is Scott, Steele, and Huntress are members of the Science Team of the Sample Analysis of Mars (SAM) instrument chosen to fly on the mission. This instrument will assess the concentration of organic molecules present in regolith and rock samples.

Co-I Steele and Collaborator Toporski are Co-I and PI, respectively, in the successful proposal to test DNA and protein microarrays in low Earth orbit to study the effects of launch vibration and radiation on the efficacy of microarrays.

Co-I Steele and Collaborators Toporski and Maule are involved in the planning and production of an instrument to assess the issue of life on Mars aboard the 2013 ESA ExoMars mission. This technology is based on the use of protein microarrays to detect hundreds of target organic molecules simultaneously.

Field Expeditions

Field Trip Name: Arctic Mars Analog Svalbard Expedition (AMASE)
Start Date: 10 August 2004 | **End Date:** 26 August 2004
Continent: Europe | **Country:** Norway/Russian protectorate
State/Province: Svalbard | **Nearest City/Town:** Longyearbyen
Latitude: 78-80° N | **Longitude:** 15° E
Name of site(cave, mine, e.g.): Bockfjorden | **Keywords:** Life detection, Mars analog, in situ testing
Description of Work: Field work encompassed detection of DNA with polymerase chain reaction (PCR), all macromolecules with an antibody microarray, adenosine triphosphate (ATP) with fluorescent luminometry, and lipopolysaccharide (LPS) with the Portable Test System (PTS).
Members Involved:
Andrew Steele
Marilyn Fogel
Jake Maule
Jan Toporski
Maia Schweizer

Field Trip Name: Kamchatka
Start Date: 4 September 2004 | **End Date:** 17 September 2004
Continent: Eurasia | **Country:** Russia
State/Province: Kamchatka | **Nearest City/Town:** Petropavlovsk
Latitude: 54° N | **Longitude:** 160° E
Name of site(cave, mine, e.g.): Volcano Mutnovsky, Uzon caldera | **Keywords:** Hydrothermal, hot springs, volcanos
Description of Work: Macromolecules were detected in the field with an antibody microarray, adenosine triphosphate (ATP) with fluorescent luminometry, and lipopolysaccharide (LPS) with the Portable Test System (PTS). Old and new hydrothermal deposits were compared.
Members Involved:
David Deamer

Cross Team Collaborations

Steele and colleagues are collaborating with Norman Wainwright of the MBL NAI team to perform

environmental microbiology on the International Space Station using a new handheld device known as the Lab-on-a-Chip Applications and Development Portable Test System (LOCAD PTS).

Steele and his team are also collaborating with Mark Sims and Dave Cullen of the Astrobiology Society of Britain on field and radiation-exposure testing of protein microarrays.

Huntress, Scott, Steele, and Vicenzi are members of the Science Team of the Sample Analysis of Mars (SAM) instrument for the Mars Science Laboratory (MSL) mission. SAM will assess the concentration of organic molecules present in regolith and rock samples. The SAM team is led by Paul Mahaffy of the NASA Goddard NAI team and includes members of NAI teams at the NASA Ames Research Center, University of Colorado, and University of Hawaii.

2. Extraterrestrial Materials: Origin and Evolution of Organic Matter and Water in the Solar System

Project Investigators: Conel Alexander, George Cody, Marilyn Fogel, Timothy McCoy, Larry Nittler, Andrew Steele, Rhonda Stroud, Ed Vicenzi

Project Progress

2. **Extra-Terrestrial Materials: Origin and Evolution of Organic Matter and Water in the Solar System**

1. Organic Matter in Extraterrestrial Samples

The abundant organic compounds in primitive meteorites and interplanetary dust particles (IDPs) are thought to originate largely in the interstellar medium. However, this material may have been modified in the protoplanetary disk and has been modified to varying extents in the asteroidal parent bodies. Thus the organic matter is a record of processes that span the prehistory and early history of the Solar System. Also, it has been suggested that meteorites and IDPs would have been a significant sources of complex organic matter on the early Earth. What compounds would have been either directly delivered to Earth or produced by weathering of extraterrestrial material is of direct relevance to astrobiology. Finally, the organic matter in meteorites is likely to be the best analogue of the refractory organics in cometary dust to be returned in January 2006 by the Stardust mission. The small size of the Stardust dust particles makes analysis of the samples very challenging. We are using the organics to calibrate microanalytical techniques for analysis of the Stardust samples.

1.1 Bulk Elemental and Isotopic Analysis

Alexander and his collaborators completed the preparation of high-purity samples of insoluble organic matter (IOM) from roughly 40 of the most primitive chondritic meteorites as well as the measurement of the bulk elemental and isotopic compositions of the IOM samples. The results have been used to select samples for more detailed studies by nuclear magnetic resonance (NMR) spectroscopy, gas chromatography/mass spectrometry (GCMS), X-ray absorption near edge spectroscopy (XANES), X-ray photoelectron spectroscopy (XPS), Raman and infrared (IR) spectroscopy, and transmission electron microscopy (TEM) and ion microscopy.

The matrix-normalized abundances of IOM in the most primitive members of the chondrite groups are all roughly CI-like, consistent with all chondrites having accreted a common IOM in their matrices. However, the IOM exhibits a complex response to asteroidal parent body processes that is also seen in detailed NMR studies of a more limited number of meteorite IOM samples. The general trend in elemental evolution of IOM during parent body processing is a large decrease in H/C (0.75 to 0.1) and more modest change in O/C (0.2 to 0.1). This is very different from terrestrial kerogen evolution in which initially O/C drops much more rapidly than H/C.

The most primitive IOM in this sequence seems to come from the CR chondrites. The IOM from EET92042 (CR2) has an elemental composition ($C_{100}H_{75}N_4O_{15}S_4$) that is very similar to the composition ($C_{100}H_{80}N_4O_{20}S_2$) of comet Halley CHON particles. It is also isotopically very anomalous (δD=3003‰, $\delta^{15}N$=184‰). These bulk compositions are also comparable to the estimated bulk compositions of IOM in interplanetary dust particles (IDPs). IDPs are often considered to be the most primitive extraterrestrial materials available to us at present.

Alteration in CI (H/C=0.66-0.57) and CM (H/C=0.64-0.57) chondrites has preferentially removed aliphatic material (lowered H/C) and was accompanied by a decrease in D (1000 to 500‰) and ^{15}N (30 to -10‰) enrichments. These characteristics suggest that the isotopically anomalous H and N are in the aliphatic component. However, the anomalous CM Bells has a H/C=0.57, but δD=2984‰ and $\delta^{15}N$=415‰. There are very modest differences between the least and most altered CMs, and the CIs, which experienced more extensive alteration at higher temperatures than the CMs, are more isotopically anomalous than all CMs

except Bells.

The CV, CO, and OC chondrites experienced varying degrees of both metamorphism and aqueous alteration. Low H/C ratios (0.19-0.16), among other evidence, indicate extensive modification of the IOM in all CVs studied. Oxidized CVs have significantly lower δD values (194-239‰) than reduced CVs 2(500-1360‰). The CO chondrites analyzed exhibit a wider range of H/C ratios than the CVs (0.39-0.09), but their total range in D enrichments is smaller (212-417‰). The OCs studied have a similar range in H/C ratios to the COs, but they show a remarkable inverse correlation between H/C and δD (0.17 to 0.5, and 5560‰ to 2321‰, respectively).

1.2 Raman Spectroscopy

Raman spectroscopy is a sensitive and relatively benign tool for analyzing the gross microstructure of carbonaceous material in meteorites, IDPs, and returned Stardust samples. Single-crystal graphite and disordered finite-sized microcrystallites exhibit the distinctive "G" and "D" Raman bands whose peak height ratio%2, relative positions, and half widths characterize the crystallinity of carbonaceous material.

Raman spectroscopic analyses have been completed on IOM extracted from >40 chondritic meteorites with a new scanning laser-induced confocal Raman microscope (WiTec α-SNOM). The large, systematic spectral differences observed can be attributed to the distinct histories experienced by the meteorites on their asteroidal parent bodies. Raman features of the IOM from the least thermally metamorphosed CI, CR, and CM chondrites are in general very similar. This finding supports the view that the chondrites all accreted similar IOM. Parent body metamorphism is reflected by strong correlations of D-band position and width or G-band width with metamorphic degree, as shown, for example, for CO3 chondrites. Moreover, the D-band position correlates perfectly with the atomic H/C ratios in the residues. H/C reflects the relative abundances of aromatic and aliphatic organic matter and largely depends on thermal alteration experienced on the parent bodies. The non-destructive Raman analysis allows one to check and identify misclassified meteorites. For instance, Allende is officially classified as CV3.2, but its IOM suggests that it is probably CV3.5/3.6 and, therefore, not as primitive as has been previously thought.

1.3 Ion Microprobe Micro-analysis

In addition to determining bulk properties of organics in primitive meteorites, Nittler, Postdoctoral Fellow Henner Busemann and others have continued microscale investigations of primitive organic matter in both meteorites and IDPs. Using the Carnegie ims-6f ion probe, ~1.5-μm resolution images have been obtained of D/H ratios in matrix fragments of the Tagish Lake (unique CC) and Al Rais (CR2) meteorites and in purified IOM from the EET92042 (CR2), Murchison (CM2), Krymka (LL3) and Allende (CV3) meteorites, and three fragments of cluster IDPs. D/H is highly variable on a 1-2 μm scale in most samples, with D/H ratios in some D-enriched "hotspots" higher than previously observed in meteorites and comparable to the highest ratios found in IDPs.

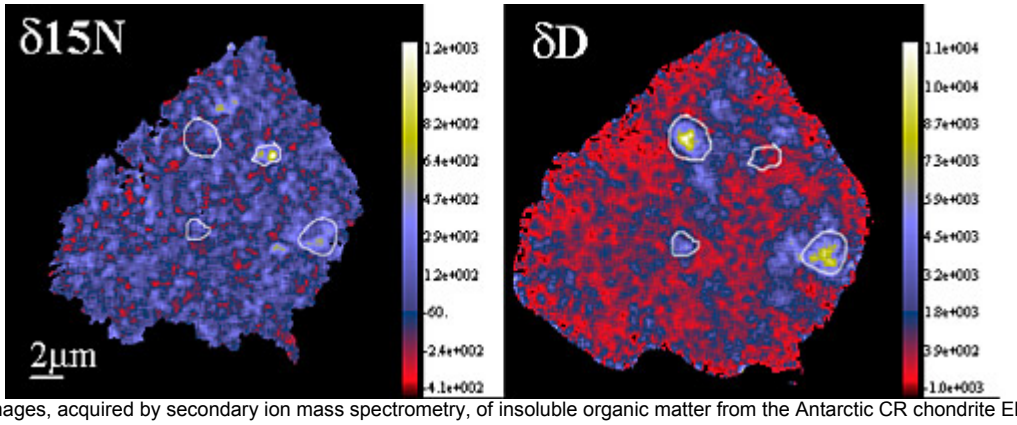


Figure 1. N and H isotopic images, acquired by secondary ion mass spectrometry, of insoluble organic matter from the Antarctic CR chondrite Elephant Moraine 92042. The material is highly isotopically heterogeneous on a micrometer scale, reflecting the variable presence of presolar molecular cloud material. The most D- and ^{15}N-rich areas (outlines) do not strongly correlate with each other, indicating that presolar D and ^{15}N anomalies are largely contained in distinct organic carriers.

Using the NanoSIMS ion probe at the Max Planck Institute for Chemistry in Mainz, the team obtained ~250-nm resolution ^{15}N/^{14}N images of many of the same samples, as well as of IOM from the unusual Bells (CM)

meteorite. These data also indicate a surprising level of isotopic heterogeneity on very small spatial scales. Although some D hotspots are clearly associated with enhanced ^{15}N, there is little spatial correlation between the measured H and N isotopic ratios. In fact, most of the highest D and ^{15}N hotspots are not associated with each other, indicating that, for the most part, presolar D and ^{15}N anomalies are contained in distinct organic carriers. The Bells data are particularly interesting as they reveal sub-micron hotspots with $^{15}N/^{14}N$ ratios higher than previously observed in most primitive organic matter, even that in IDPs. The highest ratios observed in the Bells organic matter are higher than can be explained by the low-temperature interstellar chemical processes usually invoked to explain ^{15}N enrichments in primitive organics, perhaps reflecting contributions from stellar nucleosynthesis or UV self-shielding.

A key result of the imaging studies is that even meteorites whose bulk organic matter has been significantly processed on their asteroidal parent bodies preserve on small scales some very primitive D- and ^{15}N-rich material. Identifying the nature of this material and whether it is associated with specific minerals in the host meteorites is key to understanding its origin and evolution through the solar nebula and on parent bodies. To this end, Stroud and colleagues are using focused ion beam techniques to extract ultra-thin slices of isotopically characterized samples for further characterization by TEM and synchrotron techniques. One section of a Tagish Lake sample traversing two D hotspots has been investigated by TEM so far. In this section, the D-rich material is clearly associated with carbonates; studies of additional fragments in the near future will determine whether this is common to all of the most D-rich material in this meteorite. Electron energy loss spectrometry will also be used to characterize microtomed samples of organic matter from several meteorites.

1.4 NMR and XANES Analysis

NMR analysis of pure meteorite IOM from four different groups, Orgueil (CI1), EET92042 (CR2), Murchison (CM2), and Tagish Lake (C2-ungrouped) reveal considerable variation in bulk organic composition across the different meteorite group's IOM. The fraction of aromatic carbon increases as CR2 < CI1 < CM2 < Tagish Lake. The increases in aromatic carbon are offset by reductions in aliphatic (sp^3) carbon moieties, e.g., "CH_x", and "CH_x(O,N)". Oxidized sp^2 bonded carbon, e.g., carboxyls and ketones grouped as "CO," are largely conservative across these meteorite groups. The variation in chemistry across these four meteorite groups is consistent with alteration by low-temperature chemical oxidation that occurred in the meteorite parent body. Cody, Alexander, and colleagues expanded these NMR studies to include a suite of IOM derived from CM chondrites that experienced variable degrees of aqueous alteration. Remarkably, only subtle differences in the organic structure of the IOM are found. It would appear that low-temperature aqueous alteration alone has minimal effect on the chemical structure of IOM.

The team also analyzed IOM isolated from thermally metamorphosed CV and CO chondrites by NMR and C-, N-, and O-XANES. The IOM H contents in CVs and COs are lower than the CRs, CIs, and CMs; this IOM contains significant O and N, and is, therefore, still organic. As expected, the chemical structure of IOM from both the CVs and COs differs enormously from that of the CRs, CIs, CMs, and Tagish Lake. The chemical structures of CV and CO IOM do reveal, however, spectroscopic signatures indicative of the extent of thermal metamorphism. These novel spectral features may allow the extent of thermal metamorphism to be independently ranked using IOM as recorder.

Finally, using bulk elemental compositions and NMR spectra, the group developed the first method for quantitatively determining elemental compositions from XANES spectra. Initial heating experiments also show promise for being able to use XANES spectra to determine peak temperatures and heating durations experienced by IOM. This work will have wide applications for meteorite, IDP, and Stardust research.

2. Confocal Raman Imaging Investigation of Inorganic Meteoritic Materials

Confocal Raman imaging is a relatively new technique that has only recently been applied to the study of extraterrestrial materials. Raman imaging can determine chemical composition and structural morphology of silicates, sulfides, sulfates, carbonates, metal oxides, and generally any non-metallic or highly fluorescent material. It is also uniquely sensitive to the presence and structure of carbon compounds and the presence of water both in liquid form and within crystallographic lattices. These capabilities make the confocal Raman

technique a powerful new tool for petrographic studies of both terrestrial and extraterrestrial materials. Much work remains in the characterization of Raman spectra of entire families of minerals in terms of their spectral features versus chemical composition, crystallographic orientation, and morphology, but our present understanding is sufficient to provide new insights into the composition and makeup of both meteoritic and terrestrial rock samples.

A broad array of pure samples is currently under examination with the aim of building a spectral database for Raman imaging analysis of meteorites. Postdoctoral Fellow Marc Fries and colleagues have found that it is not sufficient simply to possess spot spectra of minerals as has been done in the past. Raman spectral images of minerals are influenced by minor chemical variations, strain fields, and crystallographic orientation. In order to interpret these data, the team is continuing to analyze laboratory-prepared silicates, oxides, sulfides, and carbon as well as meteorites. Their studies of prepared, thermally annealed carbon samples in particular will allow interpretation of natural carbon in terms of its thermal history. Preparation and examination of additional silicate and sulfide standards is also planned. This new capability will be especially important in the field of meteorite and IDP research.

The aim of the meteorite studies has been to build a spectral database of minerals with different compositions and textures from typical meteorite types. The meteorite types examined thus far include ordinary chondrites (H,L,LL), carbonaceous chondrites (CH, CI, CM, CV, CK), achondrites (lodranite, aubrite, eucrite), rumurutiites, and Martian meteorites. Data collected from this suite of samples have been used to develop methods for analysis of silicates, sulfides, and carbon. However, this study has highlighted the need for carefully synthesized mineral standards of varying chemical composition if Raman imaging is to become truly quantitative. The production of these standards has become an important component of the team's development of Raman imaging techniques. Even without a complete set of standards, Fries and colleagues have been able to make a comprehensive set of measurements of inclusions within silicate grains in chondrules, which would not be possible with other types of instruments such as SEM or electron microprobe. These inclusions likely contain materials dating to chondrule formation or even earlier that have not been closely investigated. Systematic surveys of chondrule types, inclusions, and matrix materials are currently underway.

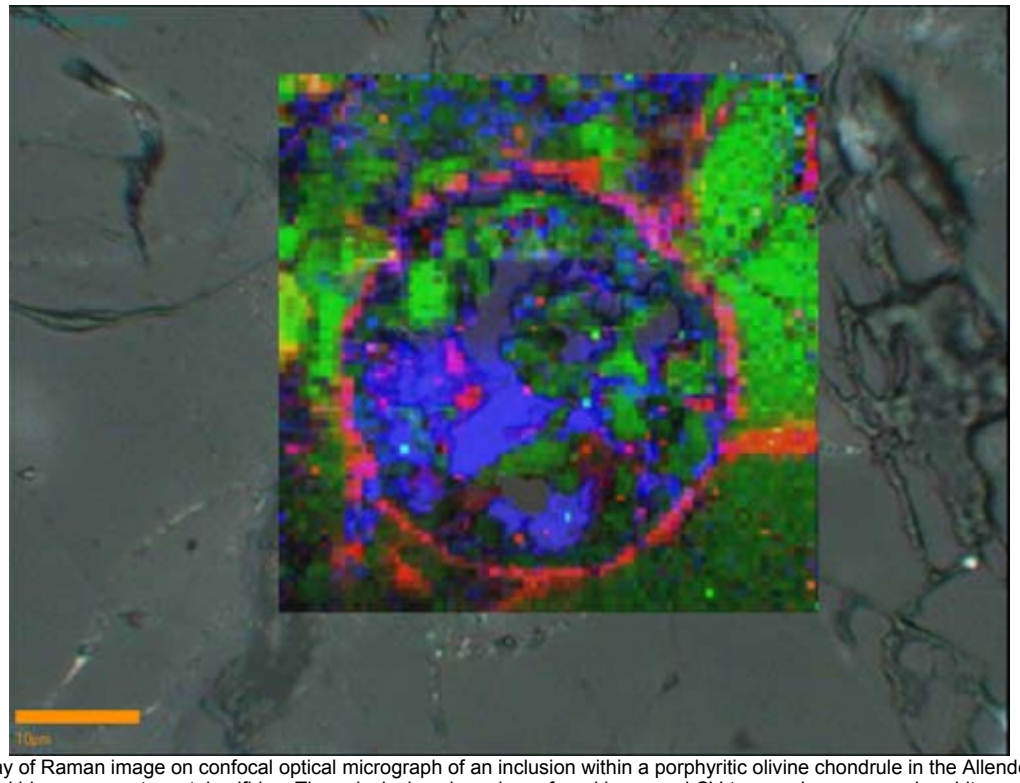


Figure 2. False-color overlay of Raman image on confocal optical micrograph of an inclusion within a porphyritic olivine chondrule in the Allende meteorite. Red is carbon, green is the olivine matrix, and blue represents metal sulfides. These inclusions have been found in several CV-type carbonaceous chondrites and represent material trapped during chondrule formation.

3. Mineralogy, Petrology, and Isotopic Compositions of Sulfides in Carbonaceous Chondrites

Sulfide minerals can reveal much about the conditions of alteration on meteorite parent bodies. They may

also act as catalysts for the formation of new organic material during alteration. Boctor and colleagues have studied the mineralogy and S isotopic compositions of sulfides from the Boriskino and Tagish Lake carbonaceous chondrites. Boriskino, a CM chondrite, contains two distinct sulfide mineral assemblages: a primary assemblage consisting of pyrrhotite, Ni-bearing monosulfide, pentlandite, and P-bearing Fe-Ni sulfide; and a secondary assemblage consisting of pyrrhotite veins, magnetite, and Fe-Ni metal with extremely variable Ni contents. The secondary assemblage is associated with aqueous alteration and carbonate precipitation. Pyrrhotite, the only sulfide in the sample investigated from Tagish Lake, occurs either as rims on magnetite framboids or as more disseminated grains.

Primary pyrrhotite in Boriskino is enriched in ^{34}S ($\delta^{34}S$ from +1.01 to +5.89 ‰). A single grain of pyrrhotite that exsolved pentlandite had a negative $\delta^{34}S$ (-1.28 ‰). Secondary pyrrhotite veins were mostly depleted in ^{34}S ($\delta^{34}S$ from –6.35 to +1.96 ‰). The $\delta^{34}S$ of pyrrhotite grains in Tagish Lake ranged between +0.99 and +1.97 ‰, whereas the pyrrhotite rims had low negative values ($\delta^{34}S$ from –1.31 to –0.05 ‰).

The S isotope data are consistent with a nebular origin for the primary sulfides. The low $\delta^{34\%}S$ of secondary pyrrhotites coexisting with magnetite may be attributed to their precipitation under more oxidizing conditions from aqueous fluids that partially dissolved some of the primary sulfides. Alternatively, it may be attributed to kinetic isotope effects due to lack of equilibration between the sulfur-bearing species in the fluid.

4. Fate of Carbon during Planetary Differentiation

During the past year, McCoy and collaborators have documented remarkable carbon isotopic heterogeneity ($\delta^{13}C$ = -55 to +75‰) in a partially differentiated meteorite, raising fundamental questions about the extent of planetary melting needed to achieve carbon isotopic homogeneity, the origin of carbon isotopic heterogeneity on Earth, and the ultimate fate of carbon incorporated into the Earth prior to differentiation and core formation.

McCoy and colleagues have begun experiments to melt samples of lodranite GRA95209 to investigate these questions, conducting sealed silica-tube experiments with Cr and V buffers to control oxygen fugacity and minimize volatilization. These experiments point to the dissolution of carbon in metal, consistent with the Fe-C phase diagram, which suggests that either austenite or cementite (Fe_3C) should co-exist with a liquid above 1140°C. This result may place upper limits on the temperature reached by GRA95209. Measurement of the carbon isotopic composition of this metal is the next step in our study. These measurements, which require technique development for the Carnegie ion probe, should occur in the next year.

5. The Martian Hydrosphere: Clues from Meteorites

Longstanding questions concerning the surface of Mars are "By what mechanism did globally distributed dust form?" and, importantly, "Was aqueous processing involved?" Vicenzi and collaborators have begun an effort to compare quantitatively the only materials of certain Martian aqueous heritage, preterrestrial secondary minerals in Martian meteorites, with soil from the Mars Exploration Rover (MER) Opportunity and Spirit landing sites. This chemical comparison permits an evaluation of whether the nearly ubiquitous dust covering Mars resulted from the interaction of an ancient ocean and igneous crustal rocks. Because the secondary phases found in veinlets within Martian meteorites are quite small (down to the sub-micrometer scale) and often intergrown, estimating the local bulk chemistry of the alteration assemblage requires a new data processing approach. A poor match between Mars soils and bulk meteorite alteration products for Si/Fe, K/Al, and other element ratios suggests that the dust did not form via low-temperature hydrous process.

Efforts have also been made to evaluate whether the complex phase assemblage often observed in preterrestrial Martian meteorite alteration formed in a single event or represents a more complex history of fluid flow. New trace-element data from clays and hydrous silicates found in contact with carbonates and halites in the Martian nakhlite meteorites indicate that at least two or more pulses of aqueous alteration are needed to explain the observations.

Distinctive bioweathering textures and microchemistry have been documented in terrestrial oceanic volcanic glass. A study aimed at evaluating the nature of olivine and pyroxene alteration from other terrestrial environments, e.g., mantle rocks, as well as Martian meteorites, suggests that similar microscale features can be found upon close examination. However intriguing, the full range of inorganic alteration mechanisms has not yet been explored. Consequently, a definitive connection to a biologically driven weathering mechanism cannot yet be made.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 2.1:** Mars exploration
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
1	Stardust	Data Analysis

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Conel Alexander, George Cody, Marc Fries, Larry Nittler, and Andrew Steele are members of the Preliminary Examination Team that will carry out the first analyses of Stardust samples.

The Habitability of the Nearest Stars to Complex Life

NAI-NRC Postdoctoral Fellow : Maggie Turnbull

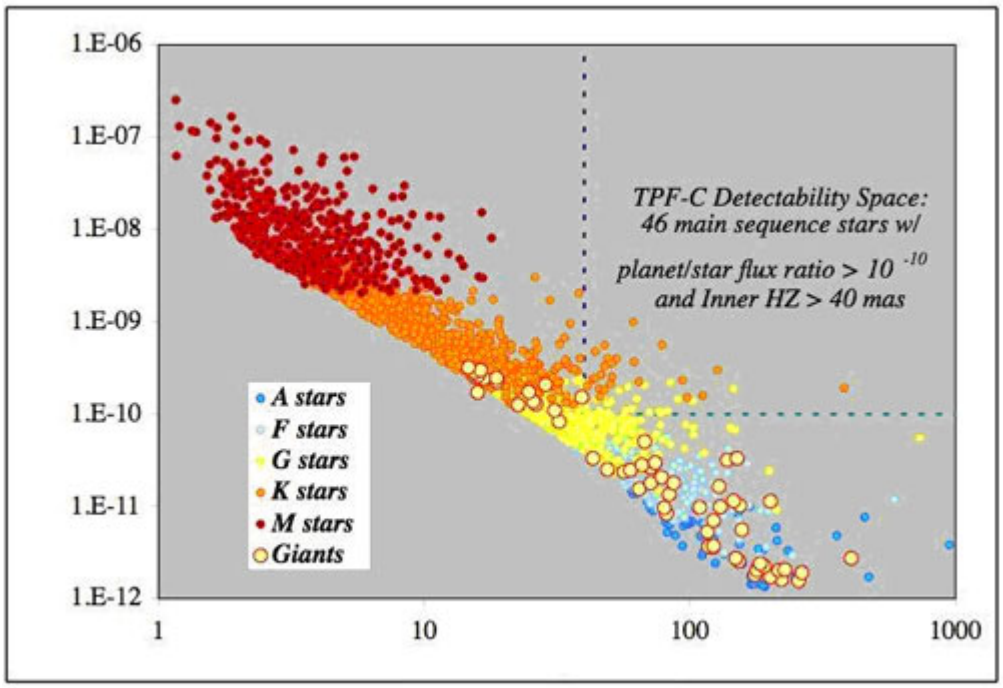
Project Progress

TPF and "Habitable" Stellar Systems.

The Terrestrial Planet Finder, a space telescope currently scheduled for launch in 2015, will be NASA's first mission to directly image habitable terrestrial planets orbiting Sun-like stars within 30 parsecs (~90 light years). The extreme technical difficulty and expense of this mission stem from the fact that terrestrial planets are a factor of 1 million (in the infrared) to 1 billion (in the optical) times fainter than the star they orbit, and yet, viewed from Earth, star and planet are separated by less than 1/3600 of a degree. Thus all of the proposed telescope architectures seek to either block out (via coronography) or cancel out (via interferometry) the light of the star while retaining all of the light from the star's "habitable zone," that location where the temperature of a terrestrial planet would be capable of supporting liquid water at its surface.

In support of this mission, I have created a "30 Parsec TPF Source List," from which to select TPF target stars. For TPF scientists, the stars of "greatest interest" are those stars which, according to all available data, will make good hosts to life as we know it on Earth. These "habstars" are the topic of my Astronomy dissertation, and I define them as stars which have (1) a habitable zone that is static and dynamically stable on a timescale comparable to the timescale of evolution of complex life, and (2) a metal content that is high enough to be consistent with the formation of terrestrial planets. Although we know nothing in advance about any terrestrial planets orbiting the nearby stars, from these two requirements we can identify *readily observable* properties of stars that indicate whether that star can provide for life on a suitable planet. Stellar age, variability, evolutionary state, metallicity, and the presence of companion stars or known giant planets are all factors that can select stars for habitability.

On the other hand, because the engineering constraints for an optical wavelength TPF-C mission very strictly limit the range of detectable planets to those which are at least ~57 milliarcseconds from their star and at least 10^{-10} times as bright as the star, choosing stars based on habitability concerns may be a luxury we literally cannot afford. One immediate consequence of these constraint is that *no star more distant than 30 parsecs is a viable target for this mission.* The following figure shows the detection space for TPF-C in terms of the brightness and angular separation of Earth-sized planets in the circumstellar habitable zone for stars within 30 parsecs:



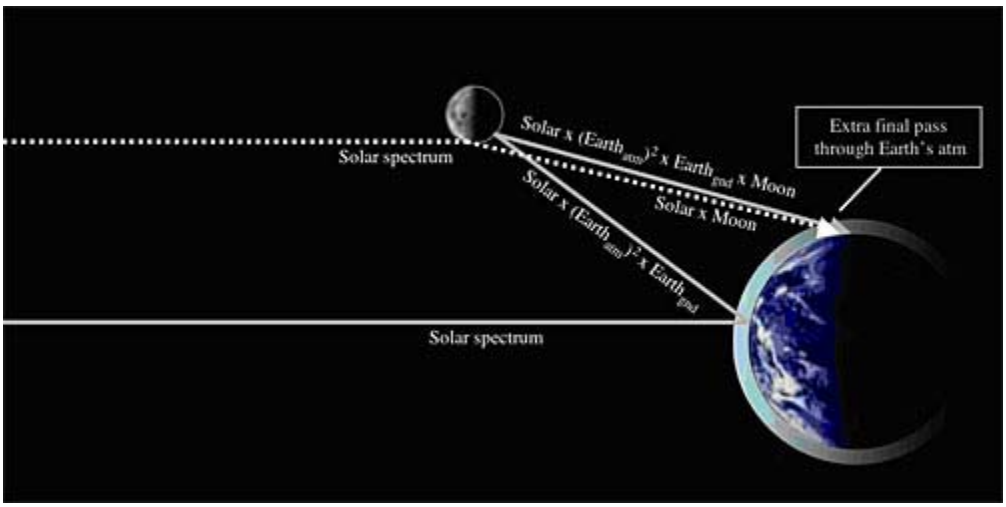
The impact of including stars that are further away than 30 parsecs is to fill in the lower left portion of the diagram, which is outside the TPF-C "habitable Earth" detection space. We can also see that a second consequence of the engineering constraints for TPF-C as currently specified is that *target stars are limited exclusively to G- and K-type main sequence stars, and giant stars are not viable targets for this mission.*

This work gives rise to questions about the purpose of the TPF mission. There are ~10 habstars falling within the habitable Earth detection space, which is perhaps not enough for a mission focused solely on the discovery of these planets. However, the TPF mission as currently envisioned could revolutionize the field of planetary science by imaging and spectrally characterizing essentially every giant planet in the Solar Neighborhood at separations beyond 1 AU. This understanding would shed substantial light on the habitability of nearby stellar systems as well as elucidating the composition, structure and dynamical evolution of extrasolar giant planets. While we should not shy away from pushing TPF technology toward the goal of imaging the first terrestrial planets, this does not have to be the mission's only (or primary) purpose in order to make a strong and lasting impact on exoplanetary exploration.

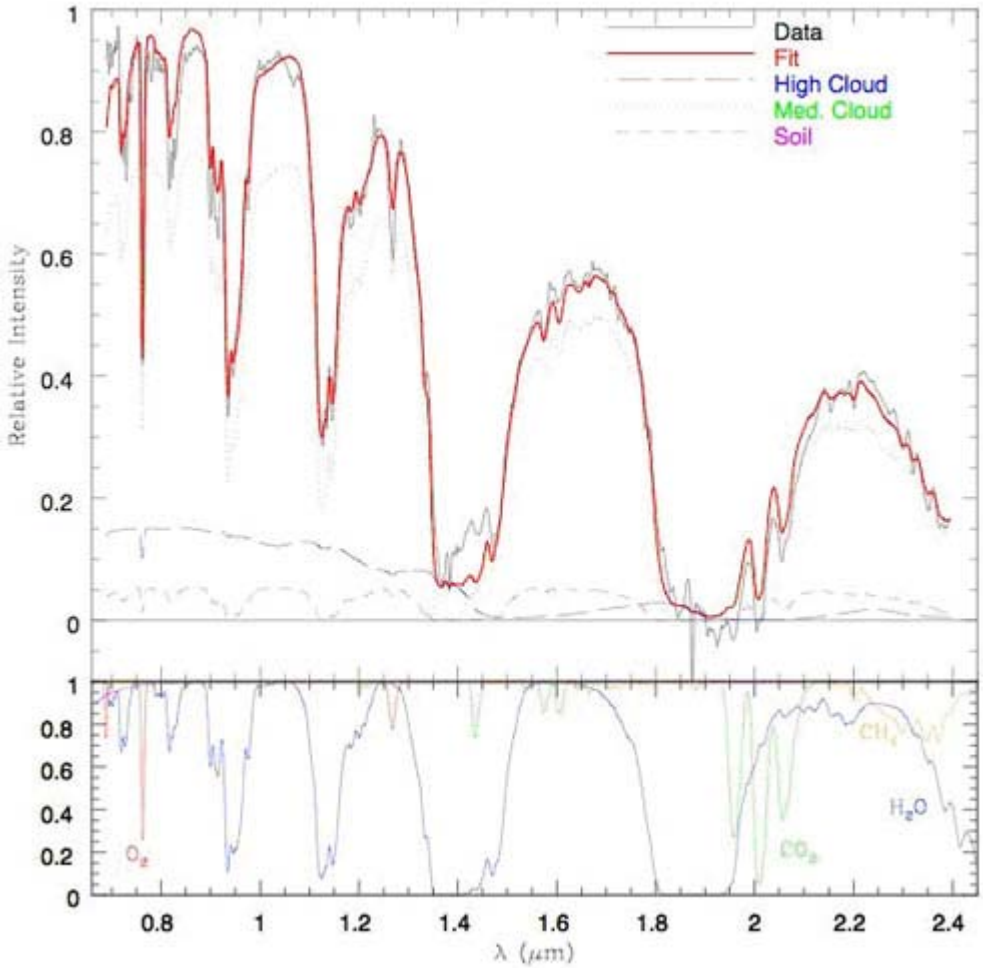
TPF and the Study of Earthshine.

At this time, no terrestrial extrasolar planet has been imaged or spectrally characterized. This is because our current technologies are not capable of extracting such a minute signal in such close proximity to a bright star. However, as we prepare to launch the Terrestrial Planet Finder in an attempt to both image and take spectra of extrasolar terrestrial planets, we do need to have *some* idea of what types of spectroscopic signals to expect. Our only means of observing the spatially unresolved spectrum of an inhabitable terrestrial planet (such as what TPF will be designed to detect) is through studying Earthshine.

Just as the light of the full Moon lights up our nights on Earth, the light of the "full" Earth brightly illuminates the nights of the Moon. This can sometimes be seen with the naked eye as we gaze at the thin crescent Moon; the "dark" side of the Moon's disk can be barely discerned, because Sunlight is reflecting off the Earth, shining on the Moon, and reflecting back to us on Earth. Observing the spectrum of this Earthshine, we see the signatures of a living planet. The light paths involved are shown in the following figure, where we can see that dividing the spectrum of the "dark" Moon by the spectrum of the bright crescent removes (1) the solar spectrum, (2) the lunar spectrum and (3) the extra pass through the Earth's atmosphere, leaving only the spatially integrated spectrum of the Earth as seen from space:



In collaboration with colleagues at the University of Arizona (Nick Woolf, Michael Meyer, Nadya Gorlova), I obtained near-infrared earthshine data to complement mid-IR data obtained from the Galileo mission and optical data previously obtained from Kitt Peak. The final data extraction and model produced with colleagues Wes Traub (JPL) and Ken Jucks (CfA) are presented in the following figure:



From these data we see that a strong indicator of planetary habitability, atmospheric water, is present and easily detectable at 1-2 microns. These absorption features are 80% to 100% signals and thus could be seen across interstellar distances even at very low spectral resolution. In comparison, the spectral signatures of water and oxygen at optical wavelengths are 5% or 10% features that may require much longer integration times with TPF-like instruments.

The next step in characterizing the spectrum of Earth as a living planet is to carry out a longer-term Earthshine monitoring campaign to quantify the level at which Earthshine (and the expected signal from extrasolar terrestrial planets) is *variable*. Daily changes in cloud cover, seasonal changes in snow and vegetation ground cover, and even different views of the planet's oceans and landmasses are bound to have very noticeable effects on the observed spectrum. However, no one has ever carried out a long term study of the Earthshine spectrum or attempted to directly compare spectra taken from different parts of the planet. Such a project is crucial for predicting which signatures TPF should be designed to pick up, how much those signatures will vary, and with how much confidence we can interpret the spectra TPF returns.

Roadmap Objectives

- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 2.1:** Mars exploration
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
0	TPF-C	

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

This project is relavant to TPF-C target selection and to the spectral characterization of planets discovered by TPF-C.

Field Expeditions

Field Trip Name: Atacama Yungay Region
Start Date: June 1, 2005 **End Date:** June 9, 2005
Continent: South America **Country:** Chile
State/Province: **Nearest City/Town:** Antofagasta
Latitude: 24° 30 S **Longitude:** 69° 15 W
Name of site(cave, mine, e.g.): Yungay **Keywords:** Atacama, Mars
Description of Work: As part of a team lead by Chris McKay at NASA-Ames, Turnbull sampled topsoils of the arid core of the Atacama desert for biological and mineralogical analysis using instruments at the Carnegie Institution of Washington. Turnbull also worked on spectral characterization of the region for remote sensing.
Members Involved:
Maggie Turnbull

Field Trip Name: Arctic Mars Analogue Svalbard Expedition
Start Date: August 12, 2005 **End Date:** August 22, 2005
Continent: Europe **Country:** Norway
State/Province: Svalbard **Nearest City/Town:** Longyearbyen
Latitude: 78° N **Longitude:** 15° E
Name of site(cave, mine, e.g.): Bockfjorden **Keywords:** Svalbard, Mars
Description of Work: As part of a team led by Hans Amundsen (PGP) and Andrew Steele (CIW), Turnbull participated in biological and mineralogical analysis of hot springs, glaciers and volcanoes in the Mars-analogue environments of Svalbard, Norway.
Members Involved:
Andrew Steele
Marilyn Fogel
Maggie Turnbull

Cross Team Collaborations

Earthshine data were modeled by Giovanna Tinetti and Vikki Meadows (VPL). M star habitability was assessed with Jill Tarter, Peter Backus, and Laurance Doyle (SETI).

EPO Reports: Carnegie Institution of Washington

Capital Science Evenings

To make science more accessible to the general public, the Carnegie Institution of Washington began the Capital Science Lectures in the fall of 1990. These free public talks are designed to help non-scientists understand scientific thinking and to appreciate the importance of basic research in our lives today. Over the past six years, many speakers have been chosen to focus on the institution's interest in astrobiology. The 2004/2005 series featured talks by such scientists as Maria Zuber of the Massachusetts Institute of Technology who presented a talk entitled 'Climate Change on Mars' and Margaret Geller of the Smithsonian Astrophysical Observatory with a talk entitled 'How to Make a Milky Way'. The series is also attended by students of local high schools. They meet with the presenter before the lecture to discuss the research and to have personal interaction with the scientist. Students from several area schools serving a high minority population have been attending since the inception of the lecture series.

Astrobiology Presentations for the General Public and Special Interest Groups

The Carnegie Institution of Washington NAI team offered many presentations for the general public and special interest groups.

Robert Hazen presented talks on the theme 'Rocks, minerals, and the geochemical origins of life' to Smithsonian Institution, Department of Paleobiology; Old Dominion University; Naval Research Laboratory; Geological Society of Washington; Philosophical Society of Washington; George Mason University, Department of Environmental Science and Policy.

John Baross and colleagues gave invited talks pertaining to the sub-seafloor biosphere to such groups as The Agouron Institute; AAAS annual meeting in Seattle; American Society for Microbiology; Goldschmidt Conference, Copenhagen, Denmark; Gordon Conference on Origin of Life, Ventura, CA; Geological Society of America, Calgary, Canada; International Extremophile Meeting, Tokyo, Japan.

George Cody's group presented talks on 'Prebiotic Chemical and Isotopic Evolution on Earth' to Gordon Research Conference; University of California Los Angeles, IGPP seminar series; Southampton Oceanography Center; Earth Science Processes II, Calgary, Canada; San Diego State University; McGill University, Canada; University of Aberdeen, Scotland; Cardiff University; Cambridge University; UCLA; GSA, Pardee Symposium; American Chemical Society; 14th Annual V. M. Goldschmidt Conference.

Sean Solomon's seminar audiences included the College of Oceanic and Atmospheric Sciences; Oregon State University; the National Radio Astromomy Observatory; the Lamont-Doherty Earth Observatory of Columbia University.

Alan Boss presented the Director's Symposium address at the Los Alamos National Laboratory in May 2005.

Astrobiology for Middle School Students

This year, the Carnegie Academy for Science Education (CASE) conducted a Saturday program for middle school students on the theme of astrobiology. Approximately 20 students from inner-city public or charter schools attended each week of the school year. Each session comprised a morning in the laboratory conducting investigations, followed by an experience in the field in the afternoon. Students excitedly examined the microscopic life-forms in water samples, made measurements of water quality, constructed Winogradsky columns from anerobic ooze to search for life, designed experiments to determine the effect of environment on growth and survival, constructed and programmed Lego robots for sampling, and so much more. Students visited the Museum of Natural History and the Air and Space Museum, the National Zoo, the National Botanic Gardens, wet-land refuges and aquatic gardens, the Baltimore Aquarium, Goddard Space Flight Center, and the laboratories of CIW astrobiologists. Field experiences were designed to build observational and analytical skills and on many occasions were for sample collection. CIW scientist James Scott was a frequent visitor, bringing students into his own lab as well as accompanying them on field trips.

Astrobiology Institute for Middle School Teachers

This year, Carnegie Academy for Science Education (CASE) developed a 2-week course in Astrobiology for Middle School teachers of Life and Earth sciences. The course is unified around the question 'What characteristics of Earth make/made it hospitable for life?' The first week of the course is centered in the laboratory with associated scientific and mathematical content. Topics include 'Water', 'Detecting Life', 'Habitable Environments', 'The Dynamic Earth', 'Remote Sensing', and 'Our Place in the Universe'. Considerable emphasis is placed on sharing the latest and most exciting astrobiology research findings. Teachers also design and conduct their own experiments. Trips to the field and visits by scientists are also an important component of the course. In the second week of the course, teachers design and present their own lesson on an astrobiology topic of their own choosing. The course admitted approximately 20 teachers in August 2005.

Interactive Astrobiology Kiosk

A portable, interactive version of the award-winning poster, Astrobiology: Discovering New Worlds of Life (published in 2002), was produced in 2003. The kiosk is available to all members of the NAI scientific and education and public outreach (E/PO) teams to be displayed at conferences, schools, universities, and public lectures, as well as museums, science centers, and libraries for public display on a rotational basis. Over the previous year, the kiosk was employed by the NAI team at the University of Hawaii as part of their multi-island E/PO project to reach underserved rural communities (January - March 2005) and has been on display at the Woods Hole Oceanographic Insitution's Exhibit Center during June-August 2005. Several hundred NAI EP/O products, including the CIW Deep Sea Vents poster have been distributed to kiosk visitors.

Carnegie Summer Intern Program

The Carnegie Summer Intern Program in Geoscience brings about 20 college students, competitively selected, to our campus every summer for an intensive 10-week experience in original scientific research. At a symposium held at the end of the program, students report on the results of their research. Several interns have been lead authors of related articles later published in scientific journals.

Summer Interns 2004

Hilary Christensen
Carleton College, Northfield, MN
Advisor: Marilyn Fogel
Project: Periodic Cicadas: Brood X and the 2004 Emergence

Rachel Dunham
Amherst College, Amherst, MA
Advisor: Robert Hazen
Project: Searching for a New Biomarker: Phenanthrene and Anthracene

Janae Eason
George Washington University, Washington, DC
Advisor: Robert Hazen
Project: Hydrothermal Stability of Amino Acids and Production of Ammonia

David Olesh
Harvard University, Cambridge, MA
Advisor: Robert Hazen

Project: Three-Dimensional Elemental Mapping of Neoproterozoic Embryos and Algae

Nivedita Thiagarajan
Rice University, Houston, TX
Advisor: James Scott
Project: Microbial Survivability in a Martian Simulation

Koyel Bhattacharrya
Montgomery Blair High School, Silver Spring, MD
Advisor: James Scott
Project: Eutectic Life: The Effect of Pressure on Baro-sensitive Bacteria

Kristin Showalter
Embry-Riddle Aeronautical University, Daytona Beach, FL
Advisor: Mark Fries
Project: Sample Preparation Systems Development for the Microarray Assay for Solar System Exploration (MASSE) Project

Sonali Shukla
New York University, New York, NY
Advisors: James Cho
Project: Atmospheric Motion under Stellar Irradiation on HD 209458b

Alicia Aarnio
Smith College, Northampton, MA
Advisor: Alycia Weinberger
Project: HD 141569: Part of a Larger Association?

Tim Means
University of North Carolina-Asheville, Asheville, NC
Advisor: Nader Haghighipour
Project: Global Dynamics of the 55 Cancri Planetary System

Abby Fraeman
Montgomery Blair High School, Silver Spring, MD
Advisor: Nader Haghighipour
Project: Modeling the Origin of Extrasolar Comets Around the Star IRC+ 10216

Summer Interns 2005

Rachel Erdil
Wellesley College, Wellesley, Massachusetts
Advisor: Marilyn Fogel
Project: Dissolved Organic Matter in Ultra-Basic Springs: A Study of the Cedars in Sonoma County, California

David Weinberger
Millersville University, Millersville, Pennsylvania
Advisor: George Cody
Project: Synthesis of Hydrocarbon Chains via Naturally-occurring Transition Metal Catalysts

Erica Staehling
Bucknell University, Lewisburg, Pennsylvania
Advisor: James Cho
Project: Magnetohydrodynamic (MHD) Shallow-water Turbulence on the Sphere

Jennifer Ortega

University of Missouri, Columbia, Missouri
Advisor: Sara Seager
Project: What Effects Could Obliquity Have on Exoplanetary Observations?

Gretchen Hartwig
University of Wisconsin, Madison, Wisconsin
Advisor: Andrew Steele
Project: Life on Mars? Sample Handling Extraction Apparatus for Life Analysis

Awards Received by Summer Interns 2004-2005

1999 intern Lan-Anh Nguyen (aka Ann N. Nguyen) will be returning to CIW as a Postdoctoral Fellow in February 2006.

2002 intern Maia Schweizer, currently a Ph.D. candidate at Oxford University, has continued as a member of the CIW NAI team since her internship. Schweizer received a 2004 Marshall Scholarship, which covers the cost of living and studying at a British university of the recipient's choice for two years.

Elena Chung, a 2003 summer intern in George Cody's laboratory, was named a semifinalist in the 63rd Annual Intel Science Talent Search competition (2003-2004). Her project was entitled: A Novel Prebiotic Route to Pyrimidine Synthesis: A Hydrothermal Threshold to the RNA World

Sonali Shukla, an intern in the summer of 2004 and now entering her senior year at New York University, received an Outstanding Student Paper Award for her presentation at the 2004 Fall Meeting of the American Geophysical Union. Shukla's presentation, given in the Planetary Sciences Section, highlighted her work with James Cho on the dynamics of large-scale atmospheric circulation driven by radiative equilibrium forcing on the extrasolar giant planet HD209458b.

2004 intern Abby Fraeman was a finalist in the 64th Intel Science Talent Search (2004-2005). The Washington Post Magazine (p. 8) featured Fraeman in its cover story, Aptitude Aplenty, by Kathy Lally, on 31 July 2005. The article focused on challenges to women who pursue scientific careers. See http://www.washingtonpost.com/wp-dyn/content/article/2005/07/26/AR2005072601834.html

Publications Resulting from Intern Program

Crossley, J. H. & Haghighipour, N. (2004). On the stability of a planetary system embedded in the Beta Pictoris debris disk. In: S. S. Holt & D. Deming (Eds.). The Search for Other Worlds: Fourteenth Astrophysics Conference, AIP (American Institute of Physics) Conference Proceedings, 713: 265-268.

Young, A. F., Nittler, L. R. & Alexander, C. M. O'D. (2004). Microscale distribution of hydrogen isotopes in two carbonaceous chondrites [Abstract]. Abstracts of Papers, 35th Lunar and Planetary Science Conference, Houston, TX. Abstract #2097.

Shukla, S. P., Cho, J. Y.-K. & Seager, S. (2004). Atmospheric circulation of the extrasolar giant planet HD209458b under diababtic heating [Abstract]. Eos Transactions of the American Geophysical Union, 85: F1274. Abstract #P51B-1423.

Carnegie Seminar Series

The Carnegie Institution holds two weekly scientific seminar series, one at the Department of Terrestrial Magnetism (DTM) and the other at the Geophysical Laboratory (GL). Speakers include visitors and members of the staff, with topics ranging from astrophysics and planetary sciences to geochemistry and seismology. The seminars are announced to the community with monthly schedules sent to 214 institutions and individuals in the Washington metropolitan area. The following seminars were given by scientists associated with the NASA Astrobiology Institute and by speakers on subjects related to astrobiology.

DTM Seminars

Sara Seager
DTM
Towards a Physical Characterization of Extrasolar Planets and the Search for Biomarkers

Subhanjoy Mohanty
Harvard-Smithsonain Center for Astrophysics
Catching Them Young: Formation, Accretion & Disks in the Brown Dwarf Domain

Jonathan Levine
University of California, Berkeley
Measuring the Meteoroid Bombardment History of the Moon, with Lunar Glass Spherules

Greg Laughlin
UC Santa Cruz
Core Issues Within the Nebular Hypothesis

Manuel de la Torre Juarez
MIT
Unveiling Planetary Atmospheric Circulations with Remote Sensing Data

John Debes
Penn State University
Digging for Planets in the Stellar Graveyard

Maria Zuber
MIT
Geophysical Measurements of Volatile Cycling on Mars

Kaspar Von Braun
DTM
Searching for Transits of Hot Jupiters in Galactic Open Clusters: EXPLORE/OC

Maud Boyet
DTM
Sm-Nd Isotopic Constraints on Early Silicate Planetary Differentiation

Pierre Cartigny
Institut de Physique du Globe de Paris
Stable Isotopes and the Origin of Diamond

Jim Kasting
Penn State
Evolution of Earth's Atmosphere and Climate

Hannah Jang-Condell
DTM
Illuminating Ideas on Planet Formation: Effects of Stellar Irradiation on Protoplanetary Disks

Christopher B. Field
Carnegie Institution of Washington, Dept. of Global Ecology
Terrestrial ecosystems in the global carbon cycle

Andrey Bekker
Geophysical Laboratory
Changes in Redox State of the Paleoproterozoic Atmosphere and Ocean

George Flynn
State University of New York, Plattsburgh
Chemical and Mineralogical Analysis of Interplanetary Dust Particles: A Window on Early Solar System Processes

GL seminars

Dianne Newman
California Institute of Technology
How Bacteria Respire Minerals

David Dobson
University College, London
Early Life and Core-Mantle Coupling

Harry McSween
University of Tennessee
Petrology and Geochemistry of the MER Landing Sites on Mars

Bryan Krapez
University of Western Australia
The Depositional Environment of Banded Iron Formations in the Hamersley Province of Western Australia

Mary Schweitzer
North Carolina State University
The Use of Immunological Techniques in Paleontology and Astrobiology

Bruce Jakosky
University of Colorado
Astrobiology, Science, and Religion

Mark van Zuilen
CNRS, Nancy, France
Carbonaceous Material in Early Archaean Rocks: Remnants of Early Life or Not?

Jan Toporski and Jake Maule
Geophysical Laboratory
Our Adventures in Kamchatka

Lars Borg
Institute of Meteoritics, University of New Mexico
Geological History of Mars Inferred from Radiogenic Isotope Studies of SNC Meteorites

Juha A. Karhu
University of Helsinki, Finland
Carbon Cycling in the Early Paleoproterozoic at the Surface and in Upper Mantle

Tim Lyons
University of Missouri
3.5 Billion Years of Biospheric Evolution Recorded in Seawater Sulfate

Daniel Glavin
Goddard Space Flight Center
A Search for Extraterrestrial Amino Acids in Antarctic Micrometeorites: Implications for Future STARDUST Analyses

Hikaru Yabuta

Arizona State University
Determining the Chemical History of Meteorite Parent Body Alteration through Molecular Analysis of Meteoritic Organics

Liane Benning
University of Leeds
The Silicification of Microorganisms

Matthew Schrenk
University of Washington, School of Oceanography
Microbial Biofilms on Mineral Surfaces at Deep-Sea Hydrothermal Vents: Ecological and Evolutionary Implications

Radu Popa
University of Southern California
Evolutionary Crossroads - From the Origin of Life to Geomicrobiology

Alan Treiman
Lunar and Planetary Institute
Martian Gullies and Groundwater: Regional and Local Geology

Oliver Rouxel
Woods Hole Oceanographic Institution
Iron Isotope Systematics in Past and Present Marine Environments

Roger Summons
MIT
Geochemical Evidence for Widespread Euxinia at the Permian-Triassic Boundary

Jay Brandes
University of Texas, Marine Science Institute
Isotope Prospecting in Amazonian Headwaters

Owen Green
Oxford University
Geological Problem Solving with Microfossils in the Archaean

Barbara Sherwood Lollar
University of Toronto
Abiogenic Gases, H2 Autotrophy and Methanogenesis in the Deep Subsurface: Implications for Astrobiology

Dominic Papineau
University of Colorado
Multiple Sulfur Isotopes in Paleoproterozoic Huronian (CANADA) Sediments as Tracers of Atmospheric and Environmental Evolution

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Textbooks and Publications for General Audiences

Robert M. Hazen (2005) Genesis: The Scientific Quest for Life's Origin. Washington, DC: National Academy of Sciences, Joseph Henry Press. 324 pp. This book provides an overview of current research on the origins of life, with special emphasis on work supported by NAI.

James Trefil and Robert Hazen (2004) The Sciences: An Integrated Approach, 4th edition. New York: John Wiley. 640+51+13 p. This textbook continues to be used nationally at more than 100 colleges and universities, as well as in several large high school districts.

Robert Hazen is preparing a 24-lecture video and audio lecture series on the origin of life for The Teaching Company (Chantilly, VA).

John Baross, W. Wilcock, D. Kelley, E. DeLong, and G. Cary (Co-Editors) (2004) The Subseafloor Biosphere at Mid-Ocean Ridges, Geophysical Monograph 144 (pp. 1-11). Washington, DC: American Geophysical Union.

John Baross and W. Sullivan (Co-Editors) (In Press, 2005). Planets & Life: The Emerging Science of Astrobiology. Cambridge, England: Cambridge University Press.

Committees, Editorial Boards, Advisory Boards

Robert Hazen served as Guest Editor for Volume 1, #3, of the new periodical Elements. The issue was on the geochemical origin of life. He also served on the AAAS Committee for the Public Understanding of Science and Technology, on the Advisory Boards of NOVA (WGBH, Boston), and the daily radio show, Earth & Sky. He edited and helped to write several scripts on topics related to the origins of life and of the environment. Hazen also served as President of the Mineralogical Society of America. His Presidential address next fall will be on minerals and the origin of life.

Alycia Weinberger was part of a NASA briefing panel 'A New Look at Planet Forming' in December 2004.

John Baross is on several editorial boards: Editorial Board and editor in charge of mini-reviews, Astrobiology Journal, Mary Ann Liebert, Inc. Publishers; Co-Editor (with A. Brack, M. Mayor, and G. Horneck) on Advances in Astrobiology and Biogeophysics Series, Springer-Verlag Press; Associate Editor, Marine Microbiology Section, The Encyclopedia of Microbiology, Third Edition, Editors-in Chief, J. Lederberg and M. Sogin, Elsevier Press, London. Baross also performed the following professional activites: Co-organized and Co-Chaired the AAAS session on The Lost City Hydrothermal System, Seattle, WA (02/04; Chair, National Research Council (National Academy of Sciences) Task Group The Limits of Carbon Life on Earth and Elsewhere, 2004-2005; Organized National Research Council (National Academy of Sciences) Workshop The Limits of Carbon Life on Earth and Elsewhere, Washington D. C., May 10-11, 2004; Member, InterRidge (International Ridge) Working Group: Biogeochemical Interactions at Deep-Sea Vents, 2004-2007; Co-organized and co-Chaired American Geophysical Union (AGU) session entitled Unraveling the 'Fingerprints' of Geochemical Processes Recorded in Earth Materials, Fall meeting, San Francisco, Dec. 13-17, 2004; Lecturer and co-organizer of Vatican Observatory Summer School (VOSS) on Astrobiology, June 15-July 14, 2005, Vatican City, Italy; Charter Member, Seamount Coordinated Network (NSF), 2004-; Chair, Science Advisory Council, International Census of Marine Microorganisms (ICoMM), 2004-2006; Organizing Committee, International Extremophile Meeting to be held in Tokyo, Japan, Nov. 2005

Astrobiologists in the Public Eye

Carnegie Institution of Washington astrobiologists appeared on radio, television, and in the national press during 2004-2005. Sara Seager, Paul Butler and Alan Boss were featured in an article entitled 'New Earths' in the December 2004 issue of National Geographic magazine. Alan Boss was featured or quoted in many press reports concerning planetary formation and the detection of extrasolar planets, such as the Washington Post and LA Times, March 2005, and the New York Times, April 2005. Paul Butler and colleages were featured in numerous publications, including the New York Times and the Washington Post, about their discovery of two Neptune-mass planets. He was also featured in PBS's Origins television series.

Publications: Carnegie Institution of Washington

There are **257** publication entries for the Carnegie Institution of Washington

Alexander, C.M.O'D. (2004). Chemical equilibrium and kinetic constraints for chondrule and CAI formation conditions. *Geochimica et Cosmochimica Acta*, 68:3943-3969.

Alexander, C.M.O'D., Cody, G.D., Fogel, M., Kelemen, S., Kilcoyne, D. & Araki, T. (2005). Composition and structure of the meteoritic macromolecule: A source of complex organics on the early Earth [Abstract]. *Astrobiology*, 5(2):215.

Alexander, C.M.O'D., Fogel, M.L. & Cody, G.D. (In Press, 2005). The compositions of chondritic insoluble organic matter [Abstract]. *Meteoritics & Planetary Science*.

Amundsen, H. & Steele, A. (2005). Arctic Mars Analog Svalbard Expedition 05 season - A summary. *http://meetings.copernicus.org/egu2005/*.

Amundsen, H. & Steele, A. (2005). Arctic Mars Analogue Svalbard Expedition 05 season - A summary [Abstract]. *Astrobiology*, 5(2):318-319.

Apel, C.L. & Deamer, D.W. (2005). The formation of glycerol monodecanoate by a dehydration/condensation reaction: Increasing the chemical complexity of amphiphiles on the early Earth [Abstract]. *Astrobiology*, 5(2):217.

Asthagiri, A.R., Downs, R.T. & Hazen, R.M. (2004). Density functional theory modeling of interactions between amino acids and chiral mineral surfaces [Abstract]. *GSA Abstracts with Programs*, 36(5):338.

Avci, R., Schweitzer, M., Boyd, R., Wittmeyer, J., Steele, A., Toporski, J., Beech, I., Teran Arce, F., Spendlar, B., Cloe, K. & McKay, D.S. (In Press, 2005). Antibody-antigen interactions on collagen as a model system for application to AFM to the search for extraterrestrial life. *Chemical Physics, Physical Chemistry*.

Avci, R., Schweitzer, M., Boyd, R.D., Wittmeyer, J., Steele, A., Toporski, J., Beech, I., Teran Arce, F., Spangler, B., Cole, K.M. & McKay, D.S. (2004). Comparison of antibody-antigen interactions on collagen measured by conventional immunological techniques and atomic force microscopy. *Langmuir*, 20:11053-11063.

Barley, M.E., Bekker, A. & Krapez, B. (In Press, 2005). Late Archean to Early Paleoproterozoic global tectonics, environmental change and the rise of atmospheric oxygen. *Earth and Planetary Science Letters*.

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Baross, J.A., Wilcock, W.S.D., Kelley, D.S., DeLong, E.F. & Cary, S.C. (2004). The subsurface biosphere at mid-ocean ridges: Issues and challenges. In: W.S.D. Wilcock, D.S. Kelley, J.A. Baross, E. DeLong & S.C. Cary (Eds.). *The Subseafloor Biosphere at Mid-Ocean Ridges. Geophysical Monograph 144* (pp. 1-11). Washington, DC: American Geophysical Union.

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Busemann, H., Alexander, C.M.O'D. & Nittler, L. (2005). Microscale D/H and C/H imaging of meteorites and IDPs - Calibration of ion microprobe data with terrestrial analogues and meteoritic residues [Abstract]. *Geochimica et Cosmochimica Acta*, 69 (10S, Special Supplement):A525.

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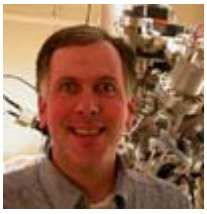

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Name:Kaspar von Braun

Project Role: Postdoc

Institution: Carnegie Institution of Washington

Projects | Publications | Update Profile

Name:Alycia Weinberger
Project Role: Co-Investigator
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Name:Boswell Wing
Project Role: Postdoc
Institution: University of Maryland
Projects | Publications | Update Profile

Name:Merri Wolf
Project Role:
Institution: Carnegie Institution of Washington
Projects | Publications | Update Profile

Name:Thomas Zega
Project Role: Postdoc
Institution: US Naval Research Laboratory
Projects | Publications | Update Profile

Executive Summary: University of Colorado, Boulder

Executive Summary: University of Colorado, Boulder
Principal Investigator: Bruce Jakosky
Reporting Period: 2005 (7/04-6/05)

The University of Colorado Center for Astrobiology member in the NASA Astrobiology Institute runs a multi-pronged program. Our research efforts span the entire range of disciplines that comprise astrobiology, and include components in the physical sciences, the biological sciences, and the humanities. In addition, we collaborate with leading players from the aerospace industrial community to provide leadership in developing technology for astrobiology. On the education side, our research program meshes with a graduate-education program in each of the sub-disciplines within astrobiology, and we provide a broad-based education to students. In addition, we offer courses and programs for undergraduates, as a way of involving them in astrobiology and, eventually, feeding into a graduate program either here or elsewhere. We also have a cutting-edge program in education and public outreach that provides significant activities at a number of different levels. Our education and outreach program will be described elsewhere, and we focus here on our astrobiology research program.

Our research activities divide up into two science themes, a humanities theme, and a technology theme. Each of these will be discussed below.

Origin and evolution of life

Chiral determinism and the origin of translation. An important part of understanding the origin of the genetic code is understanding the chirality of the molecules comprising life. Why does the ribose backbone in RNA utilize the D orientation, and amino acids the L orientation? Mike Yarus has been carrying out experiments designed to understand the relationship between the chirality of these, by looking at the ability of randomized RNA molecules to preferentially grab one chirality rather than the other of amino acids. The experiments show a remarkable preference for L histidine. However, similar experiments show the exact opposite preference, for D phenylalanine. Are the results different for different amino acid side chains (thereby giving us a clue about which amino acids entered biology via RNA activity) or is this difference the anticipated confusion arising from a chiral support? Future experiments will help us to choose.

A mechanism for the association of amino acids with their codons and the origin of the genetic code. In the origin of the genetic code, an explanation of why certain amino acids are assigned to certain codons has not been developed. Shelley Copley has been developing a model for origin of the genetic code. The genetic code has many regularities, some of which include explanation in terms of tRNA function or robustness against deleterious effects of mutations in translation. For example, there is a strong correlation between the first bases and the biosynthetic pathways of the amino acids they encode. Codons beginning with C, A, and U encode amino acids synthesized from x-ketoglutarate, oxaloacetate, and pyruvate, respectively. This and other regularities can be explained if, before the emergence of macromolecules, simple amino acids were synthesized in covalent complex of dinucleotides with alpha deto acids originating from the reductive tricarboxylic acid cycle or reductive acetate pathway. These processes could have created an association between amino acids and the first two bases of their codons that was retained when translation emerged later in evolution.

The biogeochemical evolution of sulfur on the early Earth. Rock samples retain a chemical remnant of the environmental conditions extant at the time that the rocks were formed or altered, and provide the most detailed information on the history of the Earth's habitability. Steve Mojzsis and his group have been utilizing this type of information to understand the ancient Earth. They have been examining mass-independent sulfur isotope effects as a way of tracing the transformation of the surface zone to an oxygen-rich environment between 2.5 and 1.8 b.y.a. They have been examining oxygen and sulfur isotopes in supracrustal sequences in West Greenland as a way to corroborate a sedimentary origin for Akilia iron-rich quartzitic enclaves. In collaboration with other groups, they have expanded the record of nitrogen isotopic fractionations by life into the oldest sediments from West Greenland. And, in a complementary analysis, they have been examining the detailed phylogenetic character of living stromatolites in Shark's Bay, Western Australia, in order to make inferences about early Archean habitats and the "classical" interpretation of the origin of stromatolites in the geological record.

Molecular survey of microbial diversity in hypersaline ecosystems. In ongoing work related to the microbial diversity in naturally occurring extremophile ecosystems, Norman Pace and his group have been working in hypersaline and hyperthermophilic environments. In the hypersaline environments, ~4000 new rRNA sequences were isolated and described and, therefore, organisms were described. Many new bacterial and archaeal clades were discovered, including ~15 new bacterial phylogenetic divisions (”kingdoms”). Surprisingly, cyanobacteria do not constitute the main biomass (by rRNA gene content) but, rather, green nonsulfur bacteria dominate numerically. In the high-temperature environments, the group has completed analysis of Yellowstone systems at temperatures above 70°C. Notably, organisms identified molecularly as hydrogen-metabolizing constitute the most common life in those hot springs. As well, the hydrogen abundance in a number of hot spring systems has been measured, and sufficient hydrogen to support metabolism has been identified (15-300nM).

Origin of multicellularity and complex land-based ecosystems. Understanding the symbiotic relationships between organisms at the surface of the Earth, and the distribution between above- and below-ground phases of a life cycle, is important for understanding how ecosystems evolve in response to major trauma such as that accompanying extinction-event-inducing impacts. Under William Friedman, we have been investigating the relationship between land plants and fungi. 80-90 % of all land plants have mutualistic symbiotic associations with fungi where the fungal symbionts provide increased access to essential minerals and the fungal symbionts gain access to fixed carbon. Fungal symbionts in early lineages of land plants can have a life cycle where one phase is above ground and photosynthetic and another is completely underground for as long as fifteen years. These early lineages represent a potential ancient life cycle mode that succeeded based on its fungal dependent subterranean phase. Given the diversity of fungal species capable of translocating carbon between photosynthetic plants and subterranean plants, it is possible if not probable that carbon transfer between different plant species through fungal networks may well extend beyond underground plants.

Origin and evolution of habitable planets

Biogeochemical cycling and resources on Mars. Our approach to exploring the biological potential of Mars has been to examine the environmental conditions necessary to support life and to understand their availability, accessibility, and abundance on Mars. Bruce Jakosky and his group have been focusing primarily on the availability of liquid water (and the connections to the history of climate and volatiles) and the availability of geochemical energy that can support metabolism. On the liquid water side, they have been trying to synthesize the wide range of results from the five ongoing spacecraft missions that pertain to volatiles and climate on timescales of the seasonal cycles, the obliquity cycles, and the four-billion-year history of volatiles. The synthesis differs from previous ones in significant ways and represents a change in our understanding of the driving forces behind Mars climate evolution. On the issue of available geochemical energy, we have modeled the geochemical reactions between water and rock in Mars-like environments at ambient conditions, in order to determine the availability of energy to support metabolism. We are focusing on ambient conditions given the increasingly compelling evidence for long-lived liquid water that has not been heated to hydrothermal temperatures. Our results suggest that ambient-temperature conditions provide significantly more energy from weathering reactions than do hydrothermal conditions, due to the greater energy change at low temperatures; however, the energy may be made available at a slower rate.

Untangling Europa’s evolution. Significant progress has been made by Bob Pappalardo toward determining the stress history of Europa’s lineaments to understand whether the satellite is in a steady-state or if its activity level has changed over time, with implications for its capability to support life. We have succeeded in modeling surface stresses on Europa from orbital (diurnal) stressing and from nonsynchronous rotation of the ice shell using gravitational potential theory. We find that potential theory significantly improves upon previous models of surface stresses on Europa, modifying previous predictions for the extents of zones of compression, extension, and strike-slip across the surface. We have found that combined diurnal and nonsynchronous stresses predict patterns that are a compelling match for the patterns of lineaments on Europa’s surface. We are in the process of developing and testing “graph theory” algorithms for quantitative comparison of stress orientations and styles to mapped lineaments, to constrain the temporal evolution of the surface.

The impact of atmospheric particles on life. Brian Toon and his group have been working in part with

the NASA/Ames team in the NAI to understand the forces that drive the climate and atmosphere on terrestrial planets and satellites. This has included examining processes related to atmospheric evolution on the early Earth, potential external forcing of terrestrial snowball Earth episodes, the evolution of oxygen in the Earth's ancient atmosphere using sulfur isotopes, the record of biological extinction following the K/T impact event and the implications for climate, the geomorphological processes responsible for martian gullies and their implications for near-surface and surface liquid water, and the formation of hazes in the atmospheres of Titan and the early Earth. The largest common thread is radiative forcing of the atmosphere, via interactions with the surface, with atmospheric gases, and with atmospheric aerosols. A paper on the first of these topics appeared in *Science*, with a demonstration that hydrodynamic escape could have left the Earth (or an extrasolar planet) with an atmosphere enriched in H_2, at perhaps the tens of percent level, and with an H_2/CO_2 ratio greater than 1. This would mean that the prebiotic atmosphere might have been a good source of organic molecules for the origin of life.

Geochemical-microbe interactions in chemolithotrophic communities on the Earth. Tom McCollom, along with Brian Hynek, has been using geochemical modeling and remote sensing data to evaluate the geologic history of bedrocks exposed on Meridiani Planum that have been observed by the Mars Exploration Rover Opportunity. The MER science team has interpreted the bedrock to be volcanic sediment deposited in a standing body of briny water that later evaporated to leave behind sulfate salts, implying prolonged clement conditions and a relatively benign environment that might be conducive to life. However, this interpretation appears to be incompatible with the chemistry and geologic setting of the rocks, and we have inferred that the bedrocks are, instead, volcanoclastic airfall deposits subsequently altered by sulfur-rich volcanic gases in a solfatara-like environment. This scenario would imply and environment much less conducive to life.

Star and planet formation. We have been examining the early phases of star formation, using both theoretical and observational approaches, in order to understand the conditions surrounding planet formation and the conditions under which planets do form and under which they do not form. John Bally is leading this effort. Theoretical approaches include modeling of the gas loss induced by photoablation by ultraviolet light. In particular, removal of H and He by this process increases the dust/gas ratio and enhances the formation of kilometer-sized planetesimals that are a precursor to planet formation. Simulations of the interactions between protoplanetary disks reveal that spiral shock waves can be generated; such shocks may lead to significant chemical processing, and possibly may explain the properties of chondrules found in some primitive meteorites. Observationally, we have continued our recent studies of the nearest star-cluster forming clouds such as Perseus and Orion. Results include the discovery of many proto-planetary disks surrounding young stars and thermal-infrared emission from warm dust from Orion's "naked" stars (those not surrounded by photo-evaporating disks).

Philosophical and societal issues.

The historical character of astrobiology and circumventing the problem of defining life. Carol Cleland continues to lead the field in discussing astrobiology from the perspective of philosophy of science. Two areas have been emphasized recently. The first one relates to the definition of life and the fact that, in absence of a general theory of living systems, it is unlikely that scientists will recognize genuinely strange life if they come across it. We explored the possibility of anomalous forms of microbial life on Earth today. Showing how preconceptions based on familiar Earth life can blind us to the possibilities for life in general underscores the importance and difficulties involved in searching for extraterrestrial life. Second, we explored the development of a theory of biology that encompasses all life, not just known terrestrial life; we emphasized the issue of Darwinian evolution as a component of a definition of life. We conclude that this is not necessarily a requirement for life; as software simulations of Lamarckian evolution suggest, it is possible that organisms with a different molecular architecture could utilize different physical mechanisms for achieving biological change.

Astrobiology technology development.

Astrobiotechnology development. Although astrobiology technology development is proceeding through several different programs, they are not integrated well into a single coherent program. Our goal is to provide some oversight from the community and synthesis and integration within the community to the

program as a whole, and thereby to stimulate the development of astrobiology technology in a time in which there is increasing scientific focus in these areas. We have done this by creating a consortium involving academia, national research laboratories, and industry. Our first effort was to organize a workshop on Mars astrobiotechnology development, in order to bring the various science and technology communities together into a single forum for the exchange of ideas. The workshop was held in September 2004 and was a tremendous success. Planning is ongoing for our second workshop, focusing on providing background and support for instrument development by astrobiologists who do not have much history or experience in the flight programs.

Project Reports: University of Colorado, Boulder

A mechanism for the association of amino acids with their codons and the origin of the genetic code.

Project Investigator: Shelley Copley

Project Progress

The genetic code was elucidated forty years ago. Despite decades of effort, a satisfactory explanation why certain amino acids are assigned to certain codons has not been developed. A collaboration with Dr. Harold Morowitz of George Mason University and Dr. Eric Smith of the Santa Fe Institute has led to the proposal of a novel mechanism for the association of amino acids with their codons and the origin of the genetic code. This work was recently published in Proceedings of the National Academy of Sciences.

The genetic code has many regularities, of which only a subset have explanations in terms of tRNA function or robustness against deleterious effects of mutation or errors in translation. There is a strong correlation between the first bases of codons and the biosynthetic pathways of the amino acids they encode. Codons beginning with C, A, and U encode amino acids synthesized from α-ketoglutarate, oxaloacetate, and pyruvate, respectively. There is also a long-recognized relationship between the hydrophobicity of the amino acid and the second base of its codon. Codons having U as the second base are associated with the most hydrophobic amino acids, and those having A as the second base are associated with the most hydrophilic amino acids. These regularities can be explained if, before the emergence of macromolecules, simple amino acids were synthesized in covalent complexes of dinucleotides with α-keto acids originating from the reductive tricarboxylic acid cycle or reductive acetate pathway (see Figure 1). The bases and phosphates of the dinucleotide are proposed to have enhanced the rates of synthetic reactions leading to amino acids in a small-molecule reaction network that preceded the RNA translation apparatus, but created an association between amino acids and the first two bases of their codons that was retained when translation emerged later in evolution.

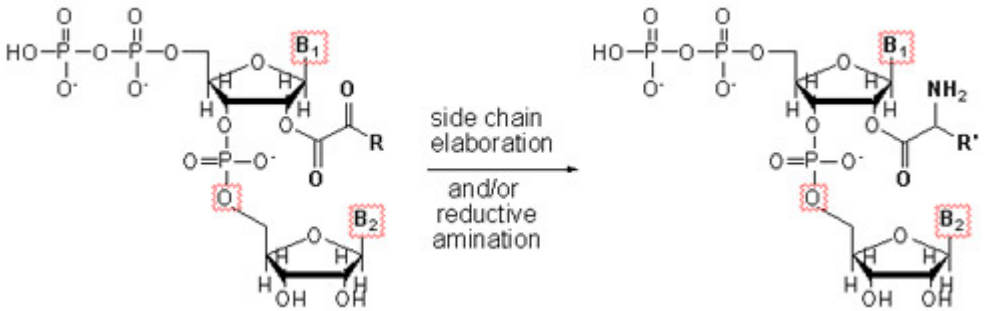

Figure 1. Model for synthesis of amino acids from a-keto acid precursors covalently attached to dinucleotides. The dinucleotide that is capable of catalyzing synthesis of a particular amino acid is proposed to contain the first two bases of the codon specifying that amino acid.

Roadmap Objectives

- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 3.2:** Origins and evolution of functional biomolecules

Mission Involvement

This work provides an exciting new hypothesis for the emergence of the genetic code, as well as suggesting specific ways in which small RNA molecules (dinucleotides) might be involved in catalysis of the synthesis of amino acids. Since amino acids are the precursors of the bases in nucleotides, this provides a positive feedback loop that would enhance the production of both amino acids and nucleotides under pre-biotic conditions.

Re-tracing Steps Towards a Habitable World: The Biogeochemical Evolution of Sulfur on the Early Earth.

Project Investigator: Stephen Mojzsis

Project Progress

**Mass-independent isotope effects in sedimentary rocks by ion microprobe analysis.* We have traced the effect of these reactions in the transformation of the surface zone to an oxygen-rich environment between 2.5 and 1.8 billion-years-ago (Papineau et al., *GCA*; Papineau et al. *submitted to Science*).

**Discrimination between preservation of original igneous zircon populations and inherited grains and Constraining the protolith of granulite facies assemblages in West Greenland.* In collaboration with the UCLA NAI Team (Manning and Harrison) we have decribed the geology, age and origin of pre-3.8 Ga supracrustal sequences in West Greenland and reported trace element, $\delta^{18}O$ and mass independent sulfur isotopes (_^{33}S) corroborate a sedimentary origin for Akilia Fe-rich quartzitic enclaves (Manning et al., 2005 in press).

**Nitrogen isotopic evolution with time*. In collaboration with the University of Helsinki (J. Karhu) and the CRPG-Nancy (B. Marty) we have expanded the record of nitrogen isotopic fractionations by life into the oldest sediments from West Greenland (Papineau et al. 2005a).

**Community structure of microbialites in Shark Bay*. In collaboration with CU Professor Norm Pace and graduate student Jeff Walker, we report the first detailed phylogenetic analysis of a living stromatolites from Shark Bay, Western Australia and use this information to make inferences about early Archean habitats and the 'classical' interpretation of the origin of stromatolites in the geologic record.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.2:** Foundations of complex life
- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials

Field Expeditions

Field Trip Name: West Greenland	
Start Date: June 8, 2004	**End Date:** June 24, 2004
Continent: North America	**Country:** Greenland
State/Province:	**Nearest City/Town:** Nuuk (Godthaab)
Latitude: N 63 55? 44?	**Longitude:** W 51 43? 52?
Name of site(cave, mine, e.g.): Akilia, Isua and Innersuartuut	**Keywords:** early life, Akilia, carbon isotopes, banded iron-formation, Archean
Description of Work: Field studies to map and sample for analysis the oldest known rocks of sedimentary origin.	
Members Involved:	

Cross Team Collaborations

*Mass-independent isotope effects in sedimentary rocks by ion microprobe analysis. We have traced the effect of these reactions in the transformation of the surface zone to an oxygen-rich environment between 2.5 and 1.8 billion-years-ago in collaboration with the UCLA Team (McKeegan, Schmitt) and University of Helsinki (Karhu) (Papineau et al., in revision to GCA; Papineau et al. submitted to Science). *Discrimination between preservation of original igneous zircon populations and inherited grains and Constraining the protolith of granulite facies assemblages in West Greenland. In collaboration with the UCLA NAI Team (Manning and Harrison) we have decribed the geology, age and origin of pre-3.8 Ga supracrustal sequences in West Greenland and reported trace element, ?18O and mass independent sulfur isotopes (?33S) corroborate a sedimentary origin for Akilia Fe-rich quartzitic enclaves (Manning et al., 2005 in press). *Nitrogen isotopic evolution with time. In collaboration with the University of Helsinki (J. Karhu) and the CRPG-Nancy (B. Marty) we have expanded the record of nitrogen isotopic fractionations by life into the oldest sediments from West Greenland (Papineau et al. 2005a). *Community structure of microbialites in Shark Bay. In collaboration with CU NAI Team Professor Norm Pace and graduate student Jeff Walker, we report the first detailed phylogenetic analysis of a living stromatolites from Shark Bay, Western Australia and use this information to make inferences about early Archean habitats and the ?classical? interpretation of the origin of stromatolites in the geologic record..

Star and Planet Formation

Project Investigator: John Bally

Project Progress

In collaboration with Henry Throop (SWRI), we realized that UV radiation may trigger the rapid formation of kilometer-scale planetesimals in protoplanetary disks (Throop & Bally, 2005). Thus, contrary to previous view that massive stars in a cluster may be hazardous to planet formation, new models indicate that their UV radiation may promote it. If grains grow and sediment to the disk mid-plane when the external UV radiation turns-on, photo-ablation selectively removes dust-depleted gas (mostly H and He). Continued mass-loss increases the disk dust:gas ratio until km-scale planetesimals form by gravitational instability. This UV-radiation induced instability may solve a long-standing problem in planetesimal formation - the in-spiral of solids as they grow.

We have continued our studies of the nearest star-cluster forming clouds such as Perseus and Orion. Recent results include the discovery of many proto-planetary disks surrounding stars which are NOT proplyds on the Hubble Space Telescope images. We used the thermal-infrared camera at the Gemini South telescope to find warm dust emission from Orion's “naked” stars (those not surrounded by photo-evaporating disks).

Graduate student Nick Moeckell has continued his numerical simulations of disk evolution in dense clusters. The close-passages with separations of only a few hundred AU are fairly common in Orion-like environments. Such interactions can generate spiral shock waves in protoplanetary disks. We have proposed that such shocks may lead to significant chemical processing, and possibly may explain the properties of chondrules found in some primitive meteorites.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
0	TPF-I	Science Team Member

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

I serve on the TPF-I Science Working Group and am responsible for developing the science case for general astrophysics

Evaluation of Habitable Environments on Mars

Project Investigator: Tom McCollom

Project Progress

Understanding the geologic history of Mars is critical to interpreting the past and present habitability of the planet and for planning future astrobiological exploration. Dr. Tom McCollom, together with collaborator Dr. Brian Hynek, has been using geochemical modeling and remote sensing data to evaluate the geologic history of bedrocks exposed on Meridiani Planum that have been observed by the Mars Exploration Rover (MER) Opportunity. The MER science team has interpreted the bedrocks to be volcanic sediments deposited in a standing body of briny water that later evaporated to leave behind sulfate salts, implying prolonged clement conditions and a relatively benign environment that might be conducive to life. However, this interpretation appears to be incompatible with the chemistry and geologic setting of the rocks, and Drs. McCollom and Hynek have instead inferred that the bedrocks are volcanoclastic airfall deposits subsequently altered by sulfur-rich volcanic gases in a solfatara-like environment. This interpretation implies an environment much less conducive to life than the interpretation favored by the MER science team. A manuscript describing these results is currently under review. In addition, Dr. McCollom has completed a review article of Mars' habitability entitled "Is (or Was) Mars Habitable for Life? A Review of the Current Evidence" to appear in the book *Solar System Update.*

Roadmap Objectives

- **Objective No. 2.1:** Mars exploration

Cross Team Collaborations

Alex Smirnov, a graduate student at SUNY Stony Brook (Ph. D. adviser Dr. Martin Schoonen, member of Penn. State Astrobiology team), visited the laboratory of Dr. Tom McCollom in Fall, 2004, to perform hydrothermal experiments investigating the stability of formic acid in early Earth environments. Several experiments were completed which are being incorporated into Alex Smirnov's Ph. D. thesis. Alex Smirnov visit was supported by an NAI graduate student research fellowship.

Biogeochemical cycling and resources on Mars

Project Investigator: Bruce Jakosky

Project Progress

Our approach has been to examine the environmental conditions necessary to support life, and to understand their availability, accessibility, and abundance on Mars. We have been focusing primarily on availability of liquid water (and the connections to the history of climate and of volatiles) and the availability of geochemical energy that can support metabolism.

On the liquid water issue, there is increasing evidence to suggest that liquid water has been abundant at or near the surface at temperatures not significantly above ambient. That is, ambient temperatures rather than hydrothermal temperatures. The evidence comes from a variety of observations from the five spacecraft currently operating at Mars, and includes geological, atmospheric, polar, and geophysical analyses that relate to seasonal, obliquity, and four-billion-year timescales. We are in the process of synthesizing these results into a coherent picture of martian volatile evolution and liquid water availability. This synthesis differs from previous ones in significant ways, and represents a fundamental new paradigm of martian volatiles.

On the energy-availability issue, we have modeled the geochemical reactions between water and rock in Mars-like environments at ambient temperature conditions, in order to determine the availability of energy to support metabolism. We assume an initial set of minerals available for weathering at or near the surface, based on spacecraft and meteorite analyses. We use geochemical modeling software to determine the stable minerals that would result from weathering under a variety of assumptions, and then calculate the Gibbs free energy available from those reactions. This energy is theoretically available for organisms to utilize. Our results suggest that ambient-temperature conditions provide significantly more energy from weathering than do hydrothermal conditions, due to the greater energy change at low temperatures; however, the energy may be made available at a slower rate. These results have significant implications for planning upcoming missions that are investigating the potential for life and for interpreting observations at Mars in terms of the potential ability of the planet to support life.

Roadmap Objectives

- **Objective No. 2.1:** Mars exploration
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
1	Mars Global Surveyor	Project Investigator
1	Mars Observer	Co-Investigator
1	Mars Science Laboratory	Co-Investigator
2	MAVEN	Project Investigator

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Cross Team Collaborations

NASA/Ames, outreach efforts, Dave Des Marais NASA/Ames, collaboration on planetobiogeochemistry, Dave Des Marais, ongoing

Philosophical Issues in Astrobiology

Project Investigator: Carol Cleland

Project Progress

My work continues to focus upon laying the logical and philosophical foundations for searching for extraterrestrial life in the absence of a definition of 'life'. Because we lack a general theory of living systems it is unlikely that scientists will recognize genuinely strange life for what it is if they come across it. Recognizing strange life presupposes an adequately general theory of life, and formulating the latter requires systematically searching for what Thomas Kuhn called "anomalies." Anomalies are physical systems that resemble terrestrial life in provocative ways and yet are neither clearly living nor clearly non-living. The recognition of strange life thus begins with the verification and exploration of anomalies. In this context, biochemist Shelley Copley and I explored the possibility of anomalous (in essence, alien) forms of microbial life on Earth today. We successfully tackled the standard arguments (alternative molecular and biochemical possibilities for the origin of life, Darwinian competition with familiar Earth life, failure to detect them, etc.) against the existence of such organisms. Showing how preconceptions based on familiar Earth life can blind us to the possibilities for life in general underscores the importance and difficulties involved in searching for genuinely alien extraterrestrial life.

My work also focused on the search for a universal biology—a theory of biology that encompasses all life, wherever it is found and whatever it is made of. Drawing upon the history of chemistry, which achieved a universal theory of chemical substance based upon our experiences with chemical substances on Earth, I explored a number of parallels with our current understanding of biology. Of particular importance is the question of whether neo-Darwinian evolution, which is frequently touted as providing the foundation for such a theory, can do the job. My tentative conclusion is "no". Among other things, the detailed molecular architecture of familiar terrestrial life (with proteins providing the foundation for morphology and nucleic acids for heredity) seems ideally suited for achieving biological change through natural selection. As software simulations of Lamarckian evolution suggest, it is possible that organisms with a different molecular architecture could utilize different physical mechanisms for achieving biological change.

Untangling Europa's Evolution

Project Investigator: Robert Pappalardo

Project Progress

Significant progress has been made toward determining the stress history of Europa's lineaments to understand whether the satellite is in a steady-state or if its activity level has changed over time, with implications for its capability to support life. We have succeeded in modeling surface stresses on Europa from orbital (diurnal) stressing and from nonsynchronous rotation of the ice shell using gravitational potential theory. We find that potential theory significantly improves upon previous models of surface stresses on Europa, modifying previous predictions for the extents of zones of compression, extension, and strike-slip across the surface. We have found that combined diurnal and nonsynchronous stresses predict patterns that are a compelling match for the patterns of lineaments on Europa's surface, indicating that these stress mechanisms have combined to shape the surface. We are in the process of developing and testing "graph theory" algorithms for quantitative comparison of stress orientations and styles to mapped lineaments, to constrain the temporal evolution of the surface. These results are also valuable input toward planning for the upcoming Europa Geophysical Explorer mission.

Roadmap Objectives

- **Objective No. 2.2:** Outer Solar System exploration

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
0	Europa Geophysical Explorer	Planning Support,Background Research,Instrument/Payload Development

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Our research provides geophysical constrains on crack formation and level of activity on Europa. This constrains models of surface-ocean communication and input is valuable to planning for a possible seismometer for the planned Europa Geophysical Explorer mission.

Chiral determinism and the origin of translation

Project Investigator: Michael Yarus

Project Progress

Thanks to earlier experiments within this project, as well as related work in my and other laboratories, it is accepted by a majority of evolutionarily concerned biologists that our immediate predecessors were a biota that made more extensive use of a molecule very like RNA, perhaps using it as the only macromolecule for a time. This congener of RNA thereby predates other modern macromolecules and more recently (post RNA world) ceded many cellular functions to the other characters of the central dogma, DNA and protein. One influential consequence of these views is that RNA must have devised translation (so that RNA catalysts could be replaced with peptides), and therefore RNA must be competent in all reactions required for coded peptide synthesis. We have published an experimental demonstration that this is a biochemically plausible proposition by showing that all types of reactions required for translation are within the RNA repertoire (1).

Thus it is likely that amino acids were admitted to proteins by the action of RNA. This immediately raises the possibility that the universal use of L-amino acids in proteins may have occurred because these amino acids were chosen in interactions with the chiral reagent RNA, with its D-ribose backbone. This, even if true, would not solve the problem of biological asymmetry, but would displace the biological breaking of chirality to the origin of RNA and therefore represent progress on one of the 'great questions' of molecular evolution.

This idea has been pursued in the past by measuring differential rates of aminoacylation of ribonucleotide models by activated D and L-amino acids. Profy and Usher (2) used racemic DNB-alanine imidazolides to acylate poly A, I, C and U. They found L was added more rapidly from almost 4-fold (poly A) to about 2-fold (poly C). However, when the DNB protecting group was removed, more nearly emulating aa-tRNA synthesis, the stereospecificity flipped, with D-amino acids selected by D-RNA. Tamura and Schimmel (3) more recently used a specific molecular model consisting of a 5' p-amino acid (emulating an amino acid adenylate) at a nick in an RNA-hybrid helix. The activated L-alanine was transferred across the nick to adenosine 3' OH at 4 times the rate of D-alanine.

Thus there is an indication of moderate stereospecificity in the literature. However, the results may not generalize given that a modest quantitative outcome depended on the sequence of the RNA, and that only alanine has been used. Furthermore, unknown constraints are hidden in both experiments in that rates (and therefore incompletely known transition states) are being surveyed, and in the Tamura-Schimmel case the effect of an arbitrarily chosen helix geometry may possibly be influential.

It might therefore be useful to ask in a more open-ended way if there is a chiral interaction between L-amino acids and D-RNAs. The basic idea is to give RNAs an unbiased chance to bin D- & L-amino acids, and to ask how well, relatively, they can do this. Our usual affinity selection protocols are well suited to this question, so we have tried to adapt them to determine chiral preference.

The basic idea is to do a selection with equal amounts of D- and L-amino acids immobilized in a column exposed to 10^{14} to 10^{15} different RNA sequences. The column is eluted with a racemic mix of amino acid, and the RNA re-amplified until RNA that binds is isolated. Under this even-handed selection, does RNA binding the L- or the D-amino acid arise first? This protocol is understood to some extent, and is a plausible way to ask whether the most abundant sequences that bind an amino acid are stereoselective (conceivably they might be unselective).

The most interesting example of this experiment we have carried out (related selection in 4) relies on selection for binding DL-histidine columns and elution by racemic histidine. One requirement for a clear experiment is that there be no other chiral molecules in the selection, so that observed chiral preferences can be attributed unambiguously to a choice between the amino acids. This makes our normal column procedure unusable because we use Sepharose, a natural product made of chiral sugars. Therefore we first sought a new non-chiral column material (but see below for more on Sepharose).

This proved to be a considerable obstacle, as the obvious alternatives were all worse; we eliminated

polyacrylamide, latex and polystyrene supports on various grounds, such as non-specific affinity for RNA, incompatibility with the solvents needed to derivatize with amino acids, and the like. We finally ended up with controlled pore glass (CPG), available with long support arms terminated in an amine. This meets the theoretical requirement nicely, because glass is a frozen liquid and can have no underlying chiral bias. D-his-glass and L-his glass were mixed in equal quantities to make columns in which the two forms of the amino acid must have equal abundances.

In brief, the selection with DL-his-glass (bound through the carboxyl group) gave an extremely clear result. The first RNA to elute with histidine was entirely L-specific, whether tested as a pool or resolved into separate sequenced isolates and tested as pure single RNA transcripts. The L-histidine binding RNA consisted of a single species of aptamer that must have been one or two orders of magnitude more abundant than D-histidine aptamers.

An important control was carried out: when the selection was carried out again from two cycles earlier, but eluting with D-histidine only, RNAs that eluted with the D-amino acid were easily recovered. This shows that the techniques were sufficient to recover the other specificity and indeed, that such RNAs existed in our experiment. Thus the predominance of the L-his aptamers was not due to some cryptic defect in the selection for D-his affinity. Given these results, it appears that L-preference may be generalizable. This would be an exciting evolutionary result, arguing that the universal handedness of modern proteins is due to RNA activity. However, now our old favorite Sepharose appears again: as a warm up using known techniques, we had previously selected on DL-phenylalanine-Sepharose using the same protocols. The results were as definitive in favor of D-phe as they had been for L-his on CPG! So now we have a dilemma – are the results different for different amino acid sidechains (thereby giving us a clue about which amino acids entered biology via RNA activity) or is this difference the anticipated confusion arising from a chiral support? Stay tuned.

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2. **Profy AT, Usher DA. 1984. *J Am Chem Soc* 106: 5030-31**
3. **Tamura K, Schimmel P. 2004. *Science* 305: 1253.**
4. **Majerfeld, I, Puthenvedu, D, Yarus, M. 2005. *J Mol Evol* , RNA Affinity for Molecular L-Histidine; Genetic Code Origins, online ahead of print, PubMed PMID:** 15999244

Roadmap Objectives

- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 3.2:** Origins and evolution of functional biomolecules
- **Objective No. 4.2:** Foundations of complex life

Mission Involvement

These data should help find and interpret evidence of life elesewhere.

The impact of atmospheric particles on life

Project Investigator: Owen Toon

Project Progress

During the past year my group at the University of Colorado published 10 papers with partial, additional support from the Ames Astrobiology Institute.

We developed a hydrodynamic escape model, which we applied to an extrasolar planet ("Transonic hydrodynamic escape of hydrogen from extrasolar planetary atmospheres"(Tian, F., Toon, O.B., Pavlov, A.A., & DeSterk, H.), Astrophys. J. 621 (2): 1049-1060 Part 1 Mar 10 2005) which we then applied to Earth ("A hydrogen-rich early earth atmosphere" (Tian F., Toon O.B., Pavlov A.A., DeSterck H.) *Science*, 308, 1014 (2005); published online 7 April 2005 (DOI: 10.1126/science.1106983). We showed that early Earth had an atmosphere with tens of percent H_2, and an H_2/CO_2 ratio greater than 1. This means the rebiotic atmosphere was a good source of organic molecules and the past 25 years of searching for extraterrestrial delivery of organics, or inspecting hydrothermal systems is not necessary. Life likely originated in the oceans using the atmospherically generated organics.

We investigated the likely results of the solar system passage through interstellar dust clouds. Such passages must have occurred many times in Earth history. we found that passage through a dense cloud would have caused particles to build up in the stratosphere and block enough sunlight to plunge Earth into a Snowball. We show how this might be shown from the geologic record using various elements and isotopes "Passing through a Giant Molecular Cloud - Snowball Glaciations produced by interstellar dust." (Alexander A. Pavlov, Owen B. Toon, Anatoli K. Pavlov, John Bally, David Pollard)Geophys. Res. Lett., 32, L03705,doi 10.1029/2004GL021890 (2005).). During a magnetic reversal while passing through a less dense cloud the Earth's ozone layer may have been destroyed (Catastrophic ozone loss during passage of the Solar system through an interstellar cloud, A. A. Pavlov, A.K.. Pavlov, M.J. Mills, V. M. Ostryakov, G. I Vasilyev, and O. B. Toon, Geophys. Res. Lett., 32, doi 10.10229/2004GL021601, (2005).).

We showed that mass independent fractionation of sulfur isotopes , the key to quantifying oxygen levels prior to 2.3 bya, can be understood in modern ice cores "Mystery of the volcanic mass-independent sulfur isotope fractionation signature in the Antarctic ice-core" (A. A. Pavlov, M. J. Mills, O. B. Toon) Geophys. Res. Lett., in press (2005).)

We showed that the biological record of extinction after the K-T event is consistent with the thermal pulse from the reentering debris. "Survival in the first hours of the Cenezoic" (D. S. Robertson, M. C. McKenna, O. B. Toon, S. Hope and J. A. Lillegraven) Geol. Soc. Am. Bull. 116, 760-768,(2004).)

We showed that Martian gullies likely form under present conditions, and mark an excellent spot to search for life on mars ("Formation of Martian gullies by the flow of liquid water flowing under current Martian environmental conditions" (J. L. Heldmann, O. B. Toon, W. Pollard, M. Mellon, J. Pitlick, C. P. McKay, and D. T. Andersen) J. Geophys. Res. 110, E05004, doi:10.1029/2004JE002261, (2005).)

Finally we investigated the formation of hazes on Titan and the early Earth. Cassini may provide a check on how closely these lab studies resemble a planetary atmosphere. For early Earth we need to understand if these particles are food for the biota, if they alter the climate, and if they are so thick that they make the early Earth look like Titan does now. ("Chemical Composition of Titan's Haze: Are PAHs present?" Melissa G. Trainer, Alexander A. Pavlov, Jose L. Jimenez, Christopher P. McKay, Douglas R. Worsnop, Owen B. Toon, and Margaret A. Tolbert, Geophys. Res. Lett, 31, L17S08, doi: 10.1029 /2004 GL0 19859 (2004). "Laboratory Studies of Butane Nucleation on organic haze Particles: Application to Titan's Cloud", (Curtis, D. B., Glandorf, D. L., Toon, O. B., Tolbert, M. A., McKay, C. P., and Khare, B. N.,) J. Phys. Chem. A 109 (7): 1382-1390 FEB 24 (2005). "Haze Aerosols in the Atmosphere of Early Earth: Manna from Heaven", Trainer,M.G., Pavlov,A.A., Curtis, D.B., McKay, C.P., Worsnop, D.R., Delia, A.E., Toohey ,D.W., Toon, O.B., & Tolbert, M.A.), Astrobiology, 4,409-419,2004.)

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 2.1:** Mars exploration
- **Objective No. 2.2:** Outer Solar System exploration
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.3:** Effects of extraterrestrial events upon the biosphere
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials

Cross Team Collaborations

Jim Kasting-JPL-jont research initiated Chris McKay-ames-several papers published

Molecular Survey of Microbial Diversity in Hypersaline Ecosystems

Project Investigator: Norman Pace

Project Progress

In the main area of research, microbiology of hypersaline ecosystems, substantial progress was made. ~4000 new rRNA sequences were determined and thereby organisms were identified from hypersaline situations: microbial mat and crystallizing halite-gypsum (brine). Many new bacterial and archaeal clades were discovered, including ~15 new bacterial phylogenetic divisions ("kingdoms"). Surprisingly, cyanobacteria do not constitute the main biomass (rRNA gene content), rather, Green Nonsulfur Bacteria dominate numerically. This has implications for the interpretation of isotopic fractionation data. Numerous novel eucaryotes also were found. Most of the eucaryotic biomass resides with nematodes, abundant in this ecosystem. Several publications are being prepared based on findings.

In a second area of work, the biology of high-temperature ecosystems, we have completed analysis of Yellowstone systems >70°C. Notably, organisms identified molecularly as hydrogen-metabolizing constitute the most common life in those hot springs. We have now measured molecular hydrogen in a number of Yellowstone hot springs and find abundant hydrogen for metabolism (15-300 nM). Also in Yellowstone we have discovered and described a new form of endolithic community, in silica sinter perfused with volcanic gases inluding hydrogen sulfide, which results in low pore water pH (<1). The community is lichen-like, but the photobiont is the organism *Cyanidium caldarium* and a supporting filamentous comunity is comprised of unidentified mycobacteria, never previously seen in such conditions. The communities are rapidly encased in silica and thereby provide long-lived traces of past life that could be examples of important biosignatures on, e.g. Mars.

Roadmap Objectives

- **Objective No. 3.2:** Origins and evolution of functional biomolecules
- **Objective No. 3.4:** Origins of cellularity and protobiological systems
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.2:** Foundations of complex life
- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

NA

Field Expeditions

Field Trip Name: Yellowstone Natl. Park	
Start Date: 090504	**End Date:** 091004
Continent: usa	**Country:** usa
State/Province: wyo	**Nearest City/Town:** Yellowstone
Latitude:	**Longitude:**
Name of site(cave, mine, e.g.):	**Keywords:** hot spring, microbial mats
Description of Work: Collect sample for analysis of high-temperature microbial mats	
Members Involved:	

Field Trip Name: Guerrero Negro	
Start Date: 020205	**End Date:** 020805
Continent: N. Am.	**Country:** Mexico
State/Province: Baja Sur	**Nearest City/Town:** Guerrero Negro
Latitude:	**Longitude:**
Name of site(cave, mine, e.g.):	**Keywords:**
Description of Work: Collect hypersaline microbial mats for molecular analysis	
Members Involved:	

Cross Team Collaborations

Results of molecular phylogenetic analyses are correlated with chemical measurements from the NASA Ames team (DesMarais, Holer, Bebout).

Origin of multicellularity and complex land-based ecosystem

Project Investigator: William Friedman

Project Progress

During the 2004-2005 year significant progress has been made characterizing the ecological and evolutionary history of fungal symbionts in early land plants. 80-90% of all land plants have mutualistic symbiotic associations with fungi where the fungal symbionts provide increased access to essential minerals and the fungal symbionts gain fixed carbon. We are characterizing the fungal symbionts in early lineages of land plants that have a life cycle where one phase is above ground and photosynthetic and another phase is completely underground for as long as fifteen years. This subterranean phase in these poorly understood plants is completely dependant on a set of fungal symbionts to provide a source of fixed carbon. These early lineages represent a potential ancient life cycle mode that succeeded based on its fungal dependant subterranean phase. Given the number of known asteroid impacts from K-T to Late Devonian, early land plant lineages with long-lived subterranean phases were potentially less affected by drastic changes in the above ground environment and therefore have persisted for hundreds of millions of years. To date, the fungal symbionts throughout the life cycle in early land plant lineages (Lycopodiaceae, Psilotales and Ophioglossales) have been identified using sequence data. In addition to studying the fungal symbionts within early land plants, we have identified the fungal symbionts in photosynthetic neighboring plants to place our data in a larger ecological and evolutionary framework. Based on our sequence data, subterranean phases of the life cycle in these early land plant lineages obtain fixed carbon through an extensive fungal network. Furthermore, multiple species of fungi and multiple species of plants have independently evolved the ability to form plant-fungal associations where the fungus provides the plant with carbon. Thus, given the diversity of fungal species capable of translocating carbon between photosynthetic plants and subterranean plants, it is possible, if not probable, that carbon transfer between different plant species through fungal networks may well extend beyond underground plants.

Highlights

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    - Glomalean fungi, the same fungi that form mycorrhizal associations with flowering plants, form symbiotic plant-fungal associations with early lineages of land plants.
    - The subterranean life cycle stage of early lineages of land plants gain fixed carbon from neighboring photosynthetic plants through shared glomalean fungal networks.
    - Multiple species of glomaelan fungi and multiple species of plants have independently evolved the ability to form plant-fungal associations where the fungus provides the plant with carbon.

Roadmap Objectives

- **Objective No. 5.2:** Co-evolution of microbial communities

EPO Reports: University of Colorado, Boulder

Journalists Workshop at Yellowstone

In August 2005, CUB teamed with NASA Ames to host a journalists' workshop in "Life in Extreme Envrionments" at Yellowstone National Park

??| t– Agenda

Public Symposium: "Astrobiology and Cosmology, Science and Religion: Our Place in the Universe"

This public symposium, held on the CU-Boulder campus, explored the connections between astrobiology and religion. We have a little over 700 people attend. The program:

Astrobiology, life, and civilization Dr. Christopher F. Chyba The Carl Sagan Chair for the Study of Life in the Universe at the SETI Institute

The origin and fate of the universe Dr. Fred C. Adams The University of Michigan at Ann Arbor

Astrobiology and Cosmic Purpose Dr. John F. Haught The Thomas Healey Professor of Theology at Georgetown University

The future of space exploration Dr. Wesley T. Huntress, Jr. Director of the Geophysical Laboratory of the Carnegie Institution of Washington

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Center for Astrobiology Seminar Series (2004-2005)

The CU Center for Astrobiology's Fall 2004 Seminar Series: The dates and speakers are as follows: September 15: Dr. John Bally University of Colorado, Boulder - Dept. of Astrophysical & Planetary Sciences, Center for Astrobphysics & Space Astronomy, Center for Astrobiology Title: Small is Beautiful: Survival of Protoplanetary Disks in Hazardous Star Forming Environments September 22: Dr. Robert T. Pappalardo University of Colorado, Boulder - Astrophysical & Planetary Sciences Dept., Laboratory for Atmospheric and Space Physics, Center for Astrobiology Title: Europa: Where Are We Now? October 6: Dr. Bruce Jakosky University of Colorado, Boulder- Laboratory for Atmospheric and Space Physics, Dept. of Geological Sciences, Center for Astrobiology Title: Liquid water and the biological potential of Mars October 20: Dr. Thomas McCollom University of Colorado, Boulder - Laboratory for Atmospheric and Space Physics, Center for Astrobiology Title: Iron-oxidizing bacteria: Inhabitants of the deep subsurface biosphere, early Earth,

and Mars? November 3: Dr. Mike Yarus University of Colorado, Boulder - Dept. of MCD Biology, Center for Astrobiology Title: Origin(s?) of the Genetic Code November 17: Dr. Carol Cleland University of Colorado, Boulder - Philosophy Dept., Center for Astrobiology Title: Searching for extraterrestrial life without a definition of 'life' December 1: Dr. Stephen Mojzsis (University of Colorado, Boulder) - Dept. of Geological Sciences, Center for Astrobiology Title: Renaming the Hadean: A progress report from the Mission to Really Early Earth ---------- CU Center for Astrobiology Spring 2005 Seminar Series:

January 26: Dr. Shelley D. Copley University of Colorado, Boulder - Dept. of Molecular, Cellular, and Developmental Biology, Cooperative Institute for Research in Environmental Studies, Center for Astrobiology Title: A Mechanism for the Association of Amino Acids with their Codons and the Origin of the Genetic Code February 9 Dr. Brian Hynek University of Colorado, Boulder - Laboratory for Atmospheric and Space Physics Title: Unraveling the geological, hydrological, and geochemical histories of Meridiani, Mars: An abode for life? March 2 Dr. Norman Pace University of Colorado, Boulder - Dept. of MCD Biology, Center for Astrobiology Title: What do Phylogenetic Trees Tell Us about the Origin and Evolutionary Course of Life? March 9 John R. Spear University of Colorado, Boulder - Dept. of MCD Biology, Center for Astrobiology Title: What can we learn from microbial ecology in some "extreme" environments? April 6 Dr. William Friedman University of Colorado, Boulder - Dept. of Ecology and Evolutionary Biology, Center for Astrobiology Title: Asteroid impacts, symbiosis, and the prevalence of subterranean plants April 20 Dr. Diane McKnight University of Colorado, Boulder - Institute of Arctic and Alpine Research, Dept. of Civil, Environmental, and Architectural Engineering Title: Glacial Meltwater streams in the McMurdo Dry Valleys: Ecosystems waiting for water ----------

Special CU Astrobiology seminars: 4 February, 2005 Dr. Charles Lineweaver Australian National University, Planetary Science Institute Title: The Galactic Habitable Zone and the Age Distribution of Complex Life in the Milky Way

(joint CU Astrobiology and Geology Seminar): 31 January, 2005 Dr. Stanley Awramik University of California, Santa Barbara - Dept. of Geological Sciences, Preston Cloud Research Laboratory Title: Life in the Balmy Waters of Lake Meentheena (Late Archean Tumbiana Formation, Western Australia) ---------- NAI - FAR video seminar: 13 September, 2004 Dominic Papineau University of Colorado, Boulder - Dept. of Geological Sciences, CU Center for Astrobiology Title: Biogeochemical responses to the changing Paleoproterozoic atmosphere ----------

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Public Presentations on Astrobiology

Scientist Involvement with the Public include:

Bruce Jakosky

8 Dec 04, Participant in panel on "An Academic Approach--Space University Research and Programs", Colorado Space Rendezvous, Denver.

10 Apr 05, radio discussion w/ Seth Shostak, life in the universe

20 Apr 05, hour-long radio discussion with Rohn Robbins, KZYR Radio, Vail,on life in the universe.

Michael Yarus, Appeared as guest on Radio America program "Are we alone?" Feb 1, 2004

John Bally - Public talk at the Denver Museum of Nature and Science 25 April 05 in honor ofthe 10-th year anniversary of the Hubble Space Telescope

Norm Pace

Sept. 27-29, 2004, Space Studies Board Committee on Origin and Evolution of Life, workshop on the ?Limits to Organic Life.?

February 17-18, 2005, Spiegelman Lecture, University of Illinois

March 9-10, 2005, Frontiers of Science Lecture, University of Utah

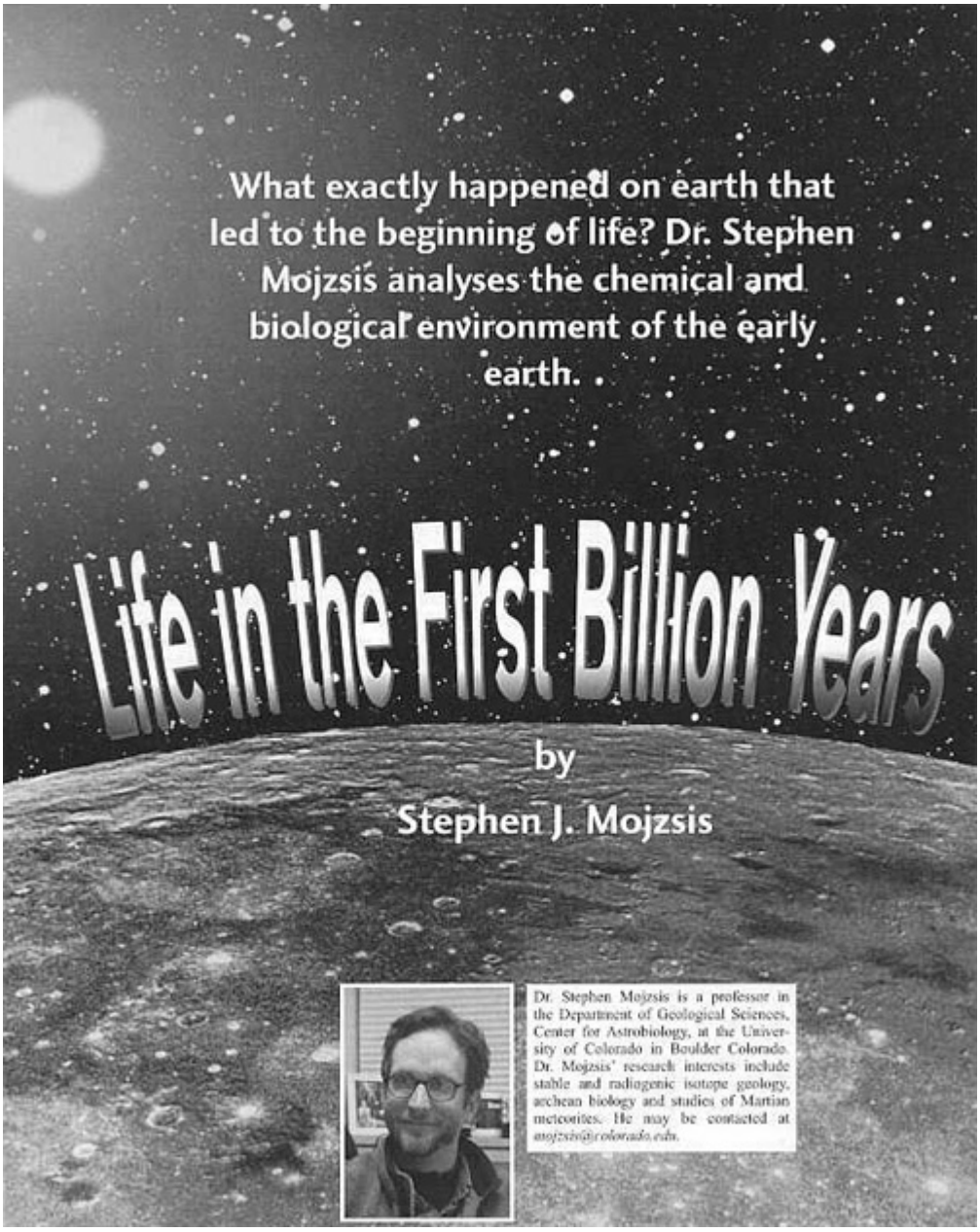
April 5, 2005, Larsen Lecture, University of Minnesota

Steve Mojzsis

Mojzsis, S.J. (2004) Life in the first billion years: Journal of High School Science (Canada) 3 (1), 46-51. [public service/outreach activity]

I have been closely involved in two NOVA television specials in cooperation with WGBH (Boston) public television and Channel 4 in the UK that highlight my work and that of colleagues in Astrobiology. These programs have already aired in the UK. US airdate was October 2004.

Robert Pappalardo "Jupiter's Water Worlds" Astronomy Magazine, July 2004



??| t☼ Mojzsis article

Jupiter's water worlds

When the twin Voyager spacecraft cruised past Jupiter in 1979, they did more than rewrite the textbooks on the giant planet. Their cameras also unveiled the astounding diversity of the four planet-size moons of ice and stone known as the Galilean satellites. The Voyagers revealed the cratered countenance of Callisto, the valleys and ridges of Ganymede, the cracked face of Europa, and the spewing volcanoes of Io. But it would take a spacecraft named for Italian scientist Galileo, who discovered the moons in 1610, to reveal the true complexity of these worlds and to begin to divulge their interior secrets. Incredibly, the Galileo data strongly suggest that Jupiter's three large icy moons (all but really Io) hide interior oceans.

Water lurks beneath the surfaces of Europa, Ganymede, and Callisto, and Europa's ocean could be an abode for extraterrestrial life.

BY ROBERT PAPPALARDO

??| t↕ Pappalardo Article

Publications: University of Colorado, Boulder

There are **80** publication entries for the University of Colorado, Boulder

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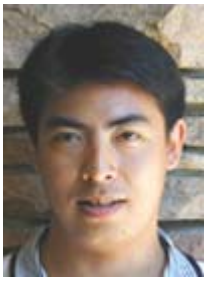

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Executive Summary: NASA Goddard Space Flight Center

Executive Summary: NASA Goddard Space Flight Center
Principal Investigator: Michael Mumma
Reporting Period: 2005 (7/04-6/05)

The central goal of the Goddard Center for Astrobiology is to understand how organic compounds are created, destroyed, and altered during stellar evolution leading up to the origin of life on a planet, such as Earth. Planetary systems form by collapse of dense interstellar cloud cores. Some stages in this evolution can be directly observed when stellar nurseries are imaged, while other stages remain cloaked behind an impenetrable veil of dust and gas. Yet to understand the origin of life on Earth, we must first develop a comprehensive understanding of the formation of our own planetary system. To understand the probability of finding life elsewhere we must understand both the similarities and differences between the evolution of our own system and that of a typical star.

Dense cloud cores are very cold (10-50 K); their dust grains are coated with ices comprised of water and organic compounds. Many of these organics have potential relevance to the origin or early evolution of life, if delivered to planets. The survival of these organics through the violent birth-phase of a star is less certain. Properties of the young star (its mass, spectral energy distribution, whether it formed in isolation or as a multiple star, etc.) help control the evolution of organic material in the proto-planetary disk. The location within the disk is important since the nature and effectiveness of such processing depends strongly on distance from the young star, on distance above the nebular mid-plane, and on time. The ultimate delivery of these primitive organics to young planets and their moons also evolves with time, as the bodies grow in size and as the nebula clears.

We seek to better understand the organic compounds generated and destroyed in the interstellar and proto-planetary environments, through observational, theoretical, and laboratory work. We have begun to examine the potential for and limitations to delivery of exogenous pre-biotic organics to planets, examining factors that enhance or restrict this potential. To follow these factors over time, from the natal cloud core through the end of the late heavy bombardment (~ 4.1 Ga) and evaluate the possible role of exogenous organic material in terrestrial biogenesis, we have divided the research into four themes as well as our education and public outreach program. These themes are:

- **Theme 1:** Establish the taxonomy of icy planetesimals and asteroids to evaluate their potential for delivering pre-biotic organics and water to the young Earth and other planets.

- **Theme 2:** Investigate processes affecting the origin and evolution of organics in planetary systems

- **Theme 3:** Conduct laboratory simulations of processes that likely affected the chemistry of material in natal interstellar cloud cores and in proto-planetary disks.
- **Theme 4:** Develop advanced methods for the in-situ analysis of complex organics in small bodies in the Solar System.

This second year of our NAI participation saw major emphasis on infrastructure: recruiting students, staff, and permanent employees, updating computational facilities, building laboratories, and furnishing them with equipment. In addition to the 5 undergraduate students recruited through our summer internship program we recruited 2 additional undergraduates and 2 high school students for part-time work. Beyond this we recruited a graduate student, 3 post-doctoral researchers, a senior soft money scientists (Oliver Botta), and hired one civil servant (Daniel Glavin).

Our Team members conducted a vigorous and highly productive research program, and participated in numerous meetings and workshops. We conducted many laboratory and field investigations (mainly astronomical), as outlined below and in the individual reports of Progress.

At Goddard, we sponsored a vigorous Seminar Series in Planetary Sciences and Astrobiology (see Agenda).

In addition to planting these seeds for the future, our Team members made significant progress in meeting our scientific goals:

Progress in Theme 1:

A primary objective of Theme 1 is to establish a taxonomy of icy planetesimals based on their chemical compositions. Such measurements are important for establishing the role of comets in replenishing Earth's oceans after Earth-Moon formation, and for delivering the seed organic molecules from which life emerged.

In our second year, Mumma, DiSanti, and their collaborators quantified CO, C_2H_6, and other volatile organic constituents (along with H2O) at high spectral resolution in three comets: the short-period Jupiter Family Comet (JFC) (73P/Tempel 1) and two long-period, Oort cloud comets (C/2001 Q4 and C/2004 Q2). Infrared spectra of 73P/Tempel 1 were obtained at high spatial and spectral resolution before and after Deep Impact — abundances were measured for H2O and six other parent volatile species. Relative to water, ethane was severely depleted in material released before impact, but its abundance in the impact ejecta was higher by a factor of three and was consistent with the value found for "typical" Oort cloud comets. Although these comets are now stored in very distinct reservoirs, it appears that they may have originated in a common region of the proto-planetary disk (see Report by M. Mumma).

Graduate student Boncho Bonev (Univ. of Toledo, in residence at Goddard) is nearing completion of his Ph. D. dissertation on OH prompt emission in comets as a direct tracer of H_2O production, and he delivered a FAR Seminar on this topic.

Along with HCN and NH_3 (both of which we also study at IR wavelengths), exogenous delivery of H_2CO is thought to play a particularly significant role in seeding Earth with pre-biotic chemicals. Analysis of infrared spectra of Oort cloud comet C/2002 T7 (acquired in year one) provided a clear detection of H_2CO. Retrospective analysis by DiSanti has now revealed formaldehyde in six other comets. Comparison with CO and CH_3OH has provided a first look into the oxidation state of volatile carbon in these comets, showing that it varies greatly among them, possibly a signature of radial gradients in the protoplanetary disk (see report by M. DiSanti).

Co-I Blake and collaborators acquired millimeter-wave observations of HCN in comets C/NEAT (2001 Q4) & C/LINEAR (2002 T7), based on OVRO and BIMA Array spectra and images (Friedel et al. 2005). Their next step is to compare the physical model developed to explain the HCN emission with those developed by GSFC co-Is (Mumma, DiSanti, et al.) to explain a suite of infrared observations of these comets. These results form an interesting counterpoint to the compelling Deep Impact spectra gathered at Keck by the Astrobiology team and recently published in Science (Mumma et al. 2005). (see Report by Blake).

Co-I Charnley and collaborators performed a series of radio observations of comets C/2001 Q4 (NEAT) and C/2002 T7 (LINEAR) using the JCMT and the ARO 12m and SMT telescopes. They detected deuterated formaldehyde (HDCO) in C/2002 T7, its first detection in a comet. The inferred D/H ratio is large, consistent with formation in a very cold environment, and a paper is being prepared for submission to Nature. (see Report by Charnley).

Co-I Charnley and collaborators made preliminary studies of gas-grain deuterium fractionation processes in the comet-forming regions of model proto-planetary disks. Their disk chemistry model includes multiple deuteration driven by H_2D^+, HD_2^+ and D_3^+ reactions. They also published several Reviews describing models of disk chemistry and the connection between these processes and the composition of primitive solar system materials. (see Report by Charnley)

Co-I Fegley and collaborators (Washington Univ.) investigated chemical and isotopic composition of presolar grains found in chondritic meteorites, and atmospheric chemistry during the accretion of Earth-like planets. Collaborators Lodders and Sachiko Amari published an invited review regarding the origin and nebular processing of carbonaceous presolar grains. They describe the search for presolar grains, the different types of presolar grains, the chemical and isotopic composition of the different types of grains, and their origin from different stellar sources. (see Report by Fegley)

Co-I Richardson and post-doc Graeme Lufkin (Univ. Maryland) modified their gravitational simulation code to handle a prescribed migration of a giant planet through a disk of planetesimals. Initial results suggest

that giant planet migration is not a catastrophic event for disks of planetesimals. The eccentricity and inclination of the planetesimals are greatly increased by the giant planet, but less than twenty percent actually get ejected from the system. Further growth of the planetesimals will be postponed until dynamical friction and gas drag can cool their orbital motion. Richardson and Zoë Leinhardt (Harvard) quantified the effect of fragmentation (based on a rubble pile model) during the early and middle stages of planetary growth. For the parameters tested, fragmentation did not play a dominant role compared to simulations that assumed perfect accretion. In addition, debris created in these simulations did not significantly affect the dynamics of the larger bodies. (see Report by Richardson)

Co-I Fegley and Laura Schaefer modeled the chemistry of silicate vapor and steam-rich atmospheres formed during accretion of Earth and Earth-like exoplanets (planetary accretion models show temperatures of several thousand degrees during Earth accretion). They predict spectroscopically observable gases that can be used to search for Earth-like planets forming in other planetary systems. Silicon monoxide (SiO) gas is the major species in silicate vapor atmospheres for T > 3080 K, and monatomic Na gas is the major species for T < 3080 K. During later, cooler stages of accretion (1500 K), the major gases (abundances >1%) in a steam-rich atmosphere are H_2O, H_2, CO_2, CO, H_2S, and N_2. Carbon monoxide converts to CH4 as the steam atmosphere cools. They also calculated the composition of volatiles outgassed from chondritic planetary bodies, finding that the major out-gassed volatiles for certain starting compositions are CH_4, N_2, NH_3, H_2, and H_2O. This important result predicts that Earth's earliest permanent atmosphere was a reducing atmosphere that favored synthesis of organic compounds by Miller – Urey type reactions initiated by lightning, UV light, and heat. (see Report by Fegley)

Co-I Walker is fingerprinting late additions to the Moon using the relative abundances of the highly-siderophile elements (HSE) that occur in generally high abundance in likely impactors, but extremely low abundance in the indigenous lunar crust. Towards this end, approximately 2g of several Apollo 14 and 17 melt breccias were obtained from the Johnson Space Center curatorial facilities. Walker is pursuing this goal in collaboration with Dr. Odette James (USGS retired) - a longstanding expert on these rocks. In the second year, they cleanly separated chips from 73215, 73255 and 72395, and analyzed them for Os isotopes and highly siderophile element abundances (Pt, Pd, Ir, Ru, Re and Os). The Apollo 17 rocks likely sample the Serenitatis basin impactor. All rocks analyzed have 187Os/188Os ratios of approximately 0.129 to 0.133. These ratios are consistent with the Serenitatis impactor having long term Re/Os similar to enstatite or ordinary chondrites, rather than carbonaceous chondrites.

Progress in Theme 2:

A vital component of Theme 2 is the observation of star- (and planet-) forming molecular clouds and of the later proto-planetary disks. This work highlights the role of prebiotic chemistry long before planetary surfaces are amenable to the synthesis of such compounds, and suggests that the chemistry leading to life is widespread throughout the universe. Since the physical conditions vary among and within such clouds, it is important to investigate the chemical and physical processes in a variety of such environments.

Irvine and colleagues in Korea have been studying molecular clouds in the vicinity of the center of our Milky Way Galaxy, where various energetic processes can influence the chemical composition of molecular clouds. They observed millimeter-wave transitions of the molecules CO, HCO^+, HNCO, and SiO toward the Sgr A region using the SEST telescope at LaSilla, Chile. The comparison of the observed transitions shows that the several prominent gas condensations in this region have very distinctive chemical properties with respect to each other, which may result from differing physical conditions in the various locations (Minh et al., 2005). (see Report by Irvine)

Pedelty, in collaboration with Mundy, planned and implemented Very Large Array (VLA) observations of the hot molecular cores (HMC) in the young stellar object IRAS 16293-2422. These 7 mm observations targeted the prebiotic molecules formic acid, methyl formate, and ethyl cyanide in sources A and B within this object - several species were detected (see Report by Pedelty).

Charnley and collaborators published Submillimeter Array maps of organic molecules in the 'hot corinos' of the low-mass IRAS 16293-2422 binary system (Huang et al. 2005). Their new H13CN interferometric data clearly shows Keplerian rotation in sub-source A, and hence the presence of a protostellar accretion disk. A

VLA proposal was submitted with NAI – GCA collaborators L. Mundy and J. Pedelty to perform high-resolution observations of this source at cm wavelengths. (see Reports by Pedelty and Charnley).

Mundy also continues his work on Spitzer projects of relevance to the early evolution of planet-forming disks. Of particular interest are the studies of cold outer disk systems that are being found through their emission in the IRAC 8 micron and MIPS 24 micron bands. The nature and evolutionary state of these systems is unclear at this point; they could be post-classical T Tauri systems that have not yet lost their outer disks; they could be more evolved systems with outer debris disks created by planetesimal collisions. Continued work with the large dataset associated with the Cores to Disks Spitzer Legacy project is likely to provide answers. (see Report by Mundy)

Using Spitzer, Blake and collaborators detected the signatures of organic molecules in ices located in the outer regions of the potentially protoplanetary disk CRBR 2242, and the abundances so obtained can be directly compared to those in comets (Pontoppidan et al. 2005). More excitingly, perhaps, they detected the gas phase absorption bands of the organics HCN, acetylene, and CO_2 that likely arise from the inner disk encircling IRS46 (another ~edge on disk in Ophiuchus, Lahuis et al. 2005). If substantiated by further observations, this source would provide the first opportunity to examine the hot (several hundred Kelvin) organic chemistry predicted to occur in the planetesimal formation region sampled by carbonaceous chondrites in our own solar system. (see Report by Blake)

Young stars are often intense sources of X-ray emission, and energetic processing of material in the proto-planetary disk could be efficient if X-rays are present in the very earliest phases before accumulation and clearing are complete. To produce pre-biotic materials in the cold circumstellar environment of the young Sun, high-energy radiation may be required to stimulate chemical reactions of molecules. Strong X-rays from the stellar core can be a significant source of such radiation, and therefore the history of their X-ray activity can be quite important. With the XMM-Newton X-ray observatory, Hamaguchi, Petre, and collaborators clearly detected for the first time strong X-ray emission from one of the earliest stages of a star at the age of 10,000-100,000 years, the so-called Class-0 protostellar phase. This demonstrates the presence of X-ray luminosity before disk clearing and suggests the importance of chemical processing in this way. (see Report by Petre).

Another aspect of Theme 2 is the search for and characterization of exoplanets. D. Deming and collaborators achieved the first detection of infrared light from an exoplanet. They applied the Spitzer Space Telescope to observe HD 209458 in and out of secondary eclipse (the star occults the planet). They quantified the difference of infrared light and showed that the amount coming from the planet agreed with models for its size and temperature. A second group achieved independent detection of a second transiting exoplanet using another instrument on Spitzer. Its significance lies in demonstrating that exoplanets can be characterized by astronomical methods. The Deming paper appeared in Nature in 2005, and the second group published their result in the Astrophysical Journal also in 2005. These Spitzer detections are the first direct measurements of planets orbiting other stars, and they open a new era in astronomy and astrobiology, where we can now directly study and compare alien worlds to those in our own solar system. Deming and Mumma and their collaborators are developing other spectral methods for characterizing the atmospheres of exoplanets. (see Report by Deming)

Progress in Theme 3:

Theme 3 is entirely focused on laboratory work. One aspect simulates the vacuum and low-temperature environment of space using a high vacuum chamber and a cryostat. Ice samples condensed on a cooled mirror inside the cryostat are irradiated with 1 MeV protons to simulate cosmic-ray bombardment or are photolyzed to simulate vacuum-UV exposure.

Co-I Dworkin finalized construction of the laboratory infrastructure in our Organics Analysis Laboratory. Significant electrical upgrades were installed along with state-of-the-art analytical equipment for determining the organic composition of the material generated in the Cosmic Ice and Cosmic Dust Laboratories, amino acid contamination in Stardust aerogels, and measurement of meteoritic organics. Dworkin and collaborators optimized conditions for the analysis of amino acids and nucleobases and are working to increase sensitivity and decrease contamination. This lab is now in full operation and is producing original research. Initial investigations include identifying refractory organic compounds in

radiation processed ices, in organics produced on reactive smokes by Fischer-Tropsch like catalysis, and in chondritic meteorites. Dworkin is actively collaborating with other laboratories from Themes 3 and 4 of the GCA and from the CIW and Ames NAI teams. (see Report by Dworkin)

Co-Is Moore and Hudson simulate the low-pressure and temperature environment of space using a high-vacuum chamber and a cryostat in the Cosmic Ice Laboratory. Ice samples condensed onto a cooled mirror inside the cryostat are irradiated with 1-MeV protons, to simulate cosmic-ray bombardment, or are photolyzed to simulate vacuum-UV exposure. Motivated by detections of glycolaldehyde ($HOCH_2CHO$) and ethylene glycol ($HOCH_2CH_2OH$) in the interstellar medium and, for ethylene glycol, in comet Hale-Bopp, they examined the low-temperature formation of these molecules. They found that irradiated methanol-containing ices produced ethylene glycol, and that ices containing this molecule produce glycolaldehyde, a simple sugar. In addition they determined that energetic processing of aliphatic alcohols produces aliphatic aldehydes and vice versa. Other new results are the detection of several amino acids in residues that resulted from irradiations of nitrile ices. (see Report by Moore and Hudson)

Co-I Nuth and Natasha Johnson (NAS-NRC) investigated production of both volatile and macromolecular carbonaceous materials via surface mediated reactions on silicate dust grains in the laboratory, to evaluate such processes in the nebular environment. They found that almost any free surface catalyzed the Fischer-Tropsch-Type conversion of CO and molecular hydrogen to complex hydrocarbons. These reactions produced a macromolecular carbon coating on the grain surface that itself acted as a catalyst for formation of hydrocarbons containing nitrogen when the reaction occurred in the presence of N_2, H_2 and CO. Far from acting as a poison, these coatings can greatly enhance the reactivity of some grain species such as amorphous magnesium silicate or silica particles. They continue to study initial composition of the volatile organic species produced on both amorphous iron-silicate and magnesium-silicate grains as a function of time, temperature and degree of previous reaction products deposited on the grains' surfaces. (see Report by Nuth)

Co-I Nuth and Yuki Kimura demonstrated that CaO and $Ca(OH)_2$ are excellent candidates to explain the 6.8 μm feature, one of the most enigmatic spectral features in young stellar objects. Earlier attempts to identify the precursor emphasize organic materials. Nuth and Kimura hypothesize that this feature is produced in the hot interiors of young stellar environments via distillation of Ca from pre-existing hibonite dust followed by the condensation of CaO and $Ca(OH)_2$ grains. (see Report by Nuth)

Progress in Theme 4:

The development of instruments for organic analysis on space missions is the crux of Theme 4. To prepare for flyby, rendezvous, and sample return missions to comets the development of advanced organic analysis techniques has been initiated. These techniques include: laser desorption mass spectrometry; pyrolysis mass spectrometry; and the solvent extraction of organic molecules followed by chemical derivatization. In the initial stages of this work a variety of Mars analog materials such as Atacama desert soils, Hawaiian basalts, meteoritic samples, and solid material generated by some of the nitrile irradiations conducted by Theme 3 have been used to cross compare these techniques. Some of these materials also serve as cometary analogs and the chemistries developed for their analysis may be relevant for future cometary research.

Co-I Mahaffy and collaborators are developing protocols for analysis of complex organic materials on space missions. During the second year, Dr. Arnaud Buch returned to a university position in Paris and plans were made for his replacement with another highly qualified astrobiologist, Dr. Oliver Botta. Botta arrived in August. His work will combine studies of organics in suitable analogues for comets and Mars with analysis of meteoritic and other terrestrial samples using GC-MS. Dr. Botta has several different types of meteorites that will be analyzed for their amino acid composition. In addition, he will study the organic composition of Antarctic meteorites with respect to contamination from the ice. In related work, Daniel Glavin has initiated a program to investigate the distribution and isotopic composition of nucleobases in carbonaceous meteorites that was also supported (in 2004) by the Exobiology program. This research is a collaborative effort between NASA Goddard (Jason Dworkin and Oliver Botta), Carnegie Institution of Washingon (Marilyn Fogel) and the Leiden Institute of Chemistry in The Netherlands (Zita Martins). Martins spent the

summer in residence at Goddard pursuing this research. (see Reports by Mahaffy and Dworkin)

Co-I Brinckerhoff (JHU/APL) work at JHU/APL is developing laser desorption (LD) and time-of-flight mass spectrometry (TOF-MS) techniques that complement ongoing non-laser GCA work at GSFC; they sample distinct yet related sets of compounds from complex samples. Advances made during year two included a "flight-scale" breadboard leveraged and completed with completed with separate NASA instrument support. (see Report by Brinckerhoff). Initial analyses of carbonaceous chondrites and simple carbon-matrix standards with laser desorption methods have contributed to a developing database of refractory macromolecular materials that may be present in comets and other small bodies. This database should lead to increased understanding of (i) parent body synthesis and processing; (ii) impact survival of more fragile incorporated compounds; and (iii) enhanced in situ protocols for determining the full breadth of cometary organics.

Education and Public Outreach:

Finally, our team has made great progress in our education and public outreach endeavors. In 2005 we hosted the second group of students under our Summer Undergraduate Internship in Astrobiology (SUIA) program. Students are paired with mentors based on their expressed research interests, and they spend 90% of their time actually doing research. Summaries of their research appear in the Reports by Deming, DiSanti, Dworkin, Mahaffy, Moore, and Mumma, and again in our EPO report. Three team members (Irvine, Hudson. Moore) developed and taught undergraduate Astrobiology courses at their institutions (Univ. Mass - Amherst, Eckerd College, and University of Maryland College Park). EPO lead S. Stockman (with other team members) also conducted year two of a high school curriculum development project with the Minority Institution Astrobiology Collaborative (MIAC). We are also jointly developing a capability to systematically observe comets through emission-line filters at optical wavelengths. This effort is led by MIAC member Dr. Donald Walter (South Carolina State University), working with (with GCA co-I DiSanti), and will utilize telescopes in Arizona. Imaging studies on the Kitt Peak 1.3-m telescope are in the science-testing phase.

Planetary Science and Astrobiology Seminars
October 1, 2004 – September 30, 2005

October 7	**Anthony Remijan**, NRC, NASA/GSFC, Earth and Space Data Computing Division **"Recent Observations in Interstellar Chemistry: New Constraints for Detecting Large Biomolecules and the Discovery of Two New Molecules Toward Sgr B2(N-LMH)"**
October 21	**Jocelyne DiRuggiero**, University of Maryland, Department of Cell Biology and Molecular Genetics **"Life on the Edge: Functional Genomics of Extremophilic Microorganisms"**
November 4	**Daniel Glavin**, NASA/GSFC Atmospheric Experiment Branch **"A Search for Extraterrestrial Amino Acids in Antarctic Meteorites: Implications for the Analysis of STARDUST Grains"**
November 18	**Alan Boss**, Carnegie Institution of Washington Department of Terrestrial Magnetism **"Giant Planet Formation and Implications for Astrobiology"**
December 2	**Doug Hamilton**, University of Maryland, Department of Astronomy **"Tilting Saturn"**
January 6	**Sean Solomon**, Department of Terrestrial Magnetism, Carnegie Institution of Washington. **"The MESSENGER Mission to Mercury: Seeking Clues to the Formation and Evolution of the Inner Planets"**
January 18 & 20	**Planetary Science and Astrobiology Posters Highlights from 2004 Building 28 Atrium, 2:00-4:00**
February 3	**Ah-Son Wong**, NRC/USRA, University of Michigan Planetary Science Laboratory. **"Atmospheric Chemistry of Mars: Methane and Oxidants"**
February 10	**Jason Dworkin**, LEP, Astrochemistry Branch **"Life Before RNA"**
March 3	**Bill Farrell**, LEP, Planetary Magnetospheres Branch. **"Mars Dust Storms, Electric Fields, and Associated Chemistry"**
March 17	**Yanping Guo**, Johns Hopkins University Applied Physics Laboratory **"The New Horizons Mission to Pluto and the Kuiper Belt"**
April 7	**Carol Grady**, GSFC/UV/Optical Astronomy Laboratory **"The Evolution of Planetary**

	Systems: An Observational View of the First 10-20 Myr of the Nearest Young Stars and Their Disks"
April 14	**Amitabha Ghosh**, Univ. of Tennessee, Department of Earth and Planetary Sciences **"Case for and Against Al26 and Electromagnetic Induction Heating"**
May 5	**John Cooper**, GSFC/Earth-Sun Exploration Division **"Habitability in High Radiation Environments: The Case for Life at Europa"**
May 19	**Derek Richardson**, University of Maryland, Astronomy Department **"Asteroids and Satellites: Origins and Implications"**
June 2	**Gözen Ertem**, GSFC/Astrochemistry Branch **"Formation of Phosphodiester Bond in Aqueous Solution by Montmorillnite Catalysis to Produce RNA-Like Oligomers: A Model Study"**
August 15	**Tom Halasinski**, St Joseph's University, Department of Chemistry **"Investigations of Nitrogen Containing Aromatic Molecules in ISM via Matrix Isolation Spectroscopy: Where is the Nitrogen in Space?"**
September 29	**Mike Mumma**, NASA/GSFC Solar System Exploration Division **"Deep Impact: A Comet's Volatile Secrets Exposed"**

NAI Distributed Workshop: Methane on Mars:

The GCA hosted the East-coast site for a distributed Workshop on Mars methane on May 18. The Workshop was sponsored by the NAI and organized by Bruce Runnegar, Mike Mumma, and Mark Allen. "Gordon Conference" Rules were adopted to encourage free and open interchange. About 50 people participated from four geographic sites (CAB, Spain; NASA Ames; CAB, Australia; Goddard). M. J. Mumma opened the Workshop with a balanced view of work by the three groups reporting detections of methane on Mars. Craig Manning (UCLA), Barbara Sherwood-Lollar (Toronto), Chris House (Penn State), and Mike Summers (George Mason Univ.) provided excellent overviews of terrestrial analogues, and Dorothy Oehler, T. C. Onstott, and Barbara Sherwood-Lollar contributed additional 10-minute remarks. Abstracts in the attached agenda provide a good synopsis of the formal talks.

Methane on Mars: NAI Distributed Workshop
May 18, 2005

8:00-14:30 PDT NASA Ames Research Center, California, USA

11:00-17:30 EDT NASA Goddard Space Flight Center, Maryland, USA

16:00-23:30 CEST Centro de Astrobiologia del CSIC-INTA, Madrid Spain

Introductory remarks

Bruce Runnegar, NASA Astrobiology Institute, Ames Research Center, Moffett Field, CA 94035, USA; Bruce.Runnegar@nasa.gov

Spectral observations of methane on Mars

Michael J. Mumma, Goddard Center for Astrobiology, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA; Michael.J.Mumma@nasa.gov

Abstract: Three groups have reported independent detections of methane on Mars. I will review the current status of these searches. On Mars, the photochemical lifetime of methane is very short (~300 years), and any methane now in its atmosphere must have been released within that time. However, the lifetime could be very much shorter if heterogeneous processes destroy methane efficiently, and this would require that estimated production rates be revised upwards. I will present evidence supporting the presence of strong latitudinal (meridional) gradients, obtained by our team. These gradients require: 1. significant local sources of methane, and 2. a removal mechanism that is much more rapid than photochemistry. The destruction lifetime might be shorter than the meridional circulation time (of order

weeks), i.e., several thousand times faster than photochemistry and this provides an important quantitative constraint for assessing the release rate. The combination provides an important constraint for assessing biogenic vs. primordial or geothermal origins.

Terrestrial analogs 1 – water-rock reactions

Craig E. Manning, Department of Earth and Space Sciences, University of California, Los Angeles, CA 90095-1567, USA; manning@ess.ucla.edu

(No Abstract available)

Terrestrial analogs 2 – deep crustal methane

Resolving abiogenic versus biogenic sources of methane and implications for Mars exploration.

Barbara Sherwood-Lollar, Department of Geology, University of Toronto, Ontario, Canada M5S 3B1; bslollar@chem.utoronto, ca

Sherwood Lollar, B.[1], Telling, J.[1], Lacrampe-Couloume, G.[1], Slater, G.F.[2], Onstott, T.C.[3] and Pratt, L.M.[4]. (1Department of Geology, 22 Russell St., University of Toronto, Toronto, Ontario Canada M5S 3B1 bslollar@chem.utoronto.ca. [2]School of Geography and Geology, McMaster University, Hamilton, Ontario L8S 4K1. [3]Dept. of Geosciences, Guyot Hall, Princeton University, Princeton NJ 08544. [4]Dept. of Geological Sciences, Indiana University, Bloomington IN 47405)

Abstract: To date the characteristics of abiogenic hydrocarbons have not been well defined. Studies of terrestrial abiogenic gases have shown that measuring the delta 13C value of methane alone is not always diagnostic. If the source of carbon is mantle-derived, as at the mid-ocean spreading centers, the delta 13C value of the methane would be expected to be relatively enriched in 13C. Away from mantle carbon input however, in crustal-dominated systems such as deep Precambrian Shield rocks, processes of water-rock interaction (including serpentinization) produce abiogenic hydrocarbons that may have much more isotopically light (12C-rich) signatures, reflecting local crustal carbon sources. Drawing on field data from terrestrial abiogenic gases and recent laboratory experiments, this paper will address key parameters that may be used as diagnostic tools for identifying biogenic hydrocarbons versus abiogenic geological sources of methane and other hydrocarbons, in particular the pattern of 13C and 2H variation between methane and higher hydrocarbon gases such as ethane.

Terrestrial analogs 3 - biogenic methane

Christopher H. House, Department of Geosciences, Pennsylvania State University, University Park, PA 16802, USA; chouse@geosc.psu.edu

Abstract: Methanogens, members of the Euryarchaeota, inhabit diverse of anaerobic habitats on Earth ranging from polar sediments to hydrothermal vents. The phylogenetic, environmental, and metabolic diversity of methanogens and methanotrophs will be discussed. Also, an overview of carbon isotopic fractionation during methanogenesis will be presented.

Fate of Disequilibrium Trace Gases in the Martian Atmosphere

Michael E. Summers, School of Computational Sciences, Department of Physics and Astronomy, George Mason University, Fairfax, Va 22030

Abstract: The recent discovery of methane in the atmosphere of Mars has provided a new approach for indirectly probing possible disequilibrium chemistry beneath the Martian surface. Methane in the Martian atmosphere has a chemical lifetime of less than about 300 Earth years, thus its existence in the atmosphere may suggest a continuous replenishment. Its chemical lifetime is several orders of magnitude longer than typical atmospheric transport timescales, and thus its mixing ratio is to first order expected be fairly uniform throughout the Martian lower atmosphere, except possibly near localized source regions. A measurement of its average value would thus provide an estimate of the total magnitude of its source. In

order to use measurements of methane as a probe of its source strength, it is important to understand its fate in the atmosphere. The chemical destruction of methane in the terrestrial atmosphere has been extensively studied. Analogous processes are likely to dominate the destruction of gaseous methane on Mars. Specifically, ultra-violet photolysis and chemical reactions between methane and both OH (hydroxyl) and O(1D) are probable loss processes on Mars. The oxidation of Martian methane will have an inconsequential impact on the overall chemical structure of the atmosphere, but understanding the details of the oxidation process may provide a means to use measurements of small variations of atmospheric methane to locate source regions. Also, understanding the kinetics of methane chemical destruction on Mars also provides a theoretical framework for understand the chemical loss of other possible disequilibrium gases such as H2S, NH3, HCN, and CH2O, that might exist in the Martian atmosphere. These latter species probably have chemical lifetimes substantially shorter than that of methane, and their distributions in the Martian atmosphere will probably show strong correlations with their respective source regions. And finally, understanding the isotopic fractionation of methane in the Martian atmosphere may provide a means to use isotopic measurements as constraints on the nature of the methane source.

Working session / brief contributions:
Dorothy Oehler

T.C. Onstott

Barbara Sherwood-Lollar

Project Reports: NASA Goddard Space Flight Center

Establishment of the Goddard Analytical Astrobiology Laboratory

Project Investigator: Jason Dworkin

Project Progress

This year Dworkin finalized construction of the laboratory infrastructure in Goddard Space Flight Center (GSFC) building 2, room W109. Significant electrical upgrades were installed along with state-of-the-art analytical equipment for determining the organic composition of the material generated in the Cosmic Ice and Cosmic Dust Laboratories, amino acid contamination in *Stardust* aerogels, and meteoritic organics. Figure 1 (right) shows the major pieces of equipment installed in the laboratory:

- **LC ToF-MS (Waters 2695XE HPLC attached to Waters LCT Premier):** Material injected in the high precision liquid chromatograph (HPLC) flows through an ultraviolet (UV)-Visible diode array and UV fluorescence detectors to the time of flight mass spectrometer (ToF-MS) with an electrospray ion source. The MS has a mass accuracy of >3 ppm, a resolution of 10,000, and a range of 20 to 30,000 m/z.

- **nLC ToF-MS (Waters nanoAcquity UPLC attached to Waters LCT Premier):** The nanoflow ultraprecision liquid chromatograph (UPLC) runs at pressures double that of HPLC and flows from 50µL/min to 10nL/min through capillary columns to a miniaturized electrospray nozzle. We anticipate purchasing a laser-induced fluorescence detector to sit between the nanoAcquity and the LCT Premier.

- **GCMS (Thermo Finnigan Trace DSQ):** This gas chromatograph-mass spectrometer (GCMS) has as a mass range from 1-1050 amu, with a scan rate up to 10,000 amu/sec.

Figure 1. Astrobiology Analytical Lab after construction as shown in 2004 (left) and 2005 (right). The right panel shows the center island with the major analytical eqipmen of the lab. These are: A. HPLC, B. UV/vis fluorscence detector, C. UV/vis photodiode detector, D. MS, E. nanoflow LC, and F. GC/MS.

Lab Personnel and Responsibilities

Name Institution Effort Specific Responsibility Dr. Jason Dworkin GSFC 70% GCMS & LC ToF-MS & nLC ToF-MS Dr. Daniel Glavin GSFC 10% meteorites & LC ToF-MS Dr. Gözen Ertem Catholic U. America 50% nucleotides & quinoline LC ToF-MS Ms. Mildred Martin Catholic U. America 50% GCMS Mr. James Doty DeMatha High School 100-10% LC ToF-MS of bases and amino acids Mr. Matthew Pasek U. Arizona occasional LC ToF-MS of phosphates

Research Projects

Amino Acid and Nucleobase Detection: We have been working on the simultaneous analysis of nucleobases and amino acids via LC ToF-MS (Figure 2). The refinement of our separation techniques was lead by our high school intern, J. Doty. He worked over the summer (100% commitment) on amino acid and nucleobase separations by LC ToF-MS. He will be assisting our analyses of these compounds in carbonaceous meteorites in afternoons after school (10% commitment). We anticipate that he will be able to present his results as a poster at the next AbSciCon and Origin of Life Gordon Conference. His future in

this laboratory depends on in what region of the country he attends college next year.

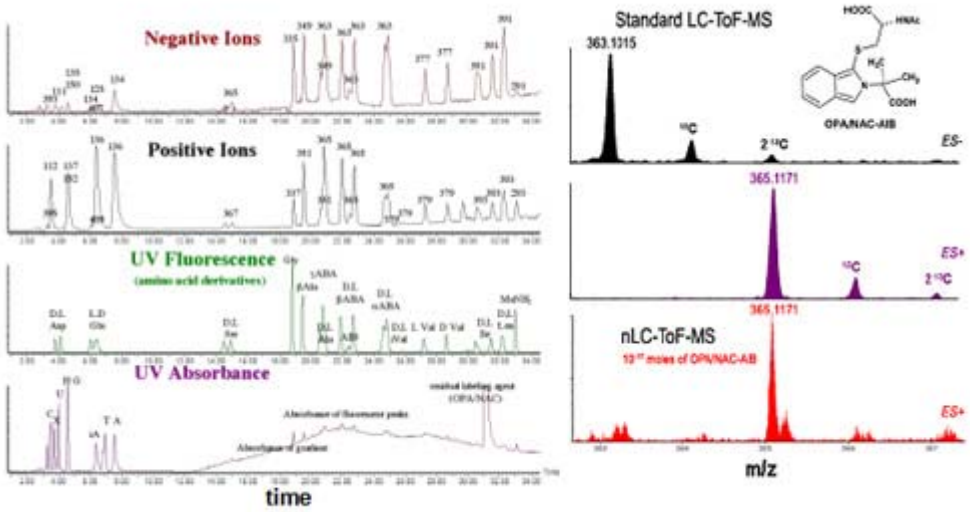

Figure 2. The simultaneous detection of 8 nucleobases, 26 amino acids, and 10 amine standards (ethyl through n-hexylamine which elute between 36 and 45 minutes are not shown) in negative and positive ions fluorescence, and absorbance via our LCMS system (left). Note that all species are detectible by all methods and that co-eluting compounds can be distinguished by their mass. The right panels show the mass spectrum of one fluorescent-labeled (OPA/NAC) amino acid. The top two are the electrospray negative and positive spectra with sample delivered via HPLC. The bottom is of 10 amol of the same compound delivered to the MS via nanoflow. The chiral OPA/NAC label allows us to chromatographically resolve chiral amino acids.

Attomolar Sensitivities: We have demonstrated the detection of the most abundant amino acids in an extract of 15 grains with a diameter of ~20µm of the carbonaceous Murchison meteorite. We are beginning to transfer our methodology to nLC ToF-MS. This will allow us to detect these compounds at ~10^{-17} mole (~10 amol) sensitivities (Figure 2, lower right).

Stardust: We are now (unfunded) members of the *Stardust* preliminary assessment team. We have been analyzing the amines in flight aerogels from 36 different cells on the collection grid as well as mud and water samples from the future landing site. We hope to use our ability to detect amino acids via nLC ToF-MS on particles from comet P/Wild 2 and aerogel returned by *Stardust* in January 2006.

Prebiotic Phosphates: We are working with D. Lauratta's graduate student, M. Pasek on the analysis and mechanism of the corrosion of the mineral schreibersite, Fe_3P, found in iron-nickel meteorites to form activated phosphates and organophosphates. Currently, we have been able to confirm via MS, the presence of pyrophosphate and related species. We are working towards understanding the inventory of organo-phosphates generated when schreibersite corrodes in the presence of small organic acids (e.g. acetic and glycolic).

NAI Research Synergy

Carbonaceous Meteorite Analysis: We are in the process of extracting nucleobases from the Murchison meteorite for stable isotopic analysis in collaboration with M. Fogel of the CIW NAI team. This work is leveraged against our ROSES Exobiology effort (PI: D. Glavin). We will be extending this work to analyze amino acids in hot water extracts of the CM2 meteorites: Murchison, LEW90500, and ALH83100 and comparing these to the soils or ices representative of their recovery environment. This work will be in collaboration with Dr. O. Botta and Dr. P. Ehrenfreund and her student, Ms. Z. Martins.

Cosmic Ice Irradiation: We have been working on the analysis of the products of the 0.8 MeV proton irradiation of acetonitrile (CH_3CN) 10 K ices via GCMS. Experiments were carried out with unlabeled, C1, C2, and double ^{13}C labeled CH_3CN ice. The products are rich and numerous, so far we have confirmed the presence of HCN, succinonitrile, 3-aminocrotononitrile, and glutaronitrile. There are still numerous tentative detections, including several heterocycles and the nitriles of glycine, β-alanine, aspartic acid. Furthermore, we have hydrolyzed the unlabeled and fully labeled material and detected an abundance of the following amino acids by LC ToF-MS: glycine, β-alanine, alanine, α, β, and γ-aminobutyric acids, aspartic acid, glutamic acid, ammonia, methylamine, ethylamine, isopropylamine, and n-propylamine. Current work is on

water-rich ices with low concentrations of acetonitrile.

Interstellar Ice Photolysis: We have analyzed amino acid samples and are working do develop conditions for the analysis of oxidized quinolines from ice photolysis experiments conducted by M. Bernstein of the NASA Ames NAI team.

***Mars Science Laboratory (MSL)* Mission:** We have contributed to the Sample Analysis at Mars (SAM) instrument suite by using our vacuum apparatus to characterize the freezing point and volatility under simulated martian conditions of the derivatization cocktail for the *MSL* GCMS.

Nucleotide Polymerization:

Dr. Gözen Ertem has been leading a research program on the analysis of the trimer and tetramers of nucleotides abiotically synthesized over montmorillonite clays in collaboration with R. Hazen of the CIW NAI team. The sequences of these oligonucleotides are non-random (as has been demonstrated with the dimers) and current work is in elucidating the sequences via MS.

Protosolar Nebular Dust: Gaseous products from the Fisher-Tropsch-type syntheses of organic compounds over simulated proto-solar grains were analyzed by freezing products onto a 1,4 dioxane or acetonitrile for GCMS analysis. Tentative identifications of xylenes, propylbenzene, indane, and naphthalene have been made. Furthermore, the decrease in production of volatile organics in the FFT simulations over time has been monitored. The next step will be to characterize the non-volatile organic production.

Highlights

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  - We have installed equipment purchased with leveraged funds for the analysis of organic compounds.
  - We have optimized conditions for the analysis of amino acids and nucleobases and are working to increase sensitivity and decrease contamination.
  - We have identified compounds in dust and ice simulations of the interstellar medium and the solar nebula. These detections will allow for a better understanding of the simulations as well as a confirmation of the infrared spectra previously used for analysis.

  - We are actively collaborating with other laboratories from Theme 3 and 4 of the GCA and from the CIW and Ames NAI teams.

Roadmap Objectives

- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 3.3:** Origins of energy transduction
- **Objective No. 3.4:** Origins of cellularity and protobiological systems

A New Paradigm for Organic Chemistry in the Nebula: Protostars as Chemical Factories

Project Investigator: Joseph Nuth

Project Progress

Protostellar nebulae are oxygen rich, yet a significant quantity of organic matter is still evident in meteorites and in comets when one might predict that such materials should have reacted with the silicate dust to form large amounts of CO. We know that nearly all meteoritic material was processed through a series of high temperature events, producing Calcium Aluminum Inclusions (CAIs), chondrules, crystalline silicate dust and amorphous condensates. By analogy a similar proportion of the carbonaceous grains should also have experienced these same conditions, yet macromolecular carbonaceous coatings exist on grains in meteorite matrices and volatile organic molecules are observed in reasonable abundance in comets. We have proposed that surface mediated reactions on silicate dust grains could have played a major role in the production of both volatile and macromolecular carbonaceous materials in the nebular environment. This is based on recognition that both inward as well as outward circulation must occur in protostellar nebulae in order to explain the presence of crystalline silicate grains, and on recent experiments in our lab that demonstrate the resilience of surface mediated organic synthesis. We have talked about the basic model of nebular circulation as it relates to the production of crystalline mineral grains found in comets at several meetings. A summary of this general circulation model is shown below.

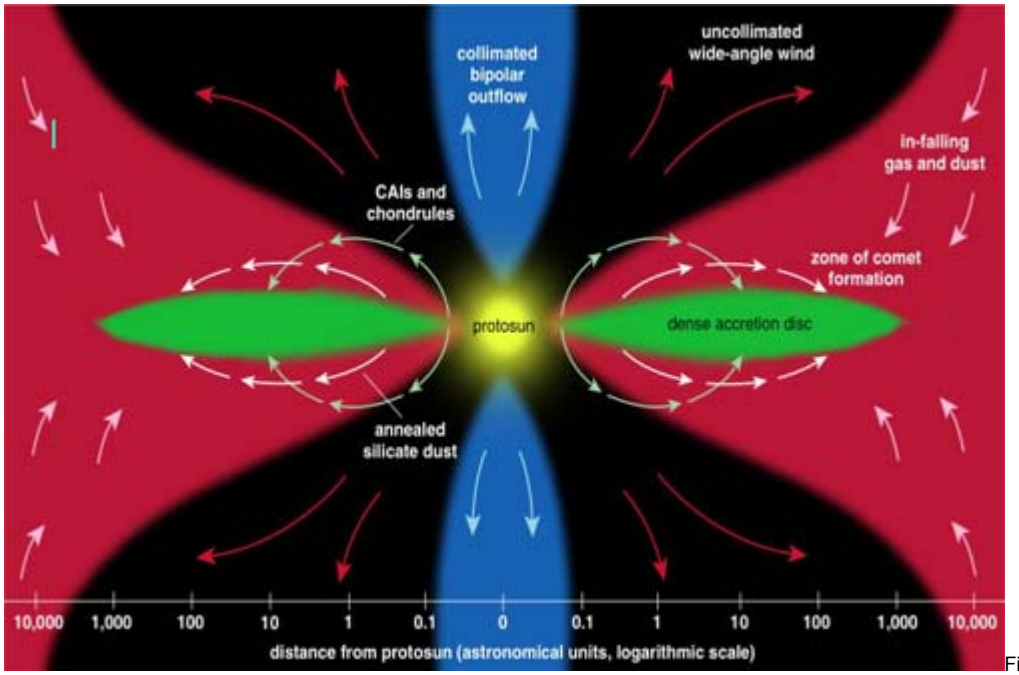

Figure 1.

Our recent experiments have demonstrated that almost any free surface will act to catalyze the Fischer-Tropsch-Type conversion of CO and molecular hydrogen to complex hydrocarbons. In addition, we have now discovered that one of the products of these reactions is a macromolecular carbon coating on the grain surface that itself acts as a catalyst to promote the formation of hydrocarbons containing nitrogen if the reaction occurs in the presence of N_2, H_2 and CO. Far from acting as a poison, these coatings can greatly enhance the reactivity of some grain species such as amorphous magnesium silicate or silica particles. The net result of this process should be a relatively uniform composition for the macromolecular carbonaceous materials deposited on meteoritic grains and a significant increase in the quantity of organic materials that may have been produced and then circulated throughout protostellar nebula compared to previous models.

We have also noted that Ed Anders and colleagues had discredited FTT type reactions as the source of meteoritic organics by noting that the products of such reactions were isotopically light whereas meteoritic carbon was isotopically heavy. However, because Anders only considered the volatile products of the FTT reactions in his analysis, and because the meteoritic organics are much more likely to consist of the macromolecular carbonaceous coatings left on grain surfaces, a logical conclusion would be to recognize

that his previous analyses actually supports the hypothesis that surface-mediated reactions were primarily responsible for the production of organic materials in the Primitive Solar Nebula. In other words, if the volatile organics are made of isotopically light carbon, then the carbonaceous coatings that remain on the grain surfaces are likely to be isotopically heavy, just like measurements of the meteoritic carbon made by Anders.

We are continuing our studies of the initial composition of the volatile organic species produced on both amorphous iron-silicate and magnesium-silicate grains as a function of time, temperature and degree of previous reaction products deposited on the grains' surfaces. We have noted that the quantity of volatile organic products decreases with increased surface coating, although the overall rate of reaction of the CO does not seem to be effected. This seems to imply that a much greater fraction of the CO is incorporated into the macromolecular carbonaceous grain coating as the surface area of the coating increases, and that the coating itself may not produce any volatile organic material at all but might simply produce a thicker organic coatings on the grains.

Laboratory synthesized calcium oxide and calcium hydroxide grains: A candidate to explain the 6.8 μm band Yuki Kimura and Joseph A. Nuth III *Astrochemistry Laboratory, Code 691, Solar System Exploration Division, NASA's Goddard Space Flight Center, Greenbelt, MD 20771, USA*

We demonstrate that CaO and $Ca(OH)_2$ are excellent candidates to explain the 6.8 μm feature, which is one of the most obscure features in young stellar objects. We discuss the condensation of CaO grains and the potential formation of a $Ca(OH)_2$ surface layer. The infrared spectra of these grains are compared with the spectra of fifteen young stellar objects. We note that CaO-rich grains are seen in all meteoritic CAIs (calcium-aluminum-rich inclusions) and that the 6.8 μm feature has only been observed in young stellar objects. Therefore, we consider CaO grains to be a much more plausible candidate to explain the 6.8 μm feature than the organic materials previously suggested in the literature and hypothesize that they are produced in the hot interiors of young stellar environments via distillation from pre-existing hibonite.

Roadmap Objectives

- **Objective No. 3.1:** Sources of prebiotic materials and catalysts

Chemical Models of Nebular Processes

Project Investigator: Steven Charnley

Project Progress

The goal of this task is to determine the chemical composition of icy bodies and establish their potential for delivering pre-biotic organic materials and water to the young Earth and other planets. This is being performed through detailed chemical modeling, coupled with physical evolution, of the protosolar nebula. Related observational, theoretical, and laboratory studies are also being undertaken.

We have made significant progress in several theoretical and observational subprojects. These are aimed at understanding the relative contributions of interstellar and nebular chemistries to cometary composition. Two book review chapters have been completed. These summarize the important physical and chemical processes occurring in protoplanetary disks, such as the early protosolar nebula. Theoretical models of disk chemistry are described and the connection between these processes and the composition of primitive solar system materials is made (Markwick & Charnley 2004; Ciesla & Charnley 2005). Using a variant of the UMIST disk chemistry code, we have made preliminary studies of gas-grain deuterium fractionation processes in the comet-forming regions of model disks. We have included a full deuterium chemistry into our disk chemistry model, including multiple deuteration driven by H_2D^+, HD_2^+ and D_3^+ reactions. A paper has been submitted for publication (Markwick & Charnley 2005). This work complements the direct searches for deuterated cometary molecules we are also undertaking (see below).

We have published more of our Submillimeter Array mapping data on organic molecules in the 'hot corinos' of the low-mass IRAS 16293-2422 binary system (Huang et al. 2005). Our new $H^{13}CN$ interferometric data clearly shows Keplerian rotation in subsource A, and hence the presence of a protostellar accretion disk. A VLA proposal has been submitted with NAI –GCA collaborators L. Mundy and J. Pedelty to perform high-resolution observations of this source at cm wavelengths. We performed a series of radio observations of comets C/2001 Q4 (NEAT) and C/2002 T7 (LINEAR) using the JCMT and the ARO 12m and SMT telescopes. We were able to detect deuterated formaldehyde in C/2002 T7. This is the first time this molecule has been detected in a comet. The inferred D/H ratio is large, consistent with formation in a very cold environment, and a paper is being prepared for submission to Nature. We also observed hydrogen cyanide emission in C/2001 Q4, in collaboration with optical observers who have determined the $C^{15}N/C^{14}N$ ratio. However, we were only able to able to determine upper limits to the important $HC^{15}N/HC^{14}N$ ratios; a paper is being prepared for submission.

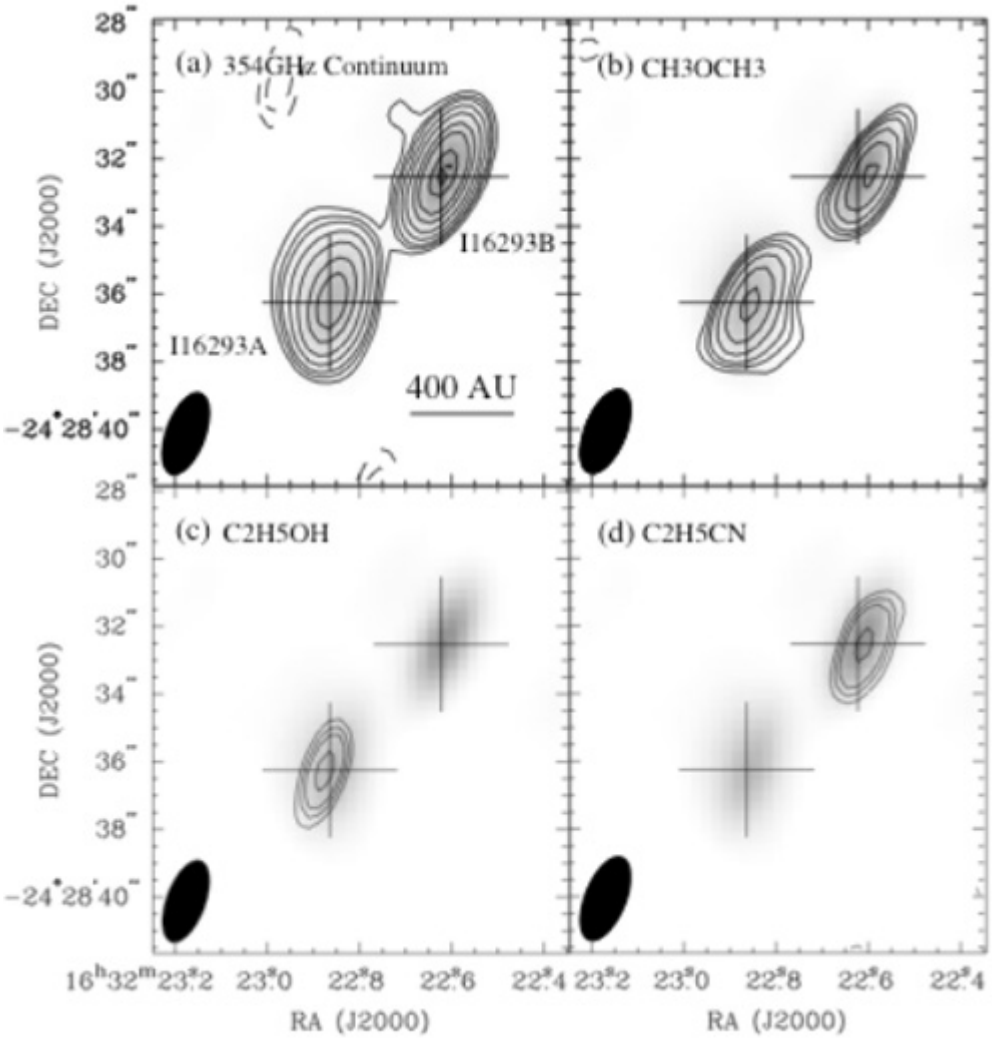

Figure 1. Spatial maps of large organic detected toward the protostellar binary system IRAS 16293-2422 (Huang et al 2005).

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts

Cosmic Ice Laboratory: Organic Synthesis in Energetically Processed Ices

Project Investigators: Reggie Hudson, Marla Moore

Project Progress

In the Cosmic Ice Laboratory we simulate the low-pressure and temperature environment of space using a high-vacuum chamber and a cryostat. Ice samples condensed onto a cooled mirror inside the cryostat are irradiated with 1-MeV protons, to simulate cosmic-ray bombardment, or are photolyzed to simulate vacuum-UV exposure. Motivated by detections of glycolaldehyde ($HOCH_2CHO$) and ethylene glycol ($HOCH_2CH_2OH$) in the interstellar medium and, for ethylene glycol, in comet Hale-Bopp, we examined the low-temperature formation of these molecules. We found that irradiated methanol-containing ices produced ethylene glycol, and that ices containing this molecule produce glycolaldehyde, a simple sugar. In addition we determined that energetic processing of aliphatic alcohols produces aliphatic aldehydes and *vice versa*.

Other new results are the detection of several amino acids in residues that resulted from ice irradiations. We performed many ice irradiation and photolysis experiments on acetonitrile (CH_3CN) since it is a nitrile of interest for comets, Titan, and circumstellar regions. IR spectra of irradiated or photolyzed CH_3CN show the formation of HCN, ketenimine, and CH_3NC, seen in the left-hand figure below. IR spectra of the residue remaining after warming to 290 K show broad features in the 4.4 – 4.7 um (2200-2080) cm^{-1}) region, consistent with C=N bonded species. However, only through chemical analysis of these residues can the details of their composition be revealed. The right-hand figure below is an HPLC trace of a residue showing many peaks not seen in the blank. Amino acids such as glycine, alanine, aspartate, and glutamate were identified in subsequent chemical analyses completed by Jason Dworkin. The complete set of ice experiments included both unlabeled and (three different) ^{13}C-labeled CH_3CN ices, along with controls to test the extraction and HPLC protocols. Details about the instrumentation and protocols that made possible these identifications are given in the discussion of the Astrobiology Laboratory. These experiments lead to our next step, the irradiation of nitriles in water-dominated ices and the search for amino acids.

Outreach

- The summer ('05) project, "Irradiation of Nitrile-Containing Ices: A Laboratory Study", was completed by Zachary Pozun, an astrobiology student intern. He took part in setting-up and performing various ice irradiation experiments and measuring infrared spectra of the ices as a function of dose and temperature. He documented isotopic shifts in many products, e.g. OCN-, HCN, CH4, and CH3CNH. The complete set of ice experiments included both unlabeled and (three different) 13C-labeled CH3CN ices. These isotopically-labeled experiments were used to confirm reaction pathways for identified products.

- Two undergraduate astrobiology courses were taught (fall, 2004)

Equipment

- New IR spectrometer brought on line; instrument purchased with separate NASA funding (needed for new work on biomolecules)
- New cryostat installed for experiments at temperatures below 12 K

Web page highlights

- Complete redesign and expansion of the Web site for the Cosmic Ice Laboratory http://www-691.gsfc.nasa.gov/cosmic.ice.lab/

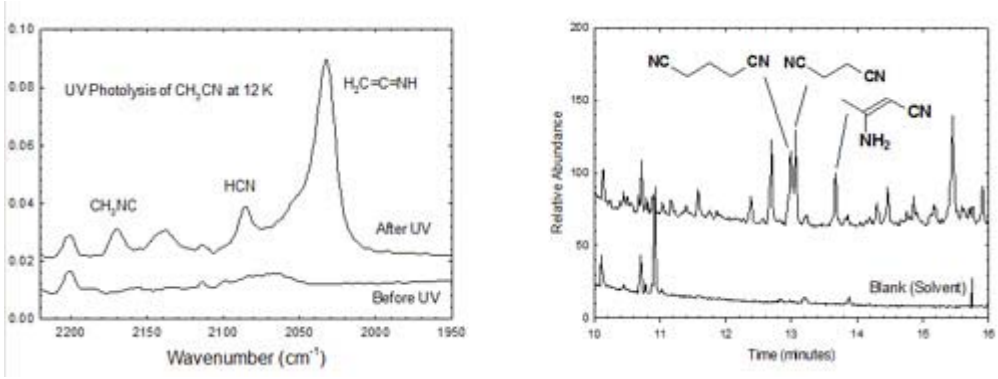

Figure 1.

Roadmap Objectives

- **Objective No. 2.2:** Outer Solar System exploration
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials

Extrasolar Planets

Project Investigator: Drake Deming

Project Progress

The existence of close-in extrasolar planets provides an opportunity to evaluate the delivery of water and pre-biotic molecules to planets, via collisions in the early stages of planet formation. Over 150 planets are known to orbit stars other than the sun, and many of these extrasolar planets occur quite close to their stars and have orbital periods of only a few days. This close-in orbital geometry has two important implications. First, it is believed that these planets migrated inward by interactions with a protoplanetary disk. This migration process is likely to have provided ample opportunity for the outer envelopes and atmospheres of close-in planets to become enriched by collisions and accretion, similar to the collision processes that enriched the early earth. Therefore studying atmospheric composition of close-in extrasolar planets, even ones not in the habitable zone, is of great interest for astrobiology.

A second implication that follows from the existence of close-in extrasolar planets is that such planets have higher probabilities of transiting their stars, and the transit geometry provides methods to detect and characterize their atmospheres. D. Deming collaborated with T. Brown (HAO), D. Charbonneau (Harvard CfA), J. Harrington (Cornell Univ.), and L. J. Richardson (GSFC), to search for carbon monoxide absorption in the atmosphere of the transiting extrasolar planet HD 209458b. High spectral resolution observations were obtained in the 2-micron atmospheric window using the Keck telescope on Mauna Kea. Although the analysis did not detect the presence of carbon monoxide, the upper limit from these Keck data requires that the atmosphere must have a high opacity, to a degree which may require new models for the planetary atmosphere.

Working with S. Seager (Carnegie DTM), L. J. Richardson (GSFC), and J. Harrington (Cornell Univ.), D. Deming used the Spitzer Space Telescope to detect the secondary eclipse of HD 209458b at 24-microns wavelength. The secondary eclipse of a transiting extrasolar planet is the time when the planet disappears behind the star, and reappears. The amplitude of the secondary eclipse in the combined light of the system is a direct measurement of the infrared brightness of the planet. Simultaneous with the Deming et al. measurement of HD 209458b, a group at Harvard CfA headed by D. Charbonneau detected the secondary eclipse of another transiting planet at 4.5- and 8-microns, also using Spitzer. These Spitzer detections are the first direct measurements of planets orbiting other stars, and they open a new era in astronomy and astrobiology, where we can now directly study and compare alien worlds to those in our own solar system.

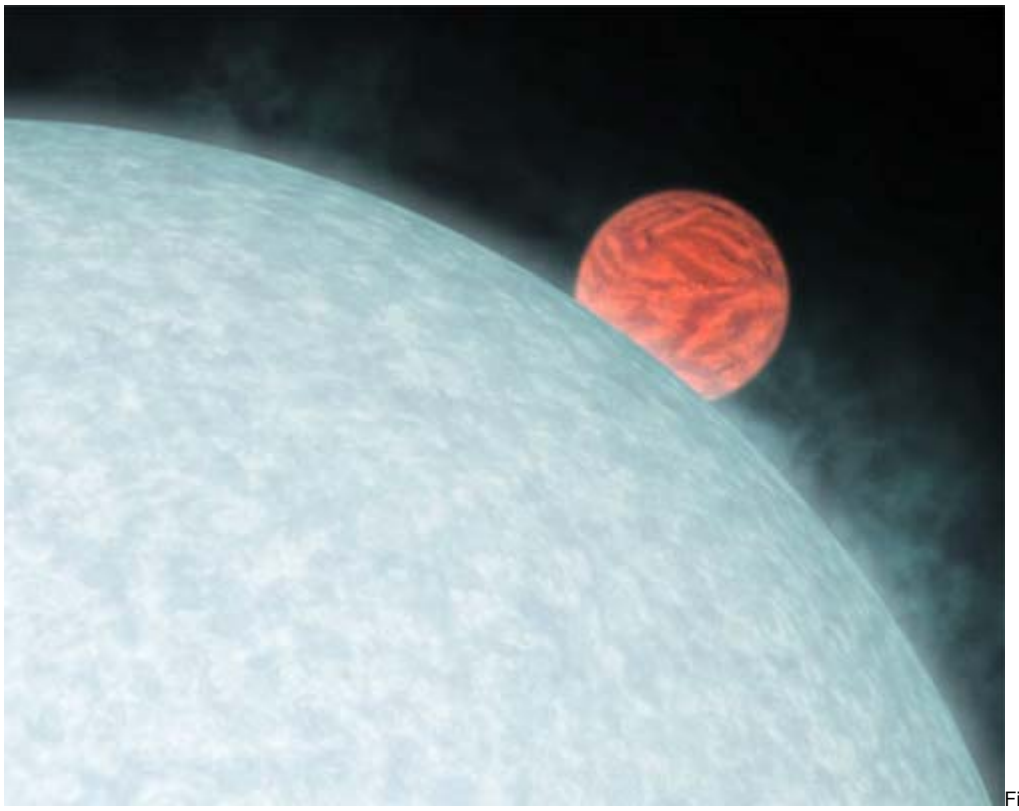

Figure 1. Artist conception of the extrasolar planet HD209458b as it emerges from secondary eclipse. The secondary eclipse occurs when the planet passes behind its parent star as seen from earth. Observations by investigators from the Godard and Carnegie nodes detected infrared radiation from the planet by measuring the decrement in the combined light of the system during secondary eclipse, using the Spitzer Telescope (Deming et al. 2005)

Roadmap Objectives

- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets

Identification of Chemical Characteristics of Basin-Forming Impactors on the Moon

Project Investigator: Richard Walker

Project Progress

The purpose of this work is to fingerprint the late additions to the Moon using the relative abundances of the highly-siderophile elements (HSE) that occur in generally high abundance in likely impactors, but extremely low abundance in the indigenous lunar crust. Towards this end, approximately 2g of several Apollo 14 and 17 melt breccias were obtained from the Johnson Space Center curatorial facilities. In collaboration with Dr. Odette James (USGS retired), a longstanding expert on these rocks, we have cleanly separated chips from 73215, 73255 and 72395, and analyzed them for Os isotopes and highly siderophile element abundances (Pt, Pd, Ir, Ru, Re and Os).

The Apollo 17 rocks likely sample the Serenitatis basin impactor. All of the rocks analyzed have $^{187}Os/^{188}Os$ ratios of approximately 0.129 to 0.133. These ratios are consistent with the Serenitatis impactor having long term Re/Os similar to enstatite or ordinary chondrites, rather than carbonaceous chondrites. Results for each rock show considerable variation in absolute abundances of the highly siderophile elements. Previous studies have utilized such variations to extrapolate to indigenous abundances by assuming very low concentrations of Ir in the target rocks. Our results for "aphanitic" melt rocks (containing relatively fine-grained melt fraction but substantial clasts) show non-linear relations between Ir and some other HSE (Fig 1a). General trends indicate that both Pd and Ru were present in the impact rocks at levels >1 ppb, considerably higher than previously assumed. This means that the abundances of these elements in the impactor were probably lower than suggested by previous studies. Results for Apollo 17 "poikilitic" melt rocks (coarser-grained melt fraction and fewer clasts than the aphanitic rocks), have much more linear relations between Ir and other HSE (Fig. 1b). Although these rocks presumably contain similar impactor materials to the aphanitic rocks, there is less indication of significant indigenous HSE. In the coming year we will attempt to deconvolute the indigeneous signal from the impactor and obtain a better understanding of the composition of the impactor.

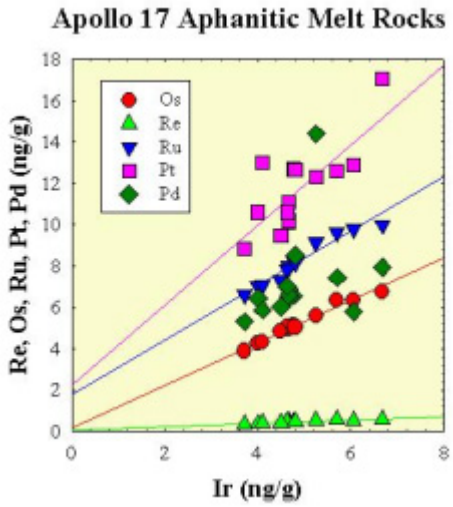

Figure 1. Plot of Ir (in ng/g) versus Re, Os, Ru, Pt and Pd for Apollo 17 impact melt rocks (likely formed by the Oriental impact). If it is assumed that the lunar target rocks contained very low Ir, the near 0 y-axis intercepts of this plot for Re, Os and Pt suggest that these elements were also present in very low abundance in the lunar taget rocks. Non-zero intercepts for Pd and Ru, however, suggest that these two elements were present in significant abundance in the target rocks, and the indigenous abundances must be subtracted from the estimate for the impactor.

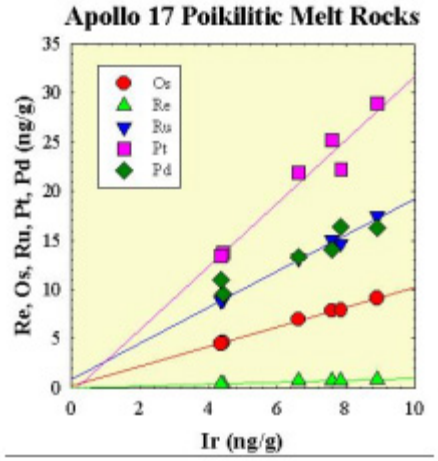

Figure 2. Plot of Ir (in ng/g) versus Re, Os, Ru, Pt and Pd for Apollo 17 poikilitic melt rocks. Non-zero intercepts for Pd and Ru, are suggested, however, the results are somewhat different from those of the aphanitic melt rocks.

Highlights

- Apollo 17 lunar melt rocks have relative abundances of highly siderophile elements most like enstatite or ordinary chondrites, rather than carbonaceous chondrites. This is similar to what has been estimated for the Earth's late veneer, so initial results suggest similar additions to Earth and the Moon.

In Situ Measurements Protocols and Techniques for Analysis of Organics in Comets

Project Investigator: Paul Mahaffy

Project Progress

Theme 4 is concerned with the development of measurement protocols and techniques that will inform the development of instruments for organic analysis on space missions to comets. Comet missions have been planned and proposed to NASA and other space agencies for a nucleus rendezvous for a period of weeks or months or for a nucleus flyby through more than one coma to explore cometary diversity. The Rosetta spacecraft developed by the member states of the European Space Agency will encounter Comet Churyumov-Gerasimenko in May 2014. For both flyby or rendezvous mission types, sample return concepts have been developed and the first such return will be in January 2006 with the Stardust samples of Wild 2 contained in the aerogel collectors on that spacecraft. Since return of cometary ices in a preserved state may not be possible in the near term from multiple comets, *in situ* measurements must be used to explore the cometary molecules that may have contributed directly (or not) to the origin of life on Earth.

There is a significant overlap in the development of instrumentation and measurement protocols for *in situ* chemical and isotopic analysis in a cometary nucleus and those that might be used to carry out a sensitive search for organic molecules on Mars. During the reporting period Dr. Arnaud Buch returned to a university position in Paris and plans were made for his replacement with another highly qualified astrobiologist Dr. Oliver Botta whose future work will be a combination of studies of organics in suitable analogues for comets and Mars and analysis of meteoritic and other terrestrial samples using GC-MS. Dr. Botta has several different types of meteorites that will be analyzed for their amino acid composition. In addition, he will study the organic composition of Antarctic meteorites with respect to contamination from the ice.

In related work Daniel Glavin has initiated a program to investigate the distribution and isotopic composition of nucleobases in carbonaceous meteorites that was also supported in 2004 by the Exobiology program. This research is a collaborative effort between NASA Goddard (Jason Dworkin and Oliver Botta), Carnegie Institution of Washingon (Marilyn Fogel) and the Leiden Institute of Chemistry in The Netherlands (Zita Martins). Dr. Glavin presented a summary of the first year research at the 2005 PI Exobiology symposium at NASA Ames. He also proposed to analyze amino acids in STARDUST comet grains using a highly sensitive liquid chromatography time of flight mass spectrometry and laser induced fluorescence detection technique. This work is a collaborative effort between NASA Goddard (Jason Dworkin) and the University of Washington (Graciela Matrajt).

Not funded by the NAI, but very relevant to our work are results from a detailed cometary coma MHD model developed by a GSFC National Research Associate Dr. Mehdi Benna. The model provides more detailed resolution of the structures due to the solar wind interactions than has previously been developed and can model either a very active comet or solar wind interactions down to the nucleus for a weak comet far from the sun. This work will be important for interpretation of data from spacecraft missions to comets as the space environment where the organic measurements are being made will be better understood. Future development of the model will add more chemical complexity and predictions of the structure and chemistry of trace species.

Highlights

- Members of the Themes III and IV team were selected to lead (Mahaffy) or be participating scientists (Brinckerhoff, Glavin, Dworkin) on the Sample Analysis at Mars Suite of instruments for the Mars Science Laboratory Mission . Pyrolysis and chemical derivatization techniques that were developed in year 1 of the NAI GCA program were part of this selected payload which consists of a sensitive gas chromatograph mass spectrometer and a tunable laser spectrometer for trace species identification and precise isotope measurements. In the second year of the NAI CGA program these techniques were further refined and techniques for determination of chirality in derivatized amino acids were developed.

Shannon Tronick (Syracuse University) interned with Co-I Paul Mahaffy (Theme IV), continuing the research into chemical derivatization techniques for expanding the breadth of organic analysis techniques. Shannon explored the impact of a range of experimental parameters on the quality of the chemical analysis. For example, she explored the impact temperature on the efficiency of transfer of derivatized amino acids into the gas chromatogram (GC) columns. She also systematically investigated impacts on sample loss for different transfer line temperatures between the GC columns and the mass spectrometer (MS) and in the ion source of the mass spectrometer itself. All these parameters can be of critical importance in a space flight experiment where heater power may be a critical resource. Shannon produced a comprehensive report on her summer research that will be of considerable value for future GCA Theme IV

research.

Roadmap Objectives

- **Objective No. 3.1:** Sources of prebiotic materials and catalysts

Laser Mass Spectrometry Technique Development for Analysis of Complex Organics in Cometary and Meteritic Materials

Project Investigator: William Brinckerhoff

Project Progress

Theme 4 work at JHU/APL using laser time-of-flight mass spectrometry (TOF-MS) techniques continues in collaboration with the GCA team and external partners. We seek to contribute to research on the following major questions within the GCA:

- What are the fine scale morphology and composition of comet nuclei?
- Do comets comprise an enabling inventory of complex pre-biotic organics?
- How should we approach the characterization of this inventory?

Laser desorption (LD) methods are complementary to ongoing non-laser GCA work at GSFC; they sample distinct yet related sets of compounds from complex samples. Our work is also a link between analyses performed with similar facility instrumentation at other labs in that we can measure quantitatively the scientific consequences of miniaturization or other resource limitations. The specific objectives of the laboratory-based effort at APL are to:

1. Examine organics in *standards* , *cometary analogs* , and *meteorites* with Laser Desorption Mass Spectrometry (LDMS);
2. Develop an LDMS sensitivity-selectivity *database for high mass, refractory organics* in various matrices and optimize the method;
3. Compare LD-based "prompt ionization" with LD + laser post-ionization (REMPI) for use as *organic chemical mapping* technique; and
4. Determine optimal *combined* LDMS and pyrolysis GCMS (and other) analyses of common samples which *advise mission design* .

We have continued to work with miniature LDMS prototypes, most recently with a "flight-scale" breadboard completed with separate NASA instrument support. To optimize this breadboard for the sample analyses we are conducting, we have improved the configuration as follows:

1. Integration into new highly compact, vertical vacuum system (**Figure 1**). Metallic seals are used to achieve lower base pressures for higher signal-to-noise for trace high-mass organics. The sample chamber has viewports to permit lateral incidence post-ionization.
2. Development of a miniature xyz sample motion stage with lateral motion precisions of less than 10 ?m and x or y travel of 12.5 mm permits larger samples to be examined without having to break vacuum. This is valuable because organics related to inclusions in meteorites can be several mm across and/or separated by several mm. The process of breaking vacuum takes time and can change sensitivity/instrument bias.
3. Sample-holding components and application techniques were further developed for a variety of minimally "prepared" materials (not dissolved, extracted, concentrated, etc.). For example, tailored surfaces such as etched silicon or otherwise treated wafer layers at sample deposit locations can entrap particles without adhesives. Results suggest that the deliberate localization of sample particles improves the mass resolution and signal to noise ratios because ions are emitted with sub-laser spot size initial spatial dispersion.

Figure 1. Miniaturized LDMS as mounted in vertical test chamber.

A number of analyses have been conducted to understand further the sensitivities of various laser TOF-MS approaches to detection of high mass organics in neat samples, and to compare those with parallel studies at GSFC with GCMS, LCMS, and other techniques. Particularly in support of the LDMS organics database, we have begun to (i) reexamine earlier spectra from carbonaceous meteorites; (ii) analyze systematically a sequence of both procedural blanks and standard reference materials; and (iii) record new spectra from geo-standard and meteorite samples under identical conditions as the blanks and references.

In earlier analyses of the Allende CV3 meteorite, a number of complex organics including PAHs and alkylated PAHs were detected consistent with known instrument sensitivities. Higher mass compounds are primarily aromatic structures broken off the macromolecular network. A closer examination of the high-mass (m/z > 300 Da) signal revealed some similarities with and differences from LDMS and other observations of known macromolecular IOM in C-chondrite acid residues (Becker et al. 1997, Kissin et al. 2003). We observe a sequence of sodiated and potassiated parent compounds (**Table 1**) with major adduct steps at ?m/z = 28 Da (dimethyl, C_2H_4, CH_2N, etc.). A parent PAH at 428 Da (octacene or equivalent) may be one of the important higher-mass "building blocks" of more aromatic macromolecular IOM. However, prompt LDMS PAH ratios do not match those in REMPI (Plows et al. 2003, Elsila et al., 2004). Furthermore, fragmentation and cationization patterns with 355 nm LDMS are different than with 337 nm wavelength. These differences are attributable to both wavelength and mineral matrix (absorptivity) effects. Preliminary analysis of the CM2/CM1 chondrite ALH83100 revealed more extensive alkylation in this meteorite, with distinct reproducible peaks at somewhat ambiguous m/z values of 116, 158, 196, and 412. Additional extensive comparative analyses of ALH83100, Murchison, and Allende are planned.

LDMS High-Mass Sequence in Allende		
M^+	$[M+^{23}Na]^+$	$[M+^{39}K]^+$
428	**451**	**467**
456	**479**	**495**
484	**507**	**523**
512	**535**	**551**
540	**563**	**579**
666	689	**705**
694	717	**733**
722	745	**761**
750	773	**789**
778	801	817

Table1: Nominal m/z values of detected (bold) and inferred (non-bold) peaks in Allende LDMS spectra.

Two new staff members are participating in the GCA research effort. Catherine Corrigan (Postdoctoral Associate) joined JHU/APL from the Smithsonian NMNH where she worked with Tim McCoy and others on meteorite research. Anita Ganesan (Astrobiology Research Associate), who joined JHU/APL from Cornell University , spent last summer as a SUIA researcher in the (Theme 3) labs of Drs. Nuth, Dworkin, and Johnson at NASA/GSFC.

References

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Elsila JE et al. (2004) *Anal. Chem. 76* , 2430-2437.
Kissin YV (2003) *Geochim. Cosmochim. Acta 67* , 1723-1735.
Plows FL et al. (2003) *Geochim. Cosmochim. Acta 67* , 1429-1436.

Roadmap Objectives

- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials

Methane on Mars: NAI Distributed Workshop

Project Investigator: Michael Mumma

Project Progress

8:00-14:30 PDT NASA Ames Research Center, California, USA 11:00-17:30 EDT NASA Goddard Space Flight Center, Maryland, USA 16:00-23:30 CEST Centro de Astrobiologia del CSIC-INTA, Madrid Spain

Introductory remarks (10 mins; 8:00 PDT/11:00 EDT/17:00 CEST)

Bruce Runnegar, NASA Astrobiology Institute, Ames Research Center, Moffett Field, CA 94035, USA; Bruce.Runnegar@nasa.gov

Spectral observations of methane on Mars (45 + 15 mins; 8:10/11:10/17:10)

Michael J. Mumma, Solar System Exploration Division and Goddard Center for Astrobiology, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA Michael.J.Mumma@nasa.gov

Abstract: Three groups have reported independent detections of methane on Mars. I will review the current status of these searches. On Mars, the photochemical lifetime of methane is very short (~300 years), and any methane now in its atmosphere must have been released within that time. However, the lifetime could be very much shorter if heterogeneous processes destroy methane efficiently, and this would require that estimated production rates be revised upwards. I will present evidence supporting the presence of strong latitudinal (meridional) gradients, obtained by our team. These gradients require: 1. significant local sources of methane, and 2. a removal mechanism that is much more rapid than photochemistry. The destruction lifetime might be shorter than the meridional circulation time (of order weeks), i.e., several thousand times faster than photochemistry and this provides an important quantitative constraint for assessing the release rate. The combination provides an important constraint for assessing biogenic vs. primordial or geothermal origins.

Discussion (30 mins; 9:10/12:10/18:10)

Break (30 mins; 9:40/12:40/18:40)

Terrestrial analogs 1 – water-rock reactions (20 + 5 mins; 10:10/13:10/19:10)

Craig E. Manning, Department of Earth and Space Sciences, University of California, Los Angeles, CA 90095-1567, USA; manning@ess.ucla.edu

Terrestrial analogs 2 – deep crustal methane (20 + 5 mins; 10:35/13:35/19:35)

Barbara Sherwood-Lollar, Department of Geology, University of Toronto, Ontario, Canada M5S 3B1; bslollar@chem.utoronto, ca

Resolving abiogenic versus biogenic sources of methane and implications for Mars exploration.

Sherwood Lollar, B.[1], Telling, J.[1], Lacrampe-Couloume, G.[1], Slater, G.F.[2], Onstott, T.C.[3] and Pratt, L.M.[4]. ([1]Department of Geology, 22 Russell St., University of Toronto, Toronto, Ontario Canada M5S 3B1 bslollar@chem.utoronto.ca. [2]School of Geography and Geology, McMaster University, Hamilton, Ontario L8S 4K1. [3]Dept. of Geosciences, Guyot Hall, Princeton University, Princeton NJ 08544. [4]Dept. of Geological Sciences, Indiana University, Bloomington IN 47405). Bslollar@chem.utoronto.ca

Abstract: To date the characteristics of abiogenic hydrocarbons have not been well defined. Studies of terrestrial abiogenic gases have shown that measuring the delta ^{13}C value of methane alone is not always

diagnostic. If the source of carbon is mantle-derived, as at the mid-ocean spreading centers, the delta ^{13}C value of the methane would be expected to be relatively enriched in ^{13}C. Away from mantle carbon input however, in crustal-dominated systems such as deep Precambrian Shield rocks, processes of water-rock interaction (including serpentinization) produce abiogenic hydrocarbons that may have much more isotopically light (^{12}C-rich) signatures, reflecting local crustal carbon sources. Drawing on field data from terrestrial abiogenic gases and recent laboratory experiments, this paper will address key parameters that may be used as diagnostic tools for identifying biogenic hydrocarbons versus abiogenic geological sources of methane and other hydrocarbons, in particular the pattern of ^{13}C and ^{2}H variation between methane and higher hydrocarbon gases such as ethane.

Terrestrial analogs 3 - biogenic methane (20 + 5 mins: 11:00/14:00/20:00)

Christopher H. House, Department of Geosciences, Pennsylvania State University, University Park, PA 16802, USA; chouse@geosc.psu.edu

Abstract: Methanogens, members of the Euryarchaeota, inhabit diverse of anaerobic habitats on Earth ranging from polar sediments to hydrothermal vents. The phylogenetic, environmental, and metabolic diversity of methanogens and methanotrophs will be discussed. Also, an overview of carbon isotopic fractionation during methanogenesis will be presented.

Fate of Disequilibrium Trace Gases in the Martian Atmosphere (20 + 5 mins; 11:25/14:25/20:25)

Michael E. Summers, School of Computational Sciences, Department of Physics and Astronomy, George Mason University, Fairfax, Va 22030

Abstract: The recent discovery of methane in the atmosphere of Mars has provided a new approach for indirectly probing possible disequilibrium chemistry beneath the Martian surface. Methane in the Martian atmosphere has a chemical lifetime of less than about 300 Earth years, thus its existence in the atmosphere may suggest a continuous replenishment. Its chemical lifetime is several orders of magnitude longer than typical atmospheric transport timescales, and thus its mixing ratio is to first order expected be fairly uniform throughout the Martian lower atmosphere, except possibly near localized source regions. A measurement of its average value would thus provide an estimate of the total magnitude of its source. In order to use measurements of methane as a probe of its source strength, it is important to understand its fate in the atmosphere. The chemical destruction of methane in the terrestrial atmosphere has been extensively studied. Analogous processes are likely to dominate the destruction of gaseous methane on Mars. Specifically, ultra-violet photolysis and chemical reactions between methane and both OH (hydroxyl) and O (^{1}D) are probable loss processes on Mars. The oxidation of Martian methane will have an inconsequential impact on the overall chemical structure of the atmosphere, but understanding the details of the oxidation process may provide a means to use measurements of small variations of atmospheric methane to locate source regions. Also, understanding the kinetics of methane chemical destruction on Mars also provides a theoretical framework for understand the chemical loss of other possible disequilibrium gases such as H_2S, NH_3, HCN, and CH_2O, that might exist in the Martian atmosphere. These latter species probably have chemical lifetimes substantially shorter than that of methane, and their distributions in the Martian atmosphere will probably show strong correlations with their respective source regions. And finally, understanding the isotopic fractionation of methane in the Martian atmosphere may provide a means to use isotopic measurements as constraints on the nature of the methane source.

Break (30 Mins; 11:50/14:50/20:50)

Working session / brief contributions (120 Mins; 12:20/15:20/21:20)

Summary and closing remarks (10 mins; 14:20/17:20/23:20)

Numerical Simulations of Planetary Dynamics

Project Investigators: Lee Mundy, Derek Richardson

Project Progress

Postdoc Graeme Lufkin joined the node in September 2004. He has worked on two areas of planetary dynamics.

First, he completed simulations from his thesis work on the mechanism of giant planet migration in a gaseous circumstellar disk. His results agree partially with previous simulations using a different numerical technique, suggesting that giant planets should migrate quickly toward their parent star, possibly creating a gap in the gas disk. In addition, the results of his non-linear simulations disagree significantly with the analytical treatment of migration. This is strong evidence that non-linear interaction is a dominant component of giant planet migration, necessitating the use of computer simulations.

Second, Dr. Lufkin, in collaboration with Drs. Richardson and Mundy, has started investigating the effect of giant planet migration on disks of planetesimals. Observations of extrasolar planets suggest that giant planets migrate inward through the traditional habitable zone early in the formation of solar systems. What is the fate of the building blocks of terrestrial planets during such an interaction? To answer this, we have modified our gravitational simulation code to handle a prescribed migration of a giant planet. We simulate disks of planetesimals under the influence of the central star and migrating planet, and observe how the distribution of orbital elements is affected. We are running many simulations, varying both the mass and migration rate of the giant planet, to quantify this dependence. Our initial results suggest that giant planet migration is not a catastrophic event for disks of planetesimals. The eccentricity and inclination of the planetesimals are greatly increased by the giant planet, but less than twenty percent actually get ejected from the system. Further growth of the planetesimals will be postponed until dynamical friction and gas drag can cool their orbital motion.

All the work described above has been performed on the computing cluster of the University of Maryland Astronomy Department. During this year the cluster has been upgraded by Richardson and Lufkin with new nodes and disk space, doubling its speed and storage.

This work was presented at the June 2005 Gordon Research Conference: Origins of Solar Systems, and will be presented at the Protostars and Planets V meeting in October 2005.

Our simulations have thus far been simple, including only the gravitational interaction of the giant planet on the planetesimals. We intend to incorporate additional physics such as gas drag and mutual gravitational interaction. These will require significantly more computing time, but appear feasible.

Dr. Richardson, in addition to working with Graeme Lufkin on the simulations described above, continued work on planet formation simulations with former graduate student Zoë Leinhardt (now a postdoctoral fellow at Harvard University). This work, title "Planetesimals to protoplanets. I. Effect of fragmentation on terrestrial planet formation" and published in ApJ 625:427 (2005), quantified the effect of fragmentation (based on a rubble pile model) during the early and middle stages of planetary growth (it was also presented by Leinhardt at the NAI meeting in April 2005). They found that, for the parameters tested, fragmentation did not play a dominant role compared to simulations that assumed perfect accretion. In addition, debris created in these simulations did not significantly affect the dynamics of the larger bodies. Leinhardt will be visiting Maryland in late October to continue this project (extending to a larger parameter space and implementing new physics) and to plan strategy for their remaining supercomputer time at the Pittsburgh Supercomputer Center. Finally, Richardson designed an algorithm for quantifying and tracking the radial movement of planetesimals in a planet-forming disk that takes into account incorporation of planetesimals into larger bodies. This algorithm will be implemented and tested in the next funding cycle.

Dr. Mundy has continued complementary work at millimeter, submillimeter and infrared wavelengths which focuses on the observational aspects of dust evolution in disks around young and forming stars. In the paper titled "Large Dust Particles in Disks around T Tauri Stars" (accepted to Astronomy & Astrophysics,

Rodmann et al Sept 2005), we present 7-mm wavelength continuum data for 14 low-mass young stars in Taurus and argue that dust grains have grown to millimeter size in some systems. Such grain growth is an important first step toward planetesimal formation and is relevant to the simulations discussed above. Dr. Mundy also continues his work on Spitzer projects of relevance to the early evolution of planet-forming disks. Of particular interest are the studies of cold outer disks systems which are being found through their emission in the IRAC 8 micron and MIPS 24 micron bands. The nature and evolutionary state of these systems is unclear at this point; they could be post classical T Tauri systems which have not yet lost their outer disks; they could be more evolved systems with outer debris disks created by planetesimal collisions. Continued work with the large dataset associated with the Cores to Disks Spitzer Legacy project is likely to provide answers.

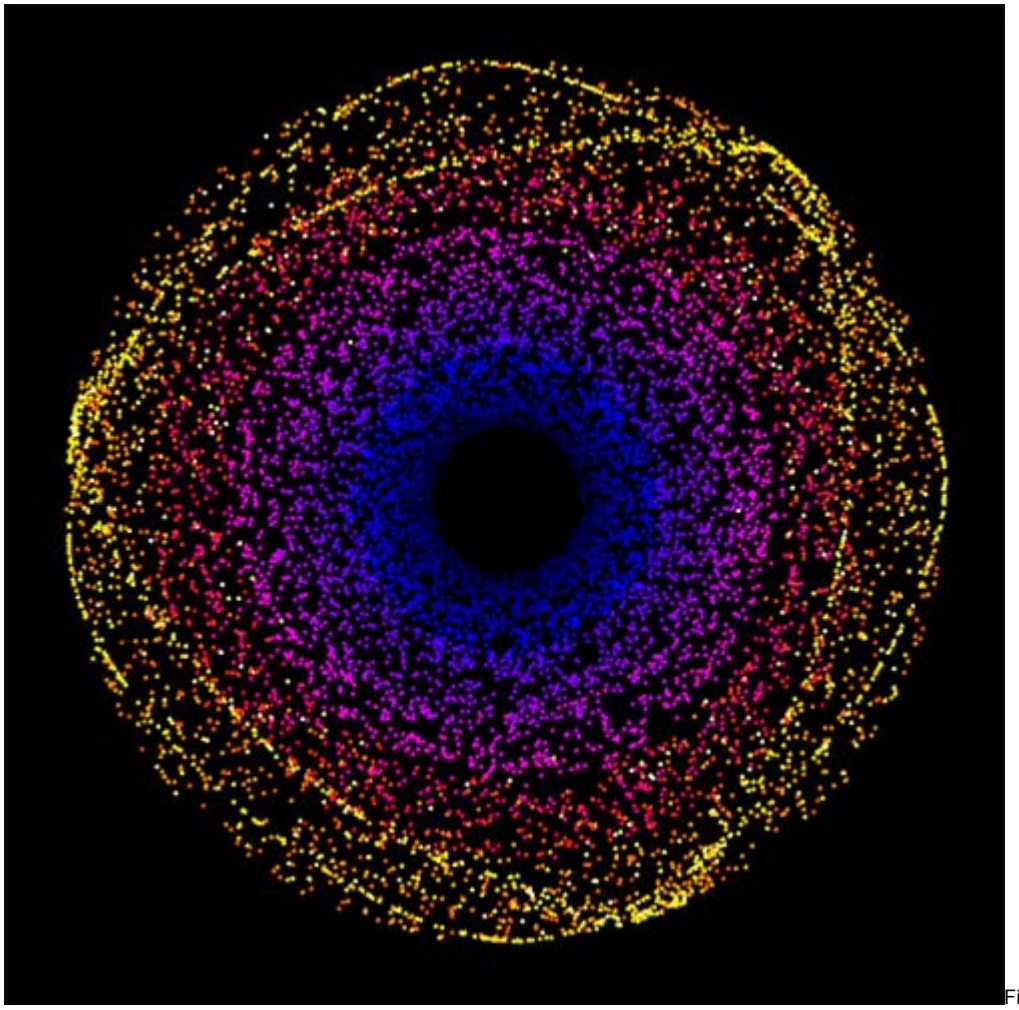

Figure 1. Mid Stage: A new face-on view of a disk of planetesimals influenced by the gravity of a migrating giant planet. A Jupiter-mass planet (located off-image) is slowly migrating toward its parent star, exciting the orbits of a swarm of planetesimals interior. The planetesimals are colored by their semi-major axis (dark is low a, bright is high a). showing how their orbits have been perturbed by the migrating giant planet. In this image, you can see bunches of particles following reonannt orbits through the disk.

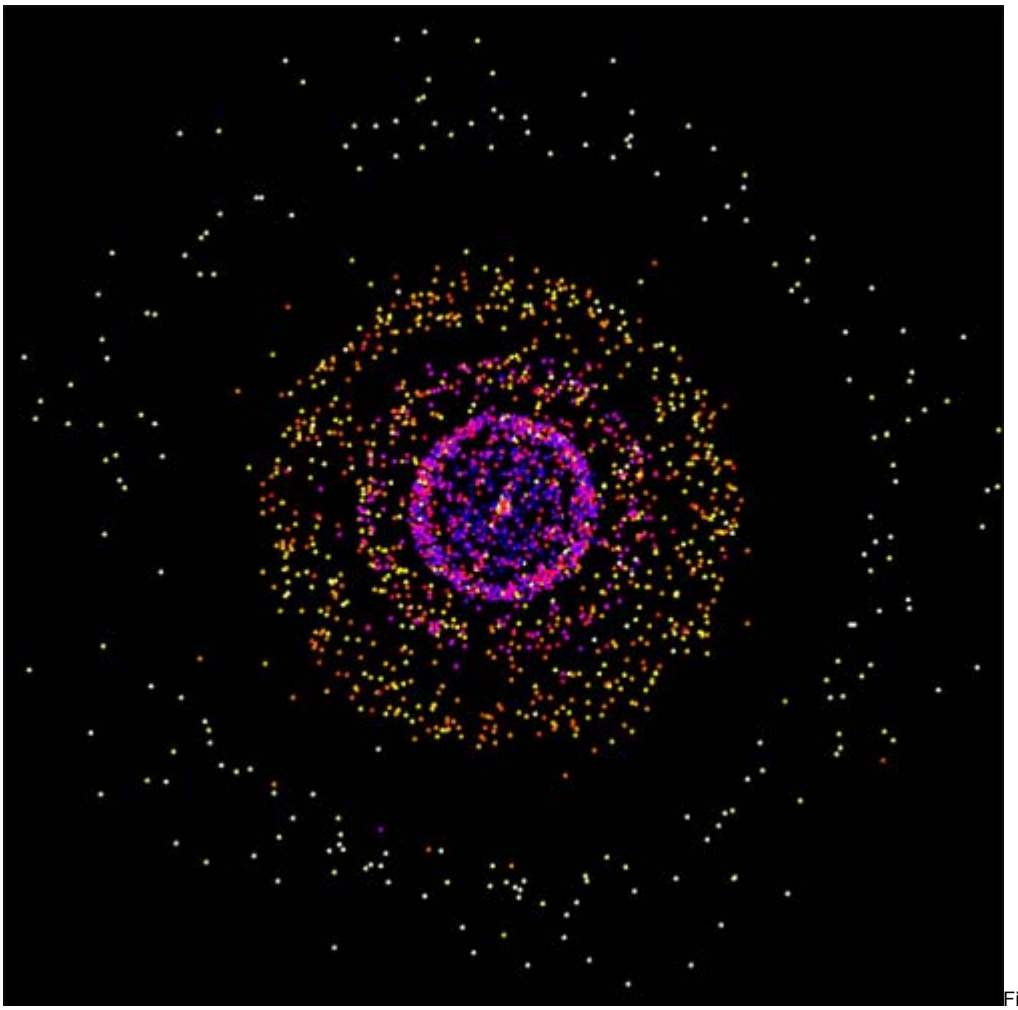

Figure 2. End Stage: A face-on view of the same disk, much later in time, colored the same way. The giant planet has swept all the way through the swarm of planetesimals. Gravitational interactions have created concentrations and voids in orbital space, fundamentally changing the structure of the disk. This will change the likelihood and properties of any planets that might form via accretion of the planetesimals.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets

Origin and Evloution of Organics in Planetary Systems

Project Investigator:

Project Progress

This progress report summarizes astrobiology research done during the first year of funding from the NASA Astrobiology Institute at Washington University in St. Louis under the direction of Professor Bruce Fegley, Jr. This research is part of the NASA Goddard Astrobiology Node. Our research focused on two topics: (1) chemical and isotopic composition of presolar grains found in chondritic meteorites, and (2) atmospheric chemistry during the accretion of Earth-like planets. Our work on these two topics is described in two refereed papers (Lodders and Amari 2005, Schaefer and Fegley 2005a) and two abstracts (Fegley and Schaefer 2005, Schaefer and Fegley 2005b).

(1) Chemical and isotopic composition of presolar grains found in chondritic meteorites The presolar grains found in chondritic meteorites are remnants of the material accreted by the solar nebula during formation of the solar system. Our knowledge of presolar grains helps us to understand the origin of our solar system and of other extrasolar planetary systems.

Klaus Keil invited research associate professor Lodders and senior research scientist Dr. Sachiko Amari to write a paper about the origin and nebular processing of carbonaceous presolar grains. Dr. Lodders has written several highly cited papers about the condensation chemistry of presolar grains around AGB stars. Dr. Amari is one of the co-discovers of presolar TiC grains and has studied presolar grains in meteorites since their discovery in 1987. Their invited review paper entitled "Presolar Grains from Meteorites: Remnants from the Early Times of the Solar System" was published in the March 2005 issue of *Chemie der Erde* (Lodders and Amari 2005 Chem. *Erde* **65**, 93-166). In this paper they describe the search for presolar grains, the different types of presolar grains, the chemical and isotopic composition of the different types of grains, and their origin from different stellar sources.

(2) Atmospheric chemistry during the accretion of Earth-like planets Planetary accretion models show temperatures of several thousand degrees during accretion of the Earth. The high temperatures result from conversion of gravitational potential energy into heat. The thermodynamic properties of iron, and the major silicates (such as olivine $(Mg,Fe)_2SiO_4$) that make up the Earth are sufficiently well known that the energy required for heating, melting, and vaporization can be calculated accurately. Professor Fegley and Laura Schaefer used thermochemical equilibrium calculations to model the chemistry of silicate vapor and steam-rich atmospheres formed during accretion of the Earth and Earth-like exoplanets. The codes used in this work are the MAGMA code (Fegley and Cameron 1987 *EPSL* 82, 207-222, Schaefer and Fegley 2004 *Icarus* 169, 216-241, Schaefer and Fegley 2005a *Earth, Moon and Planets* DOI 10.1007/s11038-005-9030-1) and the CONDOR code (Fegley and Lodders 1994 *Icarus* **110**, 117-154). Our results predict spectroscopically observable gases that can be used to search for Earth-like planets forming in other planetary systems. In particular we find that silicon monoxide (SiO) gas is the major species in silicate vapor atmospheres for T > 3080 K, and monatomic Na gas is the major species for T < 3080 K. During later, cooler stages of accretion (1500 K), the major gases (abundances >1%) in a steam-rich atmosphere are H_2O, H_2, CO_2, CO, H_2S, and N_2. Carbon monoxide converts to CH_4 as the steam atmosphere cools.

Professor Fegley and Laura Schaefer also calculated the composition of volatiles out-gassed from chondritic planetary bodies. The considered appropriate mixtures of the common chondritic meteorites (CI, CM, CV, H, L, and EH chondrites), which are widely regarded as the building blocks of the Earth. For example, the oxygen – isotope mixing model (Lodders and Fegley 1997 *Icarus* **126**, 373-394, Lodders 2000 *Space Sci. Rev.* **92**, 342-354) predicts a composition of 70% EH, 21% H, 5% CV, and 4% CI chondritic matter for the early Earth. Professor Fegley and Ms. Schaefer found that the major out-gassed volatiles for these starting compositions are CH_4, N_2, NH_3, H_2, and H_2O. This important result predicts that Earth's earliest permanent atmosphere was a reducing atmosphere that favored synthesis of organic compounds by Miller – Urey type reactions initiated by lightning, UV light, and heat.

Figure 1. Initial vapor composition for out-gassing of a homogeneous planet with the composition of an average CI chondrite (Lodders. 2003). Arrows indicate a region of stability for liquid water.

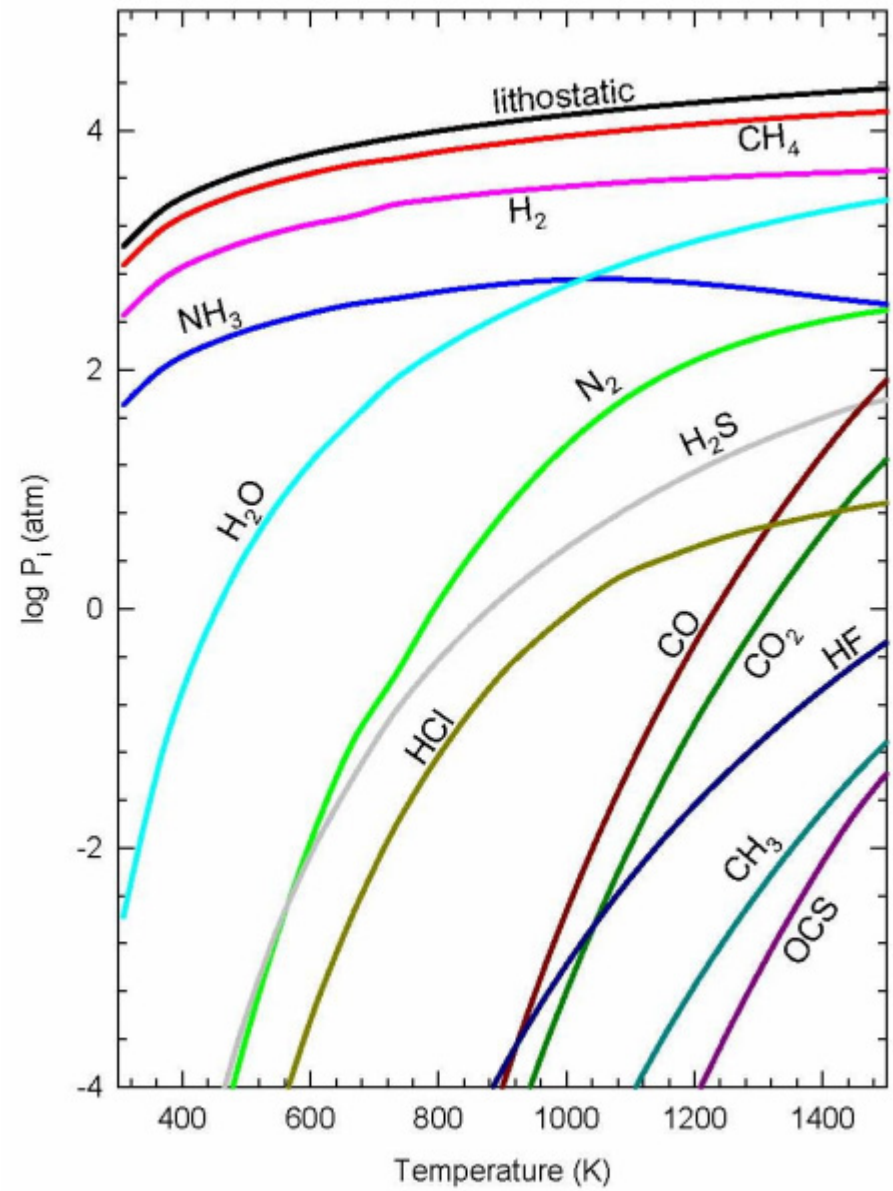

Figure 2. Initial vapor composition of out-gassing of a homogeneous planet with the composition of the Bulk Silicate Earth (BSE) as calculated from a meteorite mixing model (Lodders, 2000). The BSE is represented as a mixture of 70% EH-, 21 %H-, 5% CV, and 4% CI-chondrites.

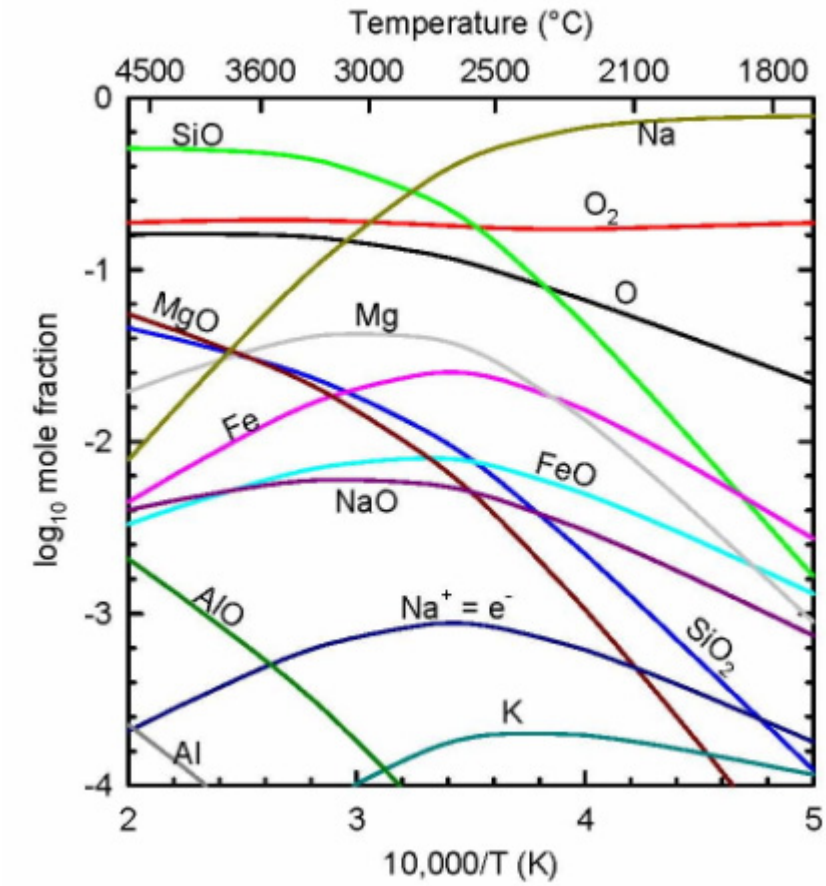

Figure 3. Composition of a dry (no H,C) silicate atmosphere over a magma ocean with the composition of the bulk silicate Earth from 2000 - 5000 K.

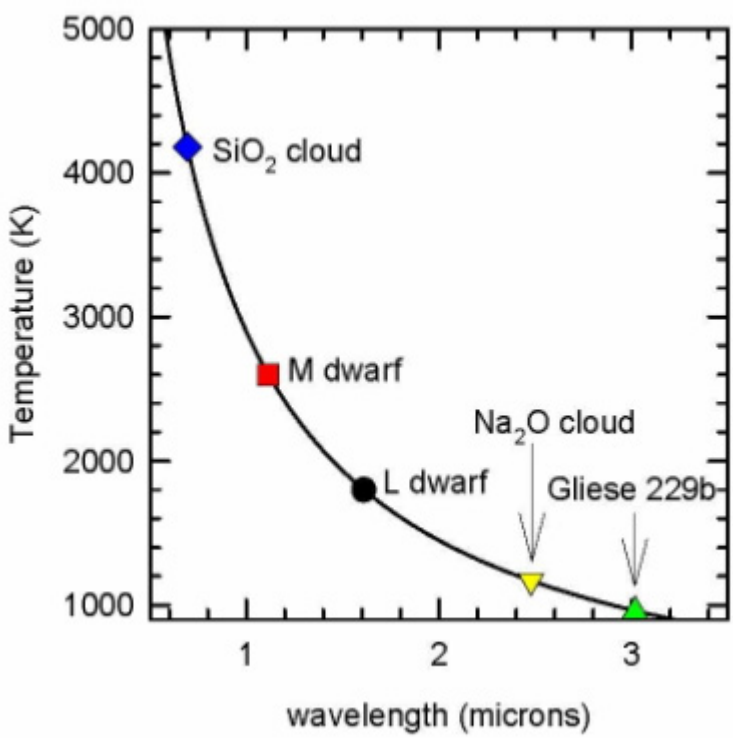

Figure 4. Wavelength at which peak emission occurs for an ideal blackbody as a function of temperature. Temperatures of the Na2O cloud (1169 K) in tthe 2000 K Magma ocean model and the liquid SiO2 cloud (4180 K) in the 5000 K magma ocean model are ploted. Approximate effective temperatures for the brown dwarf Gliese 229b (~960 K), a dust free M dwarf (~2600 K), and an L dwarf (~1800 K) are shown for comparions.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets

- **Objective No. 3.1:** Sources of prebiotic materials and catalysts

Origin and Evolution of Organics in Planetary Systems

Project Investigator: Geoffrey Blake

Project Progress

As part of the overall Astrobiology Node at the NASA Goddard Space Flight Center, whose goal is an understanding of the **Origin and Evolution of Organics in Planetary Systems** (Mike Mumma, P.I.), Co-Investigator Blake is directing both laboratory and astronomical spectroscopy programs. The goal of these observations is to determine whether complex organics are detectable in the circumstellar accretion disks that encircle young stars and in the comae of comets. Targets of study are being selected in collaboration with Node scientists investigating the organic speciation in carbonaceous chondrites, and this past year has seen exceptional progress along many fronts. The experimental work is being carried out in Prof. Blake's laboratories in the Caltech Beckman Institute, and the observational research in FY05 and beyond leans heavily on the extensive suite of Caltech telescopes, especially the Combined Array for Research in Millimeter Astronomy (or CARMA, the merging of the Caltech Owens Valley Millimeter Array and the Berkeley-Illinois-Maryland Array at Hat Creek, CA) and the Caltech Submillimeter Observatory (CSO). In the laboratory, the Blake group operates both a Fourier Transform MicroWave (FTMW) spectrometer, a THz laser difference frequency photomixer spectrometer, and high resolution mid- to near-IR diode laser spectrometers. This results in continuous coverage from the microwave to the optical with exceptional sensitivity. For observational work, the CSO has receivers that operate through all of the atmospheric windows between 180-980 GHz, and CARMA will offer superb imaging performance in the 100/230 GHz windows once the telescopes are fully operational at the new site in the Inyo Mountains (expected first light in winter 2005). In the far-infrared, we plan to utilize the heterodyne receivers under construction at Caltech/JPL for SOFIA and HERSCHEL as these platforms become operational (CY06/CY08, respectively), while our infrared observations are conducted primarily with the Keck telescope through time allocated to Caltech and with the IRS instrument aboard the *Spitzer* Space Telescope.

Over the past year our major millimeter-wave observational analyses centered on the OVRO and BIMA Array spectra and images of the comets C/NEAT (2001 Q4) & C/LINEAR (2002 T7) that reached perihelion on 2004 April 26 and 2004 May 17 respectively. Both comets passed within 0.3-0.4 AU of the Earth, and were well placed for observations from the northern hemisphere. With water production rates near perihelion in excess of $\sim 10^{29}$ mol/s, these apparitions provided us with a unique opportunity to test hypotheses about the physical and chemical processes in the inner regions of cometary comae developed from our highly successful observations of Comet Hale-Bopp in 1997 (Blake et al. 1999). Our first paper on the millimeter-wave observations of HCN has now appeared in the Astrophysical Journal (Friedel et al. 2005), and our next step is to compare the physical model developed to explain the HCN emission with those developed by the GSFC Astrobiology team to explain a suite of infrared observations of these comets. Furthermore, these results form an interesting counterpoint to the compelling Deep Impact spectra gathered at Keck by the Astrobiology team and recently accepted for publication in Science (Mumma et al. 2005).

In addition, a major focus of further data analysis will be searches for complex organics, especially sugars and polyalcohols, whose spectra we have recently assigned in the laboratory (Widicus et al. 2003, 2004). CSO observations undertaken near perihelion (D. Lis 2004, priv. commun.) have revealed that C/LINEAR (2002 T7) has the highest CH_3OH/H_2O yet measured for a comet, and so should provide an excellent target for the more complex poly-hydroxylated compounds known to be present in carbonaceous chondrites (Cooper et al. 2001). For example, we have tentatively detected the simplest three carbon ketone sugar (or ketose), 1,3-dihydroxyacetone, at the CSO (Widicus-Weaver & Blake 2005), and the confirmation of this detection with other microwave and (sub)millimeter-wave telescopes - one of the most complex species yet discovered in star- and planet-forming environments - is our highest priority and will be of great interest to Astrobiology. Toward this end, we have begun initial Ka- and Q-band microwave observations with the GBT. The GBT may well serve as an exceptional and complementary platform for the detection of complex molecules, and our first observing sessions demonstrate very good capabilities over the 40-50 GHz window that optimize the conflicting constraints of line strengths (better at higher frequencies) and telescope performance (better at lower frequencies) – *provided* the weather cooperates!

The spectra obtained for comets C/NEAT (2001 Q4) & C/LINEAR (2002 T7) are also being compared to those we are currently collecting from a number of young protostars and circumstellar disks. New capabilities at the CSO in particular are drastically increasing the throughput of searches for complex organics. In particular, new receivers and spectrometers have been installed that increase the bandwidth of data collected in a single local oscillator setting by a factor of eight. These bandwidth improvements along with more sensitive detectors mean that what formerly required many nights of integration can now be achieved in only an hour or two. With this technology we have begun acquiring line confusion limited spectra of many hot cores for the first time, and upcoming runs for Orion/Taurus are scheduled in November-December 2005.

Finally, by combining the high resolution spectroscopic capabilities of the NIRSPEC instrument on Keck with the astonishing sensitivity of the *Spitzer* IRS, we are making the first assault on the organic chemistry in circumstellar disks. Edge-on disks offer particularly promising targets, with two recent examples providing interesting contrasts of the kinds of information available. Toward CRBR 2242, for example, we detect the signatures of organic molecules in the ices located in the outer regions of this potentially protoplanetary disk, and the abundances so obtained can be directly compared to those in comets (Pontoppidan et al. 2005). More excitingly, perhaps, we have recently detected the gas phase absorption bands of the organics HCN, acetylene, and CO_2 that we believe arise from the *inner* disk encircling IRS46 (another ~edge on disk in Ophiuchus, Lahuis et al. 2005). If substantiated by further observations, this source would provide the first opportunity to examine the hot (several hundred Kelvin) organic chemistry predicted to occur in the planetesimal formation region sampled by carbonaceous chondrites in our own solar system.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 2.2:** Outer Solar System exploration
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts

Planetary Science and Astrobiology Seminars

Project Investigator:

Project Progress

October 1, 2004 – September 30, 2005

October 7 - **Anthony Remijan,** NRC, NASA/GSFC, Earth and Space Data Computing Division **"Recent Observations in Interstellar Chemistry: New Constraints for Detecting Large Biomolecules and the Discovery of Two New Molecules Toward Sgr B2(N-LMH)"**

October 21 - **Jocelyne DiRuggiero,** University of Maryland, Department of Cell Biology and Molecular Genetics **"Life on the Edge: Functional Genomics of Extremophilic Microorganisms"**

November 4 - **Daniel Glavin,** NASA/GSFC, Atmospheric Experiment Branch **"A Search for Extraterrestrial Amino Acids in Antarctic Meteorites: Implications for the Analysis of STARDUST Grains"**

November 18 - **Alan Boss,** Carnegie Institution of Washington, Department of Terrestrial Magnetism **"Giant Planet Formation and Implications for Astrobiology"**

December 2 - **Doug Hamilton,** University of Maryland, Department of Astronomy **"Tilting Saturn"**

January 6 - **Sean Solomon,** Department of Terrestrial Magnetism, Carnegie Institution of Washington. **"The MESSENGER Mission to Mercury: Seeking Clues to the Formation and Evolution of the Inner Planets"**

January 18 & 20 - **"Planetary Science and Astrobiology Posters-Highlights from 2004" Building 28 Atrium, 2:00-4:00"**

February 3 - **Ah-Son Wong,** NRC/USRA Planetary Science Laboratory, University of Michigan. **"Atmospheric Chemistry of Mars: Methane and Oxidants"**

February 10 - **Jason Dworkin,**"LEP, Astrochemistry Branch. **“Life Before RNA"**

February 24 - **Carol Grady,** Laboratory for Astronomy and Solar Physics, UV/Optical Astronomy Branch, **"The Evolution of Planetary Systems: An Observational View of the First 10-20 Myr of the Nearest Young Stars and Their Disks"**

March 3 - **Bill Farrell,** LEP, Planetary Magnetospheres Branch. **"Mars Dust Storms, Electric Fields, and Associated Chemistry"**

March 17 - **Yanping Guo,** Johns Hopkins University, **"The New Horizons Mission to Pluto and the Kuiper Belt"**

April 7 - % **Carol Grady,** GSFC/UV/Optical Astronomy Laboratory **"The Evolution of Planetary Systems: An Observational View of the First 10-20 Myr of the Nearest Young Stars and Their Disks"**

April 14 - **Amitabha Ghosh,** Department of Earth and Planetary Sciences, Univ. of Tennessee **"Case for and Against Al26 and Electromagnetic Induction Heating"**

May 5 - **John Cooper,** GSFC/Earth-Sun Exploration Division **"Habitability in High Radiation Environments: The Case for Life at Europa"**

May 19 - **Derek Richardson,** Astronomy Department, University of Maryland **"Asteroids and Satellites:**

Origins and Implications"

June 2 - **Gözen Ertem,** GSFC/Astrochemistry Branch **"Formation of Phosphodiester Bond in Aqueous Solution by Montmorillnite Catalysis to Produce RNA-Like Oligomers: A Model Study"**

August 15 - **Tom Halasinski,** Department of Chemistry, St Joseph's University **"Investigations of Nitrogen Containing Aromatic Molecules in ISM via Matrix Isolation Spectroscopy: Where is the Nitrogen in Space?"**

September 29 - **Mike Mumma,** NASA/GSFC Solar System Exploration Division **"Deep Impact: A Comet's Volatile Secrets Exposed"**

Studies of Oxidized Carbon in Cometary Ice

Project Investigator: Michael DiSanti

Project Progress

The second year accomplishments of Dr. Michael DiSanti (Co-I, Goddard Center for Astrobiology, NAI) fall into two distinct although related categories: (1) Ongoing research on the organic volatile composition of comets, and (2) E/PO-related activities.

Research:

Our group is recognized as the world-leader in studies of parent volatiles in comets through ground-based high-resolution spectroscopy at near-IR wavelengths (~ 1 – 5 μm). Year two has been very exciting. Using the high-resolution spectrometer (NIRSPEC) at the Keck2 10-m telescope, we observed the long-period (Oort cloud) comet C/2004 Q2 (Machholz) in Fall/Winter 2004/2005 and the short-period (Jupiter Family) comet 9P/Tempel-1 in June and July 2005, and measured the volatile (ice) composition of both objects.

Comet Tempel-1 was the target of the NASA Deep Impact Mission, in which a projectile impacted the nucleus on July 4, 2005 at a speed of about 10 km/s. Our compositional measurements revealed a different chemical signature between the nucleus surface material (determined from pre-impact measurements) and the impact ejecta (from post-impact spectra; Mumma et al. 2005).

Co-I DiSanti's research emphasizes the volatile carbon-oxygen chemistry, in particular the efficiency of converting carbon monoxide to formaldehyde and methyl alcohol on the surfaces of icy grain mantles prior to their incorporation into the nucleus. This process has been shown experimentally to be temperature-dependent, and we have now measured CO, H_2CO, and CH_3OH in six long-period comets, plus comet Tempel-1. Our inferred conversion efficiencies among comets in our database range from as high as 80 percent (in C/2002 T7 (LINEAR), which displayed very strong signatures of both H_2CO and CH_3OH, yet relatively weak CO), to a relatively low efficiency (maximum of ~ 30 percent) in Tempel-1.

Such measurements are important for establishing the role of comets in replenishing Earth's oceans and for delivery of the seed organic molecules from which life emerged. Along with HCN and NH_3 (both of which we also study), H_2CO is thought to play a particularly significant role in the latter process. Co-I DiSanti has applied a fluorescence model of H_2CO to existing spectral observations of comets within our database. This is the first application of the model to high-resolution spectra, allowing a line-by-line comparison between predicted and observed line intensities. We have developed a methodology for accurately measuring molecular excitation (rotational temperature); this is essential for retrieval of robust production rates. Fig. 1 shows the application to observations of C/2002 T7.

Research Goals:

1. Compare modeled and observed H_2CO line intensities, to accurately measure its abundance in comets, as well as to reveal potential discrepancies between model and data.

2. Measure relative abundances of CO, H_2CO, and CH_3OH in observed comets, for comparison with the overall volatile chemistry.

3. From these measured abundances, determine the efficiency of CO conversion in an attempt to establish the conditions (e.g., H-atom density, temperature) to which the pre-cometary ices were exposed. This requires comparison with yields from irradiation experiments on cometary ice analogues as a function of temperature, and also with observational data on these ices in interstellar and proto-stellar sources.

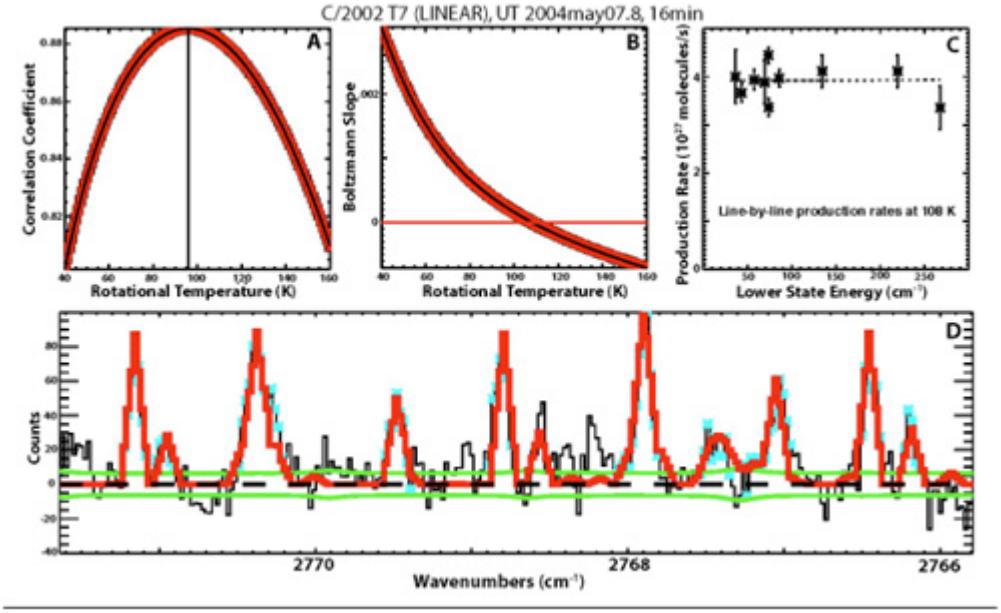

Figure 1. Formaldehyde in comet T7 LINEAR. A. Correlation between predicted (red trace) and observed comet emission in panel D, over a range of rotationl temperature. B,C. Boltzmann analysis; this is complementary to the correlation analysis of panel A. For the best-fit value of T rot (108 K in this case), the retrieved production rate is independent of lower state energy (i.e., the Boltzmann slope = 0). D. Visual comparison between data and best-fit model, at a spectral resolving power of approximately 25,000.

E/PO activities:

Co-I DiSanti mentored an undergraduate student, Constantinos Makrides, through the NAI Summer Undergraduate Internships in Astrobiology (SUIA) program. Mr. Makrides streamlined the calculation of line-by-line fluorescence efficiency factors for water, at one-degree intervals over a wide range of temperatures, for comparison with emissions seen in our comet spectra. This effort found immediate application in establishing the rotational temperature of H_2O in, and amount of H_2O released from comet Tempel-1. The methodology for measuring the excitation and production rate of H_2O is completely analogous to that shown for H_2CO in Fig. 1.

Co-I DiSanti is also the node contact for the research effort, within the Minority Institution Astrobiology Cooperative (MIAC), to systematically observe comets through emission-line filters at optical wavelengths. This effort is led by Dr. Donald Walter (South Carolina State University), and will utilize telescopes in Arizona. Imaging studies on the Kitt Peak 1.3-m telescope are in the science-testing phase. The molecules giving rise to the IR emissions are photo-dissociated in the coma, producing the "daughter" fragments (radicals) to be targeted by the MIAC filter imaging program.

Roadmap Objectives

- **Objective No. 3.1:** Sources of prebiotic materials and catalysts

Studies of the Influence of X-Rays on the Environment of Stars in the Prebiotic Molecule Formation Era

Project Investigator: Robert Petre

Project Progress

To produce pre-biotic materials in the cold circumstellar environment of the young Sun, high energy radiation may be required to stimulate chemical reactions of molecules. Strong X-rays from the stellar core can be a significant source of such radiation, and therefore the history of their X-ray activity can be quite important. With the XMM-Newton X-ray observatory, we clearly detected for the first time strong X-ray emission from one of the earliest stages of a star at the age of 10,000-100,000 years, the so-called Class 0 protostellar phase. In spite of the youth of the stellar system, the emission, originating in a super-hot plasma of ~40 million Kelvin, is one of the strongest from stars outside of flares; the X-ray luminosity is 10,000 times stronger than that of the Sun. Other Chandra and XMM observations made with an international collaboration have demonstrated that the X-ray activity of young stars correlate well with optical and infrared outbursts, and hence are likely associated with mass accretion activity. These results suggest that X-ray emission from very young stars can be quite energetic, driven by violent mass accretion activity.

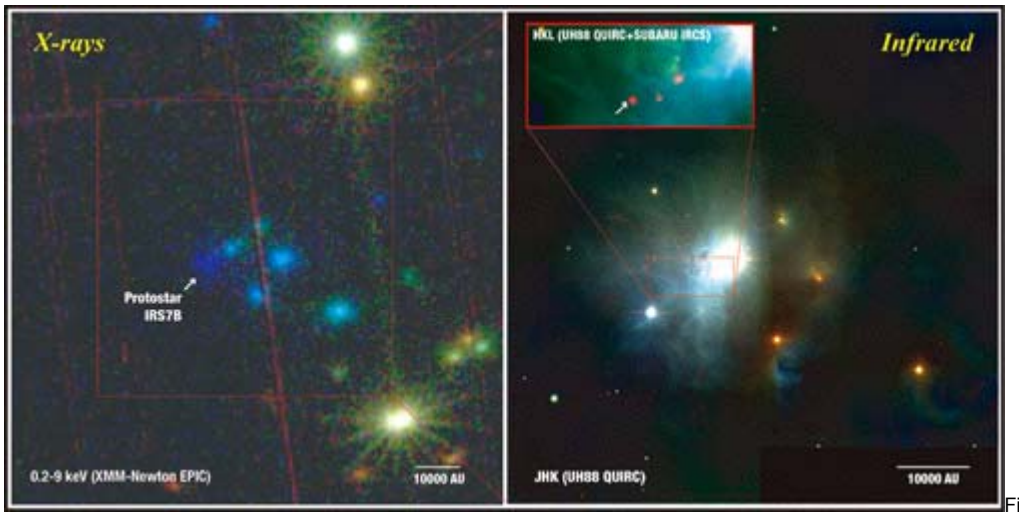

Figure 1.

Roadmap Objectives

- **Objective No. 3.1:** Sources of prebiotic materials and catalysts

The Evolution of Organics in Space

Project Investigator: William Irvine

Project Progress

Molecules in Interstellar Cloud Cores: Understanding the nature of the natal interstellar cloud is crucial to understanding the chemistry of the solar nebula, and hence the chemistry of the Sun and planets. Since that cloud no longer exists, it is necessary to study the cores of existing dense interstellar clouds where stars are forming. Moreover, since the physical conditions vary among and within such clouds, it is important to investigate the chemical and physical processes in a variety of such environments.

Irvine and colleagues in Korea have been studying molecular clouds in the vicinity of the center of our Milky Way Galaxy, where various energetic processes can influence the chemical composition of molecular clouds. They observed millimeter-wave transitions of the molecules CO, HCO+, HNCO, and SiO toward the Sgr A region using the SEST telescope at LaSilla, Chile. The comparison of the observed transitions shows that the several prominent gas condensations in this region have very distinctive chemical properties with respect to each other, which may result from differing physical conditions in the various locations (Minh et al., 2005). In particular, it seems likely that the chemistry is influenced by shocks produced by the source Sg A East.

The effect of shocks may be especially pronounced in the case of sulfur-containing molecular species such as H_2S. We have mapped the distribution of emission from H_2S in the Galactic Center region, and conclude that its abundance is enhanced by shocks that may originate in regions of massive star formation such as Sgr B2 (Minh et al, 2004).

Graduate student Jonathan Franklin studied the distribution of H_2O in regions of massive star formation, using data from the Submillimeter Wave Astronomy Satellite (SWAS). The results were compared to the distribution of other molecular species as obtained with the University of Massachusetts' 14-m diameter radio telescope at the Five College Radio Astronomy Observatory. A paper is being prepared for publication.

The chemistry of comets: Irvine completed work on a review chapter for the book, *Comets II*, on the subject of the processes undergone by organic matter that is cycled through interstellar cloud environments, into a forming solar system, and then into primitive bodies such as comets (Irvine and Lunine, 2004).

Irvine is part of a team that has a pending proposal for Target of Opportunity observations of molecular emission lines from bright comets at millimeter/sub-millimeter wavelengths, using the JCMT on Mauna Kea (Matthews et al., 2004). Unfortunately, no useful data were obtained during the period of this report, but the proposal remains active.

Reviews and Conferences Related to Astrobiology:

As part of his participation in a Working Group on "Prebiotic Chemistry: from the Interstellar Medium to the Solar System", sponsored by the International Space Science Institute in Berne, Switzerland, Irvine acted as a co-editor on a review of the current state of Astrobiology. This volume will serve as advice and background information for the European Space Agency and European universities on Exo/Astrobiology research programs and mission-related experiments (Ehrenfreund, Irvine et al., 2004a). As part of this effort, Irvine co-wrote a chapter on the future of astrobiology (Ehrenfreund, Irvine, et al., 2004b).

Irvine was invited to present a review of organic chemistry in the interstellar medium and in comets for the Fourteenth International Congress on the Origin of Life, the triennial meeting of the International Society for the Study of the Origin of Life (ISSOL), to be held in Beijing in June, 2005. In addition, he will be a co-author on a review on future perspectives in astrobiology in the concluding session of the conference.

Irvine attended the annual meeting of the Division for Planetary Sciences of the American Astronomical Society in Louisville, KY, in November 2004, and presented a poster on applications of the Large Millimeter

Telescope (see below) to astrobiology.

Irvine attended the Team Meeting of the Goddard Center for Astrobiology in January 2005 and described work related to this grant.

Facilities:

The Large Millimeter Telescope (LMT) is a joint project of the University of Massachusetts Amherst and the Instituto Nacional de Astrofisica, Optica y Electronica (INAOE) in Tonantzintla, Puebla, Mexico. The LMT will be the largest single-dish telescope in the world operating at short millimeter wavelengths when it is completed in 2007-08. It will be a powerful instrument for various fields within astrobiology, including the study of the chemistry and physics of comets, other primitive bodies in the solar system, planetary and satellite atmospheres, and the interstellar medium. Irvine continued as Chair of the Management Working Group and as a member of the Science Working Group for the Large Millimeter Telescope Observatory (LMTO), the US-Mexican organization that will operate the LMT.

Irvine spent the fall academic semester of 2004 on sabbatical leave at INAOE, developing scientific collaboration between INAOE and the University of Massachusetts and promoting the study of astrobiology in Mexico. He and Mexican colleagues are writing a short book about the LMT project (Irvine, Carrasco, and Aretxaga, 2005).

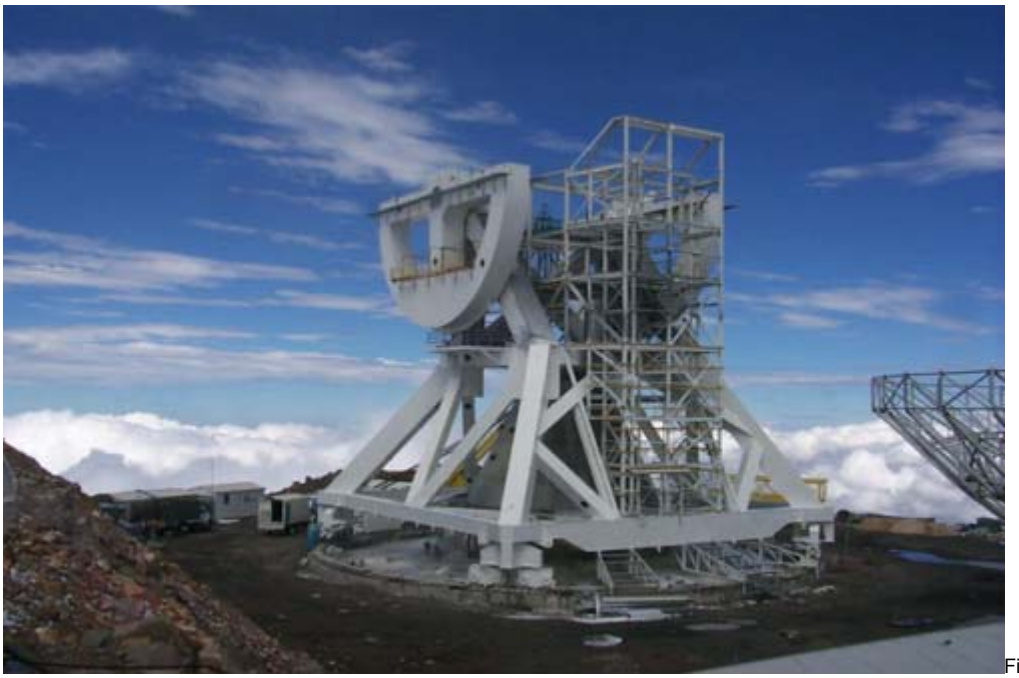

Figure 1. The Large Millimeter Telescope, being built in Mexico by the University of Massachusetts and the Mexican Nacionel de Astrofisica, Optica y Electronica. With a diameter of 50 meters and a surface accuracy permitting observations at wavelengths as short as 0.85 mm, it will be a powerful facility for astrobiology. (Photo from July 2005 - commissioning expected in 2008).

Outreach:

The University of Massachusetts has initiated an interdisciplinary course for honors students entitled "Cosmos to Humanity: From the Big Bang to the Space Age". The theme of the course is astrobiology/evolution, beginning with the evolution of the universe and continuing with the formation and evolution of the solar system, the origin and evolution of life, life in extreme environments, the evolution of complex life, the origin and evolution of humans, and the search for life elsewhere in the universe. Irvine has developed 6 lectures, associated reading material, and web-based units (http://bcrc.bio.umass.edu/courses/fall2005/biol/biol270h/) for the course on the topics of cosmology, nucleosynthesis, organic matter in galaxies, the origin of the solar system, environments in the solar system for life, and extrasolar planets and the search for life in the universe. Martha Hanner, Adjunct Professor of Astronomy at the University of Massachusetts, received some support from this grant to participate in developing lectures and discussions on comets for this new course.

Roadmap Objectives

- **Objective No. 3.1:** Sources of prebiotic materials and catalysts

VLA Observations of the Hot Molecular Core in the Young Stellar Object IRAS 16293-2422 and Proper Motions in the Orion Nebula

Project Investigator: Jeffrey Pedelty

Project Progress

Pedelty, in collaboration with Mundy, planned and implemented Very Large Array (VLA) observations of the hot molecular cores (HMC) in the young stellar object IRAS 16293-2422. These 7 mm observations targeted the prebiotic molecules formic acid, methyl formate, and ethyl cyanide in sources A and B within this object. We generated ~2" spatial resolution images and spectra that detected formic acid and methyl formate in source B of this deeply embedded system. A protoplanetary disk in source B was recently revealed in a ~0.1" resolution VLA image obtained by Rodriguez et al. (2005, ApJ, 621, L133). We obtain a formic acid column density of ~3-7 x 10^{15} cm^{-2} for temperatures of 60 – 110K. We combined our methyl formate observations with others recently obtained with the Submillimeter Array (Kuan et al. 2004, ApJ, 616, L27) and the Plateau de Bure Interferometer (Bottinelli et al. 2004, ApJ, 617, L69) to produce a rotation diagram for source B that is well fit by a temperature of 110K and a column density of 10^{17} cm^{-2}, as long as we exclude the transition at E_u = 454K that was marked as suspect by Kuan et al. These results were presented in a poster at the NAI General Meeting in Boulder, and a journal paper is in preparation.

Pedelty, Mundy, and Charnley wrote a successful VLA proposal in June 2005 for similar VLA 7 mm observations of the low mass star formation region NGC 1333 IRAS 4A. Two observing sessions should be scheduled by the end of 2005. NGC 1333 IRAS 4A and IRAS 16293-2422 are the only two lowmass star forming regions with published spectra showing HNC emission lines, and comparison of high resolution interferometric observations of IRAS 16293 and IRAS 4A should help us better understand their prebiotic chemistry.

Pedelty led the planning and execution in November 2004 of successful VLA observations of the Orion Molecular Cloud (OMC1), Trapezium, and BN region. These X-band (3.5cm) observations are in collaboration with Bally (co-I with NAI-U. Colorado) et al., with the goal of determining proper motions in this important stellar nursery.

Global Biomarkers in support of the Terrestrial Planet Finder Missions

Pedelty attended the Astronomy Focus Group meeting on Global Biomarkers for Extrasolar Planets in December 2004, co-chaired by Seager (NAI-Carnegie) and Meadows (NAI-Virtual Planetary Laboratory). The workshop's goal was to determine global-scale biomarkers from past and present Earth, and their detectability in disk-averaged planetary spectra such as those to be obtained from the Terrestrial Planet Finder missions. Pedelty presented a brief summary of Earth Observing System data. Follow-on discussions led to a large collaborative proposal to the NASA Interdisciplinary Exploration Science program in June 2005. Meadows is PI and Pedelty is the GSFC institutional PI, and the proposal team includes VPL members and Earth scientists at GSFC.

ITWG Support

Pedelty continued to serve as GCA representative to the NAI IT Working Group (ITWG). He was responsible for maintaining the local installation of the PolyCom ViewStation and the WebEx PC to support virtual collaboration. He handled the technical aspects of the GCA's participation in most Executive Council meetings and NAI seminars. Pedelty worked with NAI Central to host workshops and seminars such as the Methane on Mars workshop, Mumma\'s Director's seminar, and FAR seminars by Bonev and the GCA summer students. In this role Pedelty attended several IT-related sessions at the NAI General Meeting and participated in regular ITWG video/teleconferences. He also provided IT support to the GCA comet group led by Mumma, assisting in the specification, purchase, and assembly/configuration of a new Apple G5 Xserve and RAID disk array.

Roadmap Objectives

- **Objective No. 3.1:** Sources of prebiotic materials and catalysts

The Organic Volatile Composition of Comets: A Window on the Early Solar System

Project Investigator: Michael Mumma

Project Progress

Principal Objective:

Our long-range objective is to establish a taxonomy for comets based on chemistry, rather than orbital dynamics. The formation temperature of a given comet can be constrained by measures of the ortho-para ratios in H_2O and by the isotopic enhancements (e.g., in deuterium) in selected volatile species. We now measure the OPR routinely in even moderately bright comets, and often find relaxed spin ratios. A comparison of mid-plane disk temperatures (and chemical abundances) predicted by nebular models will assist in localizing the heliocentric distance at which the pre-cometary ices formed in the protoplanetary disk. Some volatile abundances test the presence of remnant ices from the interstellar natal cloud core. In this way, we will test cometary delivery of organics and water to the young terrestrial planets, and their role in enabling conditions favorable to the emergence of life.

Personnel:

Our core Team consists of co-I **M. A. DiSanti** (GSFC), **Karen Magee-Sauer** (Rowan University), **Erika L. Gibb** (Univ. Missouri-St. Louis), **Geronimo Villanueva** (NAS-NRC at Goddard), and graduate students **Boncho P. Bonev** (Univ. Toledo at GSFC) and **William Anderson** (Catholic Univ. at GSFC). We augment the Team with other scientists for specific projects, as appropriate. During year two of the NAI work, long-term collaborator **Neil Dello Russo** departed Goddard and began new responsibilities at Applied Physics Lab (Johns Hopkins Univ.). Post-doctoral associate Geronimo Villanueva arrived, and graduate student **Avram Mandell** (Penn State Univ., Astrobiology team) began his dissertation research at Goddard. Two undergraduate students conducted research with us at Goddard under the NAI Summer Undergraduate Internships in Astrobiology (SUIA) program: **Yana Radeva** (Connecticut College) returned for a second summer conducting research on Comet C/2001 WM1, and **Constantinos Makrides** (Iona College) worked on aspects of water fluorescence in comets.

Research:

Our group is recognized as a world-leader in studies of parent volatiles in comets through ground-based high-resolution spectroscopy at near-IR wavelengths (~ 1 – 5 μm):

- Since 1996, we characterized ten Oort cloud comets and four Jupiter Family comets.

- We routinely measure abundances for seven parent volatiles (H_2O, CO, C_2H_6, CH_4, C_2H_2, CH_3OH, HCN) and prompt OH emission (OH* - a proxy for H_2O; many multiplets observed ~2.9 —3.7 μm, spanning rotational states J = 2.5 through 17.5).

- We definitively detected H_2CO in six comets (see Report by DiSanti), NH3 in three comets, and OCS in three comets. We developed a search strategy for HDO, and have applied it to four comets.

- We use CSHELL/IRTF and NIRSPEC/Keck. A principal advantage of these instruments is the small beam size. This allows the study of the spatial distribution of emitters along the slit, and is ideal for native (parent) ices. We typically nod along slit between A- and B-beam positions. This mode of observation (coupled with our small beam sizes) further emphasizes native sources.

Progress:

Year two has been very exciting. Using the high-resolution spectrometer (NIRSPEC) at the Keck-2 10-m

telescope, we observed the long-period (Oort cloud) comet C/2004 Q2 (Machholz) in Fall/Winter 2004/2005 and the short-period (Jupiter Family) comet 9P/Tempel-1 in June and July 2005, and measured the volatile (ice) composition of both objects. Comet Machholz was observed in November 2004 by the core Team and in January 2005 by collaborators Richard Ellis and Dan Stark (Calif. Inst. Tech.). The spectral lines in January were the brightest ever observed with NIRSPEC, and multiple species were detected (H_2O, C_2H_6, HCN, CO, CH_3OH, H_2CO, C_2H_2, CH_4, NH_2, OH*, and more). A small portion of the spectrum is shown in Fig. 1. Boncho Bonev has incorporated these data into his dissertation study of OH prompt emission (OH*) as a tracer for water in comets. Other Team members quantified individual parent volatile species to characterize the overall chemistry.

The Jupiter-family comet Tempel-1 was the target of the NASA Deep Impact Mission, in which a projectile impacted the nucleus on July 4, 2005 at a speed of about 10 km/s. Eight investigators were added to six from our core team for this investigation. We quantified eight parent volatiles (H_2O, C_2H_6, HCN, CO, CH_3OH, H_2CO, C_2H_2, and CH_4) in Tempel-1 using high-dispersion infrared spectroscopy in the wavelength range 2.8-5.0 μm (Fig. 2). Our compositional measurements revealed that the impact ejecta displayed a different chemical signature compared with the nucleus surface material (determined from pre-impact measurements) (Mumma et al. 2005). The abundance ratio for ethane was significantly higher after impact (UT 4 July) whereas those for methanol and hydrogen cyanide were unchanged. The abundance ratios in the ejecta are similar to most Oort-cloud (OC) comets, but methanol and acetylene are lower in Tempel-1 by a factor of about two. These chemical similarities suggest that Tempel-1 and most OC comets originated in a common region of the protoplanetary disk; this is consistent with the view that comet nuclei in both the scattered Kuiper-Edgeworth disk (the proposed source reservoir for most ecliptic comets) and the Oort cloud originated in the outer giant-planets' region of the protoplanetary disk. The depleted ethane abundance during quiescent release and its similarity to values found for 2P/Encke and 21P/ Giacobini-Zinner suggests that the surfaces of short period comets have been processed thermally.

Cryogenic laboratory measurements show that the efficiency of converting carbon monoxide to formaldehyde and methyl alcohol on the surfaces of icy grain mantles depends on temperature, and so their abundance ratios in a comet may reveal the temperature at which pre-cometary ices formed prior to their incorporation into the nucleus. Co-I DiSanti has now measured CO, H_2CO, and CH_3OH in Tempel-1 and six long-period comets in our database. The inferred conversion efficiencies among these comets range from ~ 30 percent in Tempel-1 to 80 percent in C/2002 T7 LINEAR (T7 displayed very strong signatures of both H_2CO and CH_3OH, yet relatively weak CO). Such measurements are important for establishing whether comets seeded Earth with pre-biotic organic molecules after Earth-Moon formation. Along with HCN and NH_3 (both of which we also study, lead by Magee-Sauer), H_2CO is thought to play a particularly significant role in the latter process. (see Report by DiSanti)

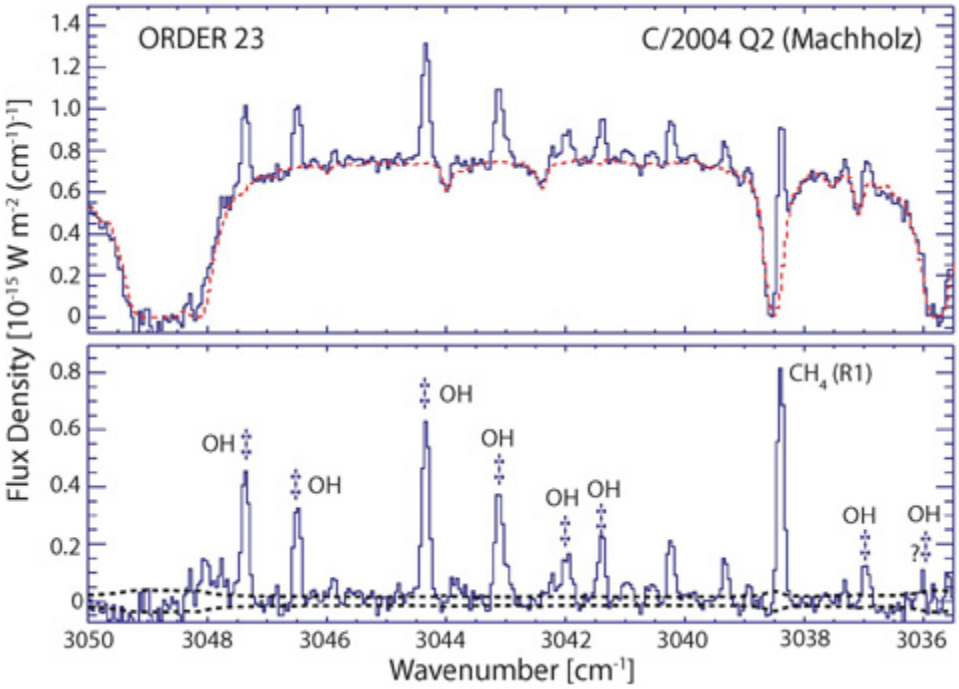

Figure 1. A small portion of spectra of comet Machholz, acquired with NIRSPEC (Keck-2) on 19 January 2005. Spectral lines of OH prompt emission (OH*) and methane CH_4R1) are marked. The dashed line (upper panel, red) is a synthetic model of the terrestrial transmittance, normalized to the cometary continum. The lower panel shows residual line emission after subtraction of the continuum. The double dashed line (lower panel) is the stochastic noise envelope. These data form a key part of the Ph.D. dissertation of Boncho P. Bonev (Univ. of Toledo at GSFC).

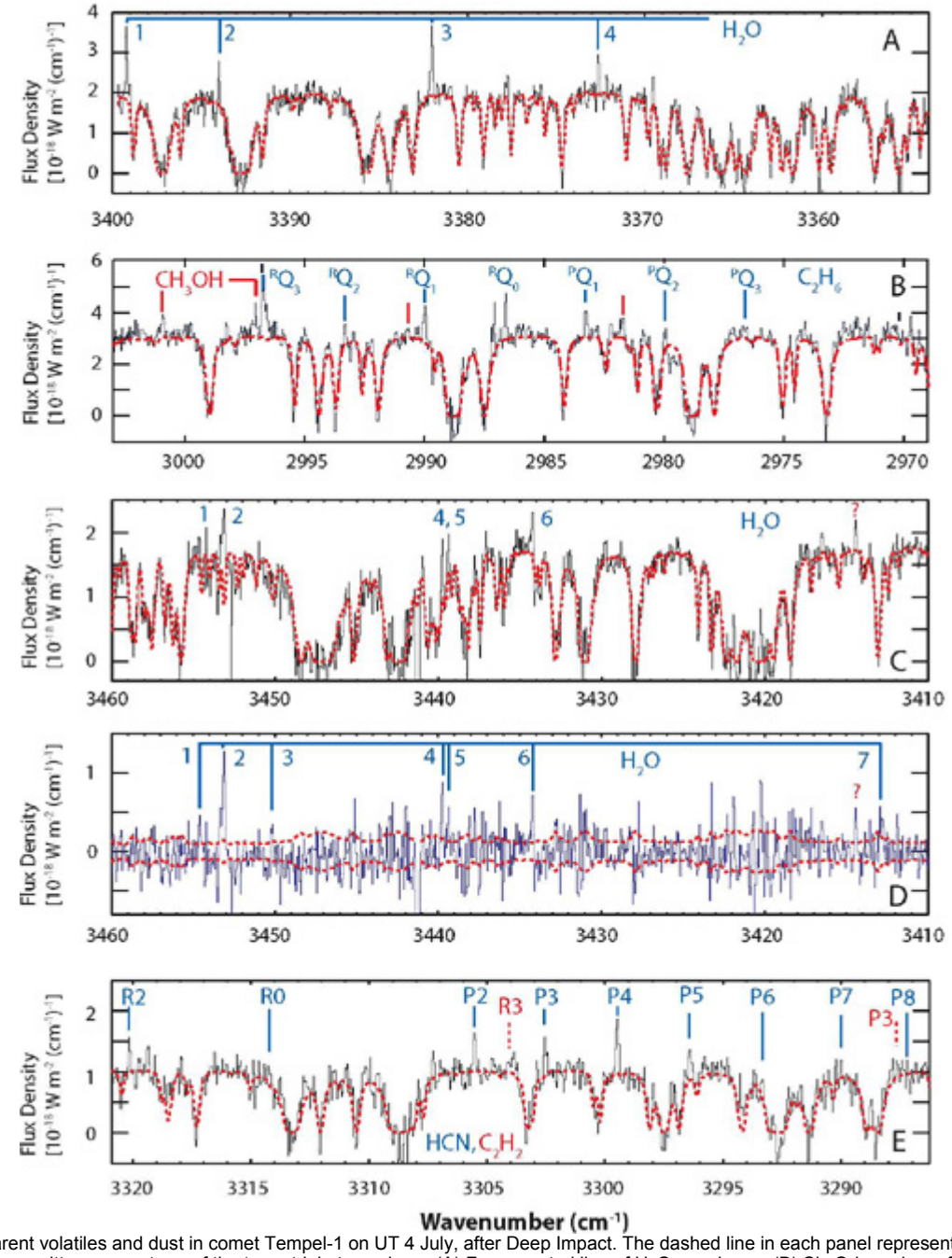

Figure 2.Detection of parent volatiles and dust in comet Tempel-1 on UT 4 July, after Deep Impact. The dashed line in each panel represents the cometary continuum convolved with a synthetic transmittance spectrum of the terrestrial atmosphere. (A) Four spectral line of H_2O are shown. (B) Six Q-branches of C_2H6 are detected along with features of CH_3OH. (C) Five spectral lines of H2O are marked. (D) Seven H_2O spectral lines are seen in the residuals of (C) afer subtraction of the cometary continuum. (E) Eight spectral lines of HCN are detected, along with two lines of C_2H_2. Quantitative results are given in Mumma et al., *Science* 310, 270 (2005).

Invited Talks:

2005 March 28 "Methane on Mars: Geochemistry or Biology?" Director's Seminar Series, NASA Astrobiology Institute.

March 17 "Methane on Mars: Geochemistry or Biology?" University College of New Jersey (Trenton).

Feb. 25 "Methane on Mars: Geophysics or Biology?" Scientific Colloquium Series, Goddard Space Flight Center (Greenbelt , MD).

Jan. 20 "Detection and mapping of Methane on Mars: Evidence for intense local sources." Space Telescope Science Institute (Baltimore , MD).

2004 Nov. 29 "Comets! What are they? Why are they important? Did they deliver water and pre-biotic organics to early Earth? What mysteries are being solved? What new Puzzles are emerging?". Keck Observatory Public Lecture Series (Waimea , HI).

July 23 "An Emerging Chemical Classification of Comets: Implications for the early Solar System." Invited review in Symposium B1.2: "Interpretation of the remote and in-situ observations of small bodies", 35th COSPAR 2004 (Paris , France , 18-25 July).

July 16 "Chemical Diversity among Comets: Implications for delivery of Water and pre-biotic organics to early Earth." Invited Review. BioAstronomy 2004 - Habitable Worlds (Rejkyavik , Iceland , 12-16 July).

July 15 "Discovery and Mapping of Methane on Mars." (Inserted Invited). BioAstronomy 2004 - Habitable Worlds (Rejkyavik , Iceland , 12-16 July).

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 2.1:** Mars exploration
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.3:** Effects of extraterrestrial events upon the biosphere

EPO Reports: NASA Goddard Space Flight Center

Minority Institution Astrobiology Collaborative

The MIAC group continued their work on developing modules for the Origin and Evolution of Organics in Planetary Systems. The six modules: 1) Changes in the View of Science and Perceptions of Comets Over Time, 2) Observation of Comets, 3) Chemical Composition of Comets, 4) Systems/Life Delivery of Organic Materials to Earth? 5) Comets Deliver Water and Prebotic Organic Materials, 6) Comets and Early Earth Time line.

We initiated collaboration with the CIW team to bring in DC teachers as field testers and conduct joint workshops beginning Summer 2006. During the school year MIAC teachers drafted lessons and activities and did some preliminary field-testing in their schools. The MIAC teachers came to GSFC July 5- 7, 2005 to continue their work on module development. They will also meet September 16-17 at South Carolina State University (hosted and funded by Dr. Donald Walter-EPO team member) to complete their modules and prepare them to by field tested by CIW teacher partners.

We are also working with the IPTAI team to bring high school teachers from Knoxville, TN to attend the first OEO workshop at Tennessee State University in summer 2006. GCA, CIW and IPTAI have agreed to seek NAI EPO Collaborative funding to support this effort.

Co-I Michael DiSanti is the GCA Team contact with the Minority Institution Astrobiology Collaborative (MIAC), for a research effort to systematically observe comets through emission-line filters at optical wavelengths. This effort is led by Dr. Donald Walter (South Carolina State University), and will utilize telescopes in Arizona. Imaging studies on the Kitt Peak 1.3-m telescope are in the science-testing phase. The parent volatiles giving rise to the IR emissions studied under Theme I are photo-dissociated in the coma, producing the ?daughter? fragments (radicals) to be targeted by the MIAC filter imaging program.

Astrobiology undergraduate courses taught Goddard Team Co-Is

Three undergraduate astrobiology courses were developed and taught by Goddard team Co-Is in the fall 2004,

Astrobiology and Life in the Universe Eckerd College http://home.eckerd.edu/~hudsonrl/chn/CH210/index210.htm CH210, Fall Semester, 2004 Instructor: Reggie L. Hudson (Co-I)

Life in the Universe University of Maryland College Park ASTR380, Fall Semester, 2004 Instructor: Marla H. Moore (Co-I)

Cosmos to Humanity: From the Big Bang to the Space Age Biology 290H, Fall Semester, 2004 Lecturer W. M. Irvine (Co-I) (astrobiology component in a larger course)

Summer Undergraduate Internship in Astrobiology

The 2005 program had 24 applicants, 8 Students selected and 6 accepted to work with Moore, Mumma, DiSanti, Dworkin, Deming, Mahaffy, and Bonev. Students visited the labs of Co-I Marla Moore, Richard Walker (UMCP), Paul Mahaffy, Joe Nuth, Jason Dworkin and the UMCP Astronomy Dept with presentations from Lee Mundy, Derek Richardson and took a field trip to Greenbank Radio Observatory. Our students met with visiting interns from the Penn State astrobiology program for a one-day set of talks and tours at Goddard on June 28, 2005. Students also met with MIAC educators during their visit to GSFC in early July

2005 GSFC Undergraduate interns (I) and their mentors. Left to right: Boncho Bonev, Jeff Pedelty, Michael DiSanti, Jason Dworkin, Zachery Pozun (I), Shannon Tronick (I), Constantinos Makrides (I), Yana Radeva (I), James Doty (I), Karen Horning (I), Drake Deming, Michael Mumma, Marla Moore

GSFC and Penn State interns tour the clean room during the Penn State team's visit to GSFC

GSFC and Penn State interns tour the cosmic ice lab during the Penn State team's visit to GSFC

NASA Explorer Institutes initiative for Informal Education

1) NASA Explorer Institutes initiative for Informal Education

National Park Service--From Earth to Sky was a program that ran concurrently at NASA AMES and NPS Training Center in Shepherdstown, WV. Participants included 50 National Park Service Interpreters. Stockman served on planning committee, identified potential Astrobiology speakers (Mike Myer) and represented NAI EPO during workshop. Girl Scouts USA--A Vision for Girls in Earth and Space Science was a two part program a including a workshop at JPL to train experienced GSUSA trainers and a workshop at GSUSA training Center in NY to train novice trainers. The participants included 30 GSUSA regional trainers. Stockman served on the planning committee and lead activities linking earth and space science.

NASA Explorer School Institutes - Formal Education Initiative

Workshops were held at Regional NSTA meetings in Indianapolis (30 K-12 teachers) and Seattle (52 K-12 teachers). Stockman was involved in planning and implementation for both 4 hour workshops. The Indiana science presenter was NAI PI Lisa Pratt and U. Washington presenter for Seattle workshop was a member of the University of Washington NAI team. Stockman led Astrobiology hands on activities during workshops.

Fall 2004 AGU GIFT workshop

The GiFT program is a two-day workshop held in conjunction with AGU Fall meeting and the theme for the 2004 meeting was ?Extreme Exploration. Stockman was workshop organizer and 35 K-12 and community college educators participated. The workshop included Astrobiology and NAI overview by Rosalind Grymes and NAI education modules as hands on activities.

Publications: NASA Goddard Space Flight Center

There are **33** publication entries for the NASA Goddard Space Flight Center

Beaty, D.W., Miller, S., Zimmerman, W., Bada, J., Conrad, P., Dupuis, E., Huntsberger, T., Ivlev, R., Kim, S.S., Lee, B.G., Lindstrom, D., Lorenzoni, L., Mahaffy, P., McNamara, K., Papanastassiou, D., Patrick, S., Peters, S., Rohatgi, N., Simmonds, J.J., Spray, J., Swindle, T.D., Tamppari, L., Treiman, A., Wolfenbarger, J.K. & Zent, A. (2004). Planning for a Mars in situ sample preparation and distribution (SPAD) system. *Planetary and Space Science*, 52:55-66.

Benna, M. & Mahaffy, P. (2004). MHD model of comet 46P/Wirtanen [Abstract]. *35th COSPAR Scientific Assembly*:1484. Paris, France.

Benna, M. & Mahaffy, P.R. (2004). CASIM: A Multi-fluid MHD Cometary Atmosphere Simulator [Abstract]. *American Geophysical Union, Fall Meeting 2004*:Abstract #P31A-0975.

Benna, M., Mahaffy, P.R., MacNeice, P. & Olson, K. (2004). A Multiscale Central Difference Scheme Applied to Magnetohydrodynamic Simulations of Cometary Atmospheres. *The Astrophysical Journal*, 617 (1):656-666.

Bockelee-Morvan, D., Crovisier, J., Mumma, M.J. & Weaver, H.A. (2005). The Composition of Cometary Volatiles. In: M. Festou, H.U. Keller & H.A. Weaver (Eds.). *Comets II* (pp. 391-423). Univ. of Ariz. Press.

Bonev, B.P., Mumma, M.J., Dello Russo, N., Gib, E.L., DiSanti, M.A. & Magee-Sauer, K. (2004). Infrared OH Prompt Emission as a proxy of water production in comets: Quantitative analysis of the multiplet near 3046 cm-1 in Comets C/1999 H1 (Lee) and C/2001 A2 (LINEAR). *Ap. J.*, 615:1048-1053.

Bonev, B.P., Mumma, M.J., Dello Russo, N., Gib, E.L., DiSanti, M.A. & Magee-Sauer, K. (2004). Infrared OH Prompt Emission as a proxy of water production in comets: Quantitative analysis of the multiplet near 3046 cm-1 in Comets C/1999 H1 (Lee) and C/2001 A2 (LINEAR). *Astrophysical Journal*, 615:1048-1053.

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Executive Summary: University of Hawaii

Executive Summary: University of Hawaii
Principal Investigator: Karen Meech
Reporting Period: 2005 (7/04-6/05)

Water is the medium in which the chemistry of all life on Earth takes place. Water is the habitat in which life first emerged and in which all of it still thrives. Water has modified Earth's geology and climate to a degree that has allowed life to persist to the present epoch. We propose to create a research and education framework that links the biological, chemical, geological, and astronomical sciences to better understand the origin, history, distribution, and role of water as it relates to life in the universe. We focus on scenarios involving the sources and distribution of water in planetary systems and the delivery and incorporation of water into rocky planets that orbit within stellar habitable zones. Our framework connects research on major aspects of planetary water – in effect we aim to understand the terms of a "watery Drake equation". Sub-themes of our research include:

- Water is formed in the interstellar medium and in the denser molecular clouds that give rise to star-forming regions. Differences in elemental abundance, gas-phase chemistry, and grain chemistry will result in measurable variation in the abundance of water in those regions. Our team will use sub-millimeter and infrared facilities to quantify the presence of water ice in the interstellar clouds, and to characterize and understand the environments where water exists in space.

- Comet ices preserve a chemical record of this precursor interstellar material, and detailed remote measurements of the isotopes of hydrogen in these icy bodies has shown that comets contributed some, but not all of the water to the Earth's oceans. Comets are also rich in the organic materials which are essential for life on Earth, and team members will investigate the inventory of both organics and ices in these small outer solar system denizens: comets, Centaurs and Kuiper Belt objects.

- Because of the high abundance of water ice in the interstellar medium, water has played a vital role in physical and chemical processes which have lead to the formation of astrobiologically important molecules. UH NAI team members will perform cutting-edge laboratory chemistry experiments to address the questions of how the basic life ingredients can be formed abiotically in extraterrestrial environments such as molecular clouds and the crucial role that water has played in their formation, and to understand the physical processes.

- UH NAI team will use lab equipment to study the minerals in meteorites which formed as a result of interaction with liquid water early in the solar system. These minerals preserve a record of aqueous activity in their parent bodies that provides information about the abundance and distribution of water in the primordial solar nebula. The meteorites record the incorporation of water into silicate material in the primordial Solar System as an early step in its eventual inclusion in larger bodies, including planets. The cosmochemical record in meteorites shows that a large range of water abundance existed in the early Solar System, perhaps as a result of removal of water from the warm interior of the primordial nebula.

- Mars is the planet most resembling Earth, it contains unambiguous evidence for the activity of past and present water, and is probably the most likely to host or have hosted extant or extinct life. Studies of the history and action of water on Mars are thus of great importance in this regard. Our studies will model the hydrothermal and low-temperature alteration of crustal minerals and rocks by water, and team members will combine this with data from Earth observations and recent Mars missions to assess the Mars water inventory and its habitability.

- Water has been involved in life since its first appearance on early Earth. Leading life origin theories invoke prebiotic chemistry in low-temperature aqueous solutions, supplied with prebiotic molecules by atmospheric chemistry, or in the hydrothermal brines produced by high-temperature water-rock interactions. The first 3 Gy of life on this planet was played out entirely in aquatic environments. Water is also involved in geochemical reactions that maintain surface conditions permissive of life. The presence of water significantly alters the properties of minerals in Earth's crust and mantle,

something crucial to the operation of plate tectonics. We are investigating the water-rock chemistry in the deep oceans and its relation to habitats for life. The reaction between silicate rocks and water, at high temperature (submarine hot springs near mid ocean ridges), produces aqueous fluids and altered mineral surfaces whose thermodynamic disequilibria are potential energy sources for life

- Besides water, life also requires a source of carbon and nutrients, and an environment that is conducive to the propagation of genetic information. Many aquatic environments on Earth are extreme from this point of view. By studying these we can better understand what may limit the origin and persistence of life in aquatic habitats elsewhere in the universe. These extreme environments include lava-water interfaces in the Hawaii Volcanoes National Park as the magma from Kilaeua flows into the ocean, as well as steam geysers, high altitude, and field work in volcanically active Iceland. We will focus here on a comparative study of microbial biodiversity and metabolic activity in these extreme aquatic habitats.

- We will develop an integrated model of planetary water and its early history on Earth-like planets, which can be used to explore the time-evolution of water on the early Earth, as well as Earth-size planets whose space environment or composition differ from Earth's. Extraterrestrial aquatic environments may be far more extreme than most encountered on Earth. Water inventories and cycles in Earth-sized planets around other stars may be quite different from our own. Planetary water abundance may be a very sensitive function of the chemistry in the planet-forming nebula, the water abundance in that nebula, the presence of giant planets and factors such as ultraviolet radiation from the central star.

- Finally, we will develop concepts and prototype hardware for instruments that could be used to detect and characterize life on other planetary bodies. By developing and testing models and exploring the outcomes of alternative scenarios we seek to determine what controls the abundance and distribution of water and hypothetical aqueous habitats in other planetary systems. This research will directly support the NASA search for past or present life on Mars and efforts (such as the NASA Terrestrial Planet Finder) to directly detect and characterize Earth-sized exoplanets.

Accomplishments

Science Highlights

- During year 7 we have improved our experimental apparatus for ultra-high vacuum ice irradiation experiments. In addition to experiments on pure water ice, our team has investigated the formation of the amino acid glycine, and several other organic and inorganic molecules which may be important constituents of outer solar system surfaces.
- Research continues in the area of looking at eruptive events in young variable stars. Such events are important not only for the growth it provides to the young star, but also for processes of irradiation of disk material, which may give clues to the short-lived intense heating events that affected chondrites and aqueous alteration products in the early solar system. Planetary magnetic fields play a critical role as a shield against irradiation of the planet’s atmosphere. New work is beginning in our group in order to investigate the signatures of extrasolar planetary magnetic fields and to try to understand planet-star interactions, including both stellar activity and extreme-ultraviolet radiation.

- We have an active program of KBO research which includes orbital studies, physical observations to study the state of the water and organic material on the surfaces of these small outer solar system bodies, in addition to chemical modeling and ice irradiation experiments. A parallel study of the composition of chondritic meteorites and the different aqueous alteration processes will allow us to search for links between different primordial solar system materials.

- Related to the study of KBOs and comets and the laboratory ice irradiation experiments is a joint observational and laboratory program to understand the comet activity seen in small bodies far from the sun, where equilibrium temperatures are too cold for water ice to sublimate. These investigations help us understand the chemistry and physical processes in the outer solar system.

- Progress had been made in modeling several aspects of the planet formation processes including dust

grain growth, satellite accretion, and delivery of icy planetesimals (water) to the habitable zones of planetary systems.

- Several areas of research within our team are looking at placing limits on the duration of aqueous alteration events on Mars, and the stability of ice in sublimation environments on Mars, the Moon and in Antarctica. These investigations are combining modeling with laboratory data, meteorite data and space mission observations.

- UHNAI support has contributed to the development of a center for mass spectrometer development at UH, as well as for the establishment of the Keck Cosmochemistry Laboratory (lead by co-I K. Keil). The lab will be an interdisciplinary environment centered on the delivery of a new ion microprobe (to be delivered by the end of 2005). This new facility will be used to address UH NAI science goals, including investigating how stars, planets and solar system material formed and evolved, looking at the origin of Earth's water, and understanding processes in interstellar clouds and star forming regions. Linking ion microprobe data from meteorites and comet dust to astronomical observations, while harnessing the perspectives of astronomers, chemists and meteoriticists, will fuel our studies of our origins. Gary Huss has joined the group as head of the laboratory.

- Looking at the interaction of water and life on Earth, other members of the UHNAI team are working on understanding how biomolecular structure allows microorganisms to adapt to extreme aqueous environments. Thriving microbial communities have been discovered inhabiting physical and chemical regimes which were once assumed to be limiting to life. In related work, our group is beginning a new initiative to study key steps in the evolution of complex life and the potential relationship to aqueous conditions at the time of those events.

- The team is conducting an exploration of other extreme extreme environments through the utilization of the Ocean Drilling Program borehole observatories to access fluids which sample the sub-seafloor basement biosphere. The efforts are being directed at developing equipment and methods to extract high integrity samples for microbial genetic and metabolic experiments and to characterize the physical conditions in these environments. Our researchers are also part of a rapid response team that can take advantage of seafloor eruptive events which can make material accessible that is not normally sampled. In addition, the team is studying the chemistry at the seafloor, and has made significant progress in understanding the origin of methane and extremely high pH levels in the Mariana forearc.

- Team members are also setting up to conduct new field work in extreme environments with plans to investigate the sub-surface biosphere in lava tube ecosystems, and an expedition is being planned next year in Iceland to explore sub-glacial lakes, based on new equipment built and tested this year.
- Many of the research programs being undertaken by the team can benefit from automation and the development of new interdisciplinary computational tools. We are applying genetic algorithms, sophisticated database development, and AI techniques to many of these problems. These new tools will ultimately be useful and implemented for remote autonomous operation of equipment in extreme environments and in space.

Other Collaborative Efforts

- As an outgrowth of ideas seeded during the post-conference tours during the Bioastronomy 2004 meeting in Iceland a collaborative effort has begun tying together researchers from the UCLA team (E. Young), the Goddard team (M. Mumma) and our Icelandic colleagues to investigate the origin of Earth's water. Team member G. Huss made ion microprobe measurements on 7 samples from Iceland in order to develop techniques for D/H measurement in preparation for submitting a major proposal to the NASA Interdisciplinary Exploration Science Program.

- We are collaborating with Lowell Observatory colleagues in order to gain access to some telescope time for our UH NAI research and outreach programs. To this end we have been developing an intelligent scheduler for automated scheduling of the telescope driven by requests. The Lowell 31-inch telescope observing database has been upgraded. An interface to interact with the database has been created, and an intelligent scheduler developed and nearly fully debugged. The complete system will

be used for scheduling astronomical observations, both for research and outreach.

Mission Involvement

- UH NAI Principal Investigator K. Meech is a co-Investigator on NASA's Deep Impact mission. In addition to continuing to obtain data on the mission target, 9P/Tempel 1 from Nov. 2004 through encounter, Meech undertook the major coordination of world observatories leading up to and during encounter. Along with the outreach activities, these efforts involved 5 postdocs and 5 graduate students.

- Co-I Toby Owen is heavily involved with the Cassini Saturn mission.

Scientific Conferences & Meetings

Bioastronomy 2004 Meeting – Reykjavik July 12-16, 2004

The series of previous Bioastronomy meetings have played an important role in integrating the broader interests and techniques of both astronomy and biology to understand the origin and evolution of living systems in the universe, and to generating a context for exploration in our solar system and in extrasolar planetary systems. These conferences provide an opportunity for astronomers, biologists, geologists, planetary scientists and those from other disciplines to meet and discuss research of mutual interest for addressing the question of the origin and evolution of life on this planet and elsewhere. Iceland was selected as the meeting site because of its unique environment, boasting a unique sub-arctic ecosystem, at the separating boundary of the Eurasian and North American continental plates. Subglacial Icelandic volcanic eruptions and deposits in Antarctica help us to understand the ice/volcano interacting both on Earth and other astrobiologically important environments.

The SOC, lead by Alan Boss, consisted of 15 international NAI members and collaborators, and the LOC, chaired by Thorsteinn Thorsteinsson of 10 Icelandic colleagues and K. Meech. A total of $104,844 was raised in support of the meeting, from NASA, NSF and private sources, much of this earmarked for travel support. We were able to provide substantial travel support for 24 participants. A total of 230 abstracts were submitted to the conference, 54% from the US, 32% from Europe, 11% from Australia and 19% from other countries. These abstracts were divided into 100 invited and contributed oral talks in a single plenary session, and 130 poster talks. The conference was held at the University Cinema and Conference and Cultural Center on the campus of the University of Iceland and was supported with services from Iceland travel. There were 3 public talks organized during the conference: K. Meech: "Water and Life in the Universe", E. Gaidos: "Life Under Ice: From Iceland to the outer Solar System", and A. Boss: "Looking for Earths in Nearby Solar Systems". A mid-week teacher workshop was organized by UH NAI EPO lead Mary Kadooka and SETI Institute member Pamela Harmon in conjunction with Icelandic colleagues Asta Thorleifsdottir and Thorsteinn Thorsteinsson. Finally, there were 3 post-conference field trips organized to highlight both the unique geology and sub-arctic biology of Iceland as well as Icelandic history.

Star and Planet Formation Day – June 24, 2005

Bo Reipurth organized the Star and Planet Formation Day at the Institute for Astronomy in Hilo. Nineteen talks were presented on a variety of topics in star and planet formation, all by researchers residing within one of the institutes in the Hawaiian islands. About 50 persons attended. The goal of these yearly mini-workshops, of which this is the second, is to bring together all active researchers within Hawaii in the field of star and planet formation, the early solar system, and meteoritics, to present on-going research, and to stimulate joint research across the boundaries of these disciplines.

09:30	Harold Butner (JAC)	Comet Observations using the JCMT
09:50	Chad Trujillo (Gemini)	Latest Surface Constraints, the Two Intrinsically Brightest KBOs
10:10	Robert Jedicke (IfA)	The Thousand Asteroid Light Curve Survey

10:30	Joseph Rhee (Gemini)	Gemini Debris Disk Database and Search for IR Excess Stars
10:50		Coffee Break
11:10	Crystal Brogan (IfA)	SMA Observations of High Mass Protostellar Objects
11:30	Jonathan Williams (IfA)	SMA Observations of the Orion proplyds
12:00		Lunch
13:00	G. Moriarty-Schieven (JAC)	L1551 - Sequential Starburst
13:20	Chris Davis (JAC)	AO-corrected IR spectroscopy of the base of the SVS13/HH7-11 jet
13:40	Michael Connelley (IfA)	An Infrared Imaging Survey of Nearby Class I Objects
14:00	Tracy Beck (Gemini)	Tracy Beck (Gemini)
14:20	Michihiro Takami (Subaru)	Subaru IR Echelle Spectroscopy of Herbig-Haro Driving Sources
14:40	Watson P. Varricatt (JAC)	A Near IR Imaging Survey of Massive Young Stellar Objects
15:00		Coffee Break
15:30	Evgenya Shkolnik (IfA)	Spectral Signatures of Star-Planet Interactions
15:50	Eric Gaidos (SOEST)	Physics of Planetary Winds and Some Consequences
16:10	Nick Moskowitz (IfA)	Hydrodynamic Mass Loss of Planetary Atmospheres
16:20	Eugene Magnier (IfA)	Resolving the Brown Dwarf Deficit in Taurus
16:40		Bo Reipurth Persson's Star: A New FU Orionis Object

Protostars and Planets Meeting – October 24-28, 2005

Bo Reipurth is the principal organizer of the Protostars and Planets V conference. The Protostars and Planets series of conferences are the flagships in the field of star and planet formation and meteoritics. Held every 7 years, they review the state of the field and bring scientists and students together from a wide range of disciplines. The PPV conference will be held at the Waikoloa Hilton on the Big Island of Hawaii from 24 to 28 October, 2005. Karen Meech and Bo Reipurth are co-chairs of the Local Organizing Committee. Full details will be given in next years report.

Staffing and Infrastructure

The UHNAI team welcomed several new people to the group:

- Michele Sonoda – our new astrobiology assistant, has taken over the management of our visitor program, and our visitor apartment, Astro Hale. In addition, she is handling all group purchasing, travel and logistics for meetings and workshops.

- Minghui Chen – is our new NAI computer support person. He has spent the spring developing a new web-driven purchasing database system that the team can use for submitting purchasing requests for review and action. This is coupled to our budget database for accurate tracking of expenses. Ming has also been developing the new web page for our group, and has been working with our publications editor to start a series of Astrobiology Research Discoveries articles and bring them online.

- Evgenya Shokolnik – is our new NRC postdoc, and she arrived early in 2005 to work with E. Gaidos

on extrasolar planets.

- Karen Stockstill – is a new postdoc working with team members Scott Anderson and Jeff Taylor on Mars research, and is partly supported by and collaborating with our NAI group.

- Jacqueline Keane – currently at NASA Ames, has been selected to be one of our new UH NAI postdocs, and she will be arriving during the fall 2005.

Education/Public Outreach Activities

The UH NAI has been very active in its outreach programs this year. Our formal education program included an international Astrobiology Winter School, developed by B. Reipurth and K. Meech, which hosted 39 graduate students and young researchers, and was held in Hawaii from January 10-21, 2005 on the theme of Water on Earth and in Space. Additionally, we offer several courses (Astrochemistry, an Astrobiology Seminar, Special Topics in Astrobiology through the Planetary Ecosystems & Biosystems Lab (PEBL), and an Astrobiology course through the Information and Computer Science Department).

Our EPO activities are grouped into K-14 workshops for students and teachers, public talks, involvement in the Hawaii State Science Fair, and we have hosted a traveling Astrobiology exhibit. The combined contact hours for the formal and informal education programs this year are large (17,069 hours), in part because of the Deep Impact Encounter. We are also developing a new collaborative effort with personnel at the Hawaii Volcanoes National park in partnership with the NASA Ames NAI lead team.

- Alii Summer Teacher Workshop – The Astrobiology Laboratory Institute for Instructors is held for 1 week each summer and gives teachers hands on experience and content background in astrobiology, with the participation of a large fraction of our team.

- Deep Impact and the Faulkes Telescope Facility – During the spring, leading up to and including our team's participation in the Deep Impact mission, we conducted 4 teacher workshops in collaboration with teachers from Iceland and the UK, and had 4 public lectures related to the mission.
- Deep Impact Encounter – The UHNAI team participated in 4 major activities at encounter ranging from public events at the Maui Community college (400 people), Univ. of Hawaii at Hilo (500 people), a Lecture at Sunset on the Beach (10,000 people) and activities at the Bishop museum.

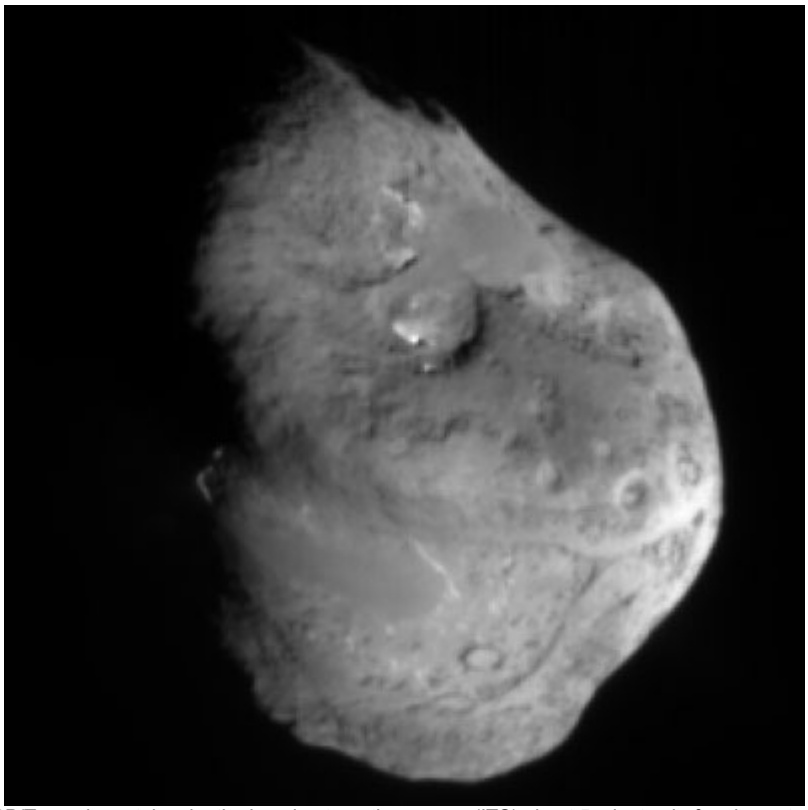
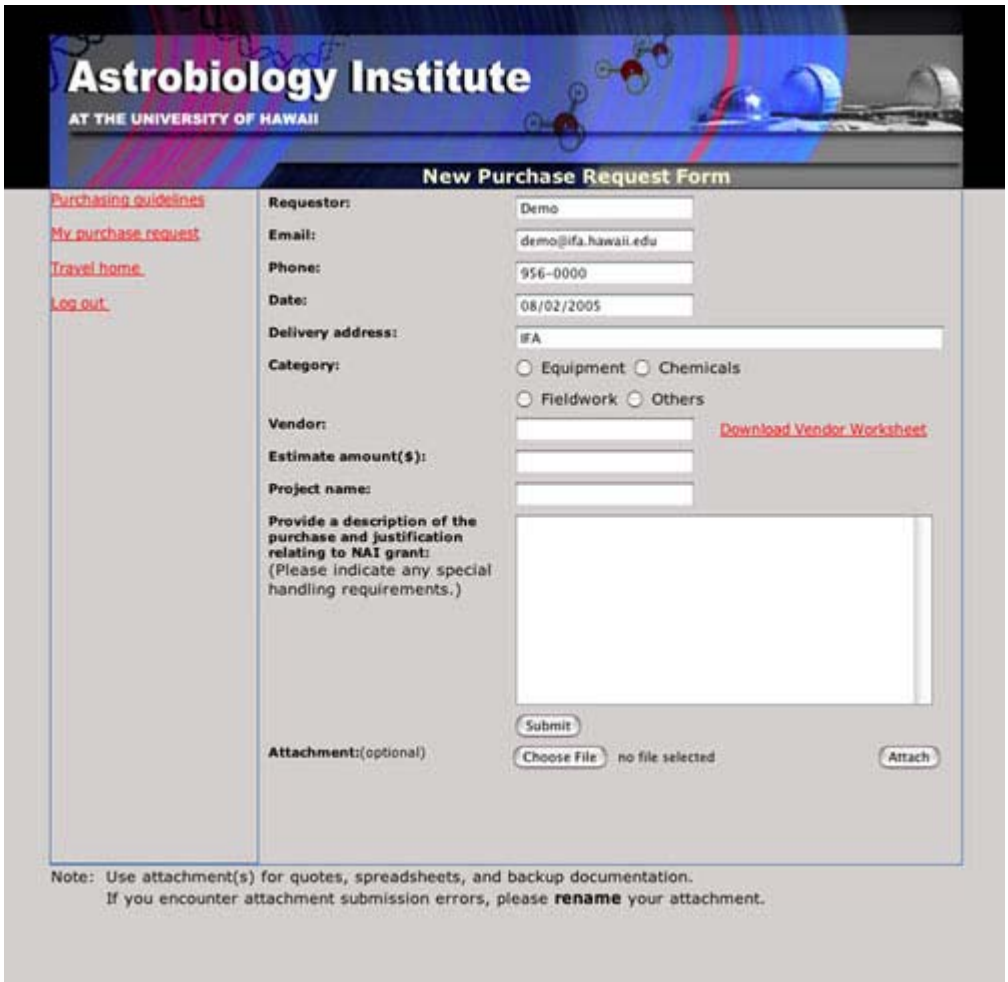


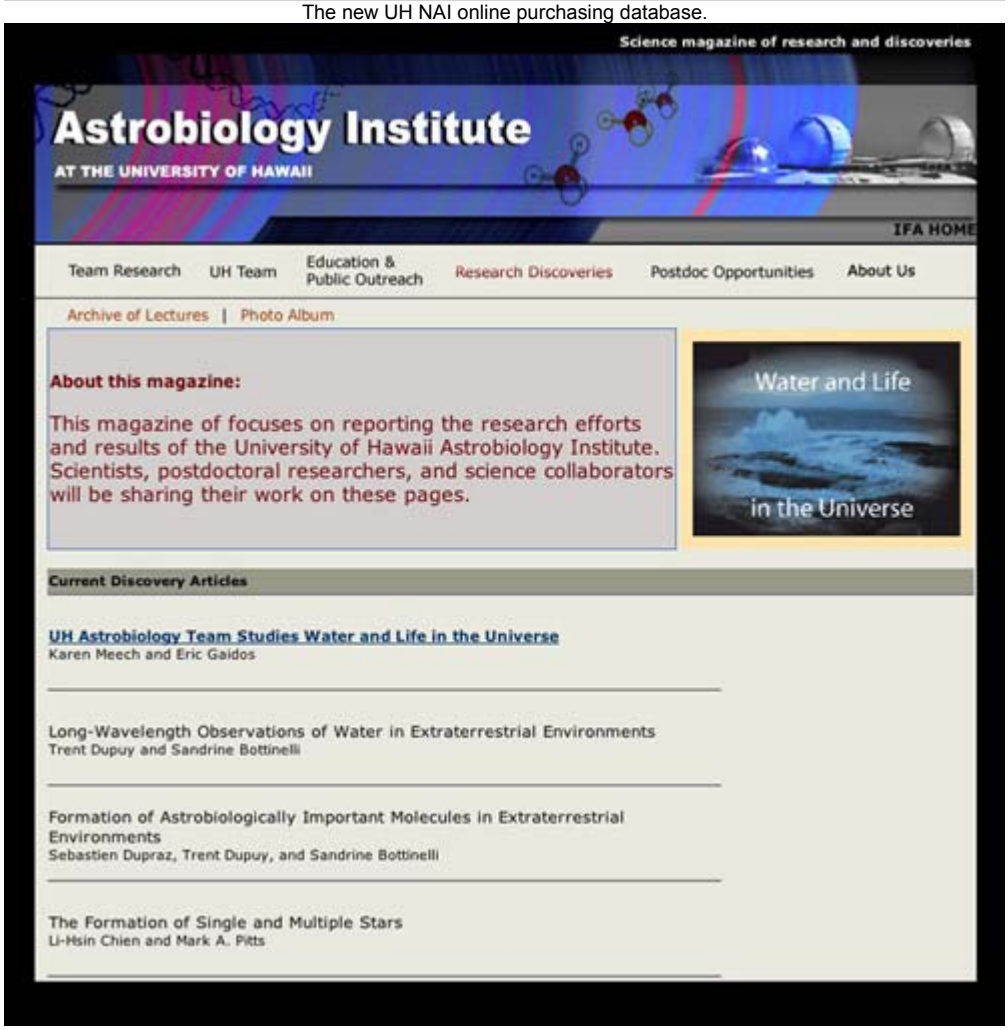
Image of the nucleus of comet 9P/Tempel one taken by the imaging targeting sensor (ITS) about 5 minutes before impact. Credit: NASA/JPL-Caltech/UMD

Impact of comet Tempel 1.67 seconds after impact, taken with the high resolution camera. Credit: NASA/JPL-Caltech/UMD

The new UH NAI website.



The new UH NAI online purchasing database.



Project Reports: University of Hawaii

Chondritic Meteorites as Records of Aqueous Activity on Asteroidal Parent Bodies

Project Investigator:

Project Progress

Carbonaceous chondrite meteorites contain abundant evidence of aqueous alteration that occurred on the asteroidal parent body. We have been investigating several components of these meteorites in order to better understand aqueous alteration and the formation of these components.

1) Amoeboid olivine aggregates effectively document parent body alteration. With an REU student, we have been imaging and analyzing the chemical composition of these aggregates in order to constrain the alteration history of 9 CO_3 chondrites which have not been extensively studied before. This will increase the number CO_3 chondrites with known alteration level to 22. We will be able to better understand the distribution of the different alteration levels on the parent asteroid which should yield insights into the mechanisms and dynamics of asteroidal alteration.

2) Refractory inclusions are thought to have formed 2-3 Ma before chondrules (mm-sized igneous spherioles). These objects have fine-grained accretionary rims around them in CO_3 chondrites. We have been analyzing the chemical composition of these rims in order to determine if these rims document any chemical evolution of the solar nebula. Our preliminary data shows that the rims are identical regardless of which object they surround. This implies that the rims formed at the same time and therefore, the chondrules and inclusions must have been brought together before rim accretion. This has implications for dynamic models of solar system evolution.

3) The fine-grained materials in carbonaceous chondrites contain a significant amount of amorphous material. In order to test the hypothesis that these materials could have accreted in an amorphous state, we have set up experiments to aqueously alter artificially produced amorphous smokes and will analyze their resultant textures and mineralogy. We will react the smokes to cold water (5° C), warm ice (ice + ethanol: -10° C) and cold ice (CO_2 + ethanol: -78.5° C).

Roadmap Objectives

- **Objective No. 2.2:** Outer Solar System exploration
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts

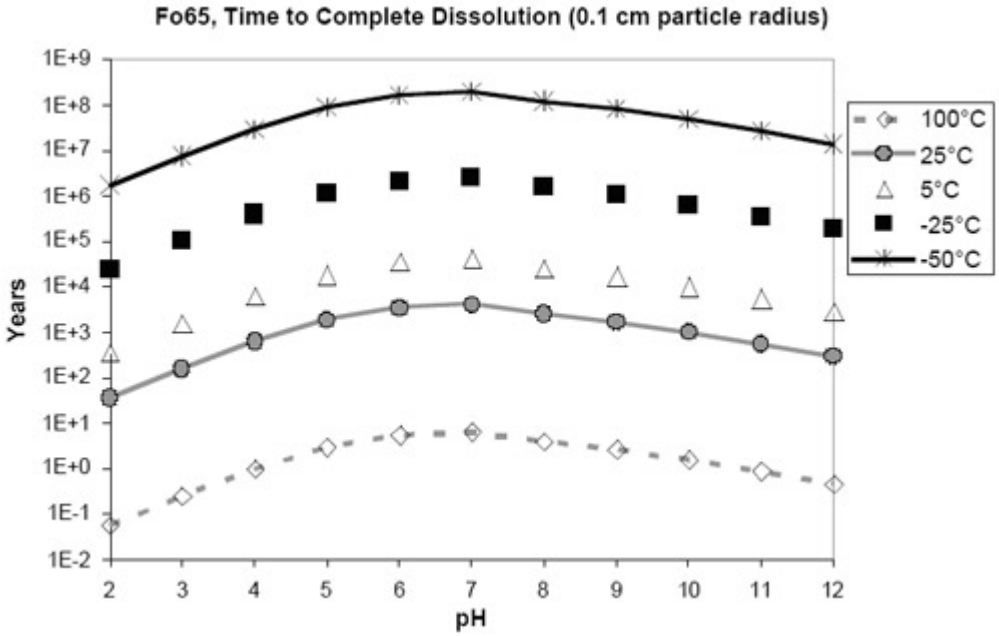
Aqueous alteration on Mars

Project Investigator: Jeff Taylor

Project Progress

This project focuses on using our understanding of aqueous alteration from terrestrial laboratory experiments and field observations to try to place limits on the duration of aqueous alteration events on Mars. We are working on several aspects of this. We describe the most mature one here (to be submitted for publication in August, 2005).

Olivine alteration: Orbital, landed, and meteorite data show that liquid water shaped the Martian surface, raising the possibility that life could have originated. An important question is how long each epoch of wet conditions lasted. The duration can be inferred from mineralogy and chemical composition of surface materials, from millimeter to multi-kilometer scales. The products formed during wet periods depend on crustal composition, mineral dissolution, temperature, water chemistry, pH, and rock/water ratio. Dissolution rates have been measured in both the laboratory and the field. Studies show that dissolution rates are 100 to 10,000 times slower in the field than ideal laboratory conditions. This difference is largely controlled by rock permeability and local rock/water ratio. Nevertheless, laboratory studies can provide useful lower limits for the duration of aqueous events on Mars. We calculate that areas rich in olivine sands (such as at Meridiani Planum) could not have been exposed to water for more than a few thousand years at conditions far from equilibrium. For example, the residence time of a 0.1 cm (radius) particle of Fo_{65} composition at 25°C ranges from ~40 years at pH 2 to ~4,000 years at pH 7 (see figure). At lower temperature (5°C), dissolution of the same particle will take ~10 times longer. We also use observations of Martian meteorites to gain insight into alteration processes on Mars and the nature of incipient alteration. MIL 03346 (a nakhlite) shows incipient alteration of olivine, providing clues into the difference between laboratory and field rates.



Roadmap Objectives

- **Objective No. 2.1:** Mars exploration

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
0	Mars Odyssey	

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Deep Impact Target Characterization

Project Investigator: Karen Meech

Project Progress

The Deep Impact mission is the first planetary mission to carry out direct experimentation on a cometary body by delivering a 360-kg impactor to comet 9P/Tempel 1 at 10.2 km/s on UT July 4, 2005. UHNAI team members were closely involved in the world-wide effort of ground- and Earth-orbital observations to characterize the target nucleus pre-impact and to observe throughout the period of Encounter. The specific accomplishments during year 7 for this mission included:

- 6 nights of telescope time on the Univ. of Hawaii 2.2m telescope to observe the development and evolution of the dust coma. Beginning in Nov. 2004 observations revealed that the outgassing had begun the development of the coma, and by January 2005, jets were observed. Deep composite images are enabling the team to apply dust-dynamical models to the images to understand the grain size distributions in the coma, the grain ejection velocities and when the activity began. Deep searches for large particles left in a dust trail from the previous apparition were negative, suggesting the absence of small particles.
- 3 half nights were awarded on the Keck 10-m telescope for low resolution spectroscopy to observe the onset of sublimation and measure the production rates of gas species (CN, C_2, C_3, NH_2, OH).

  Simultaneous observations of the dust indicated that the coma grew redder as the activity increased, consistent with the increased outflow of gases being able to lift larger particles off the nucleus.

- Astrometric (position) measurements were made for the entire 8 year database of observations that we had for the comet and contributed to the orbit solutions used to navigate to the comet. Of the total world-wide observations, only 951 were high enough quality to be used in the orbit solution, and 374 of these were from Mauna Kea.

In addition to coordinating the world observing encounter effort through multiple video conferencing (with up to 32 sites simultaneously), and near real-time accessibility of observations from all sources via the web, UH NAI team members played a leading science role at encounter by leading several observing efforts and collaborating on several others:

- Dust evolution after impact (utilizing the Cerro Tololo interamerican observatory 4m, 1.5m, 0.9m and Schmidt telescopes, along with the CFHT 3.6m telescope on Mauna Kea): goal to assess whether the dust characteristics change post-impact.
- Gaseous isotope ratios using high resolution spectroscopy on Keck to examine fractionation processes in comet formation.

- Gas and dust volatile composition – using the Spitzer space infrared telescope to watch the evolution of organic species post impact.

- Light curve evolution – observations using the Hubble Space Telescope and the Lowell Observatory 72-inch telescope showed a complex light curve. We are analyzing this in the context of impact cratering dynamics.

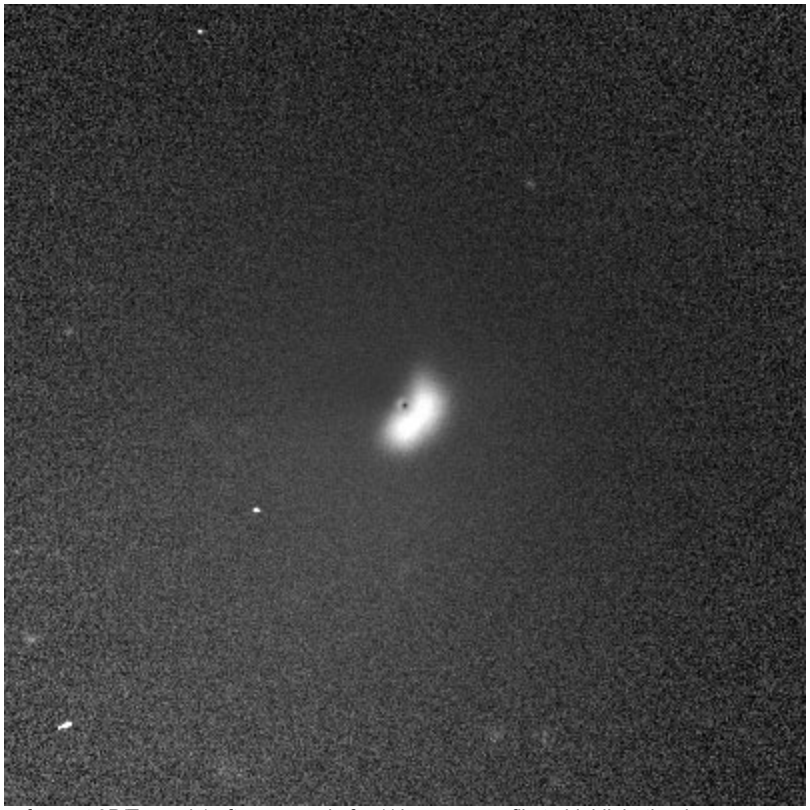


Figure 1. r-band image of the dust coma of comet 9P/Tempel 1 after removal of a 1/rho coma profile to highlight the dust structures in the coma. This image is from July 4, 2005 (using the CFHT telescope on Mauna Kea, Pittichova & Fernandez). N is up and E to the left in this image which is about 75 arcsec across, or about 50,000 km at the comet.

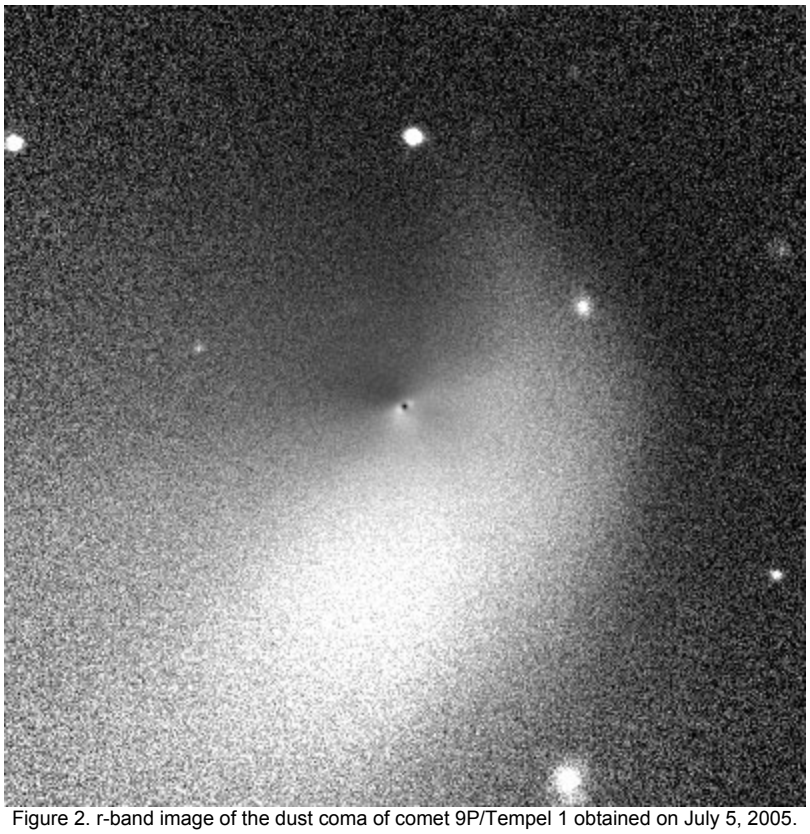


Figure 2. r-band image of the dust coma of comet 9P/Tempel 1 obtained on July 5, 2005.

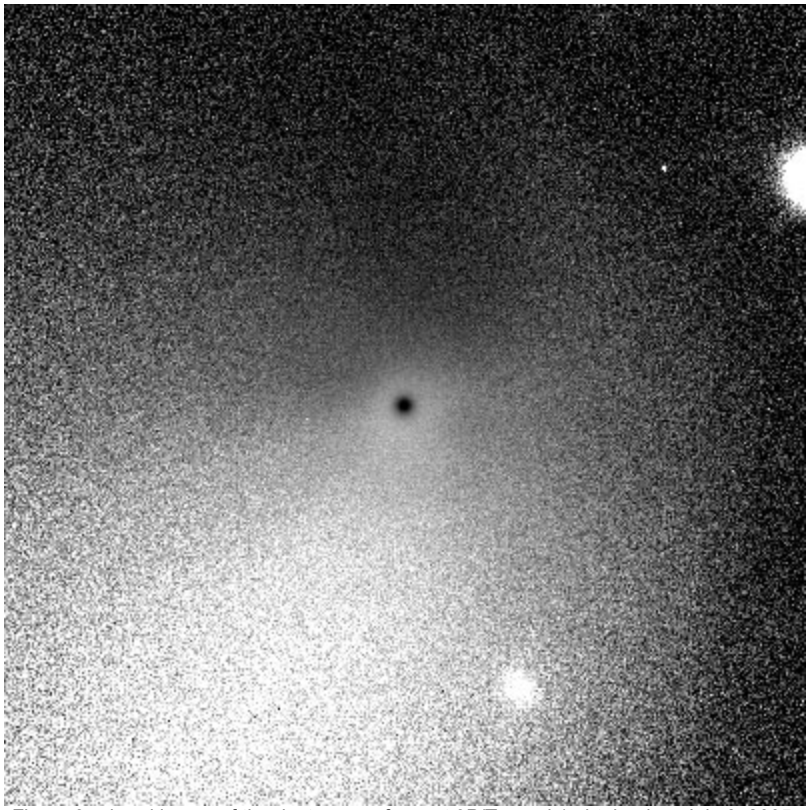


Figure 3. r-band image of the dust coma of comet 9P/Tempel 1 obtained on July 6, 2005.

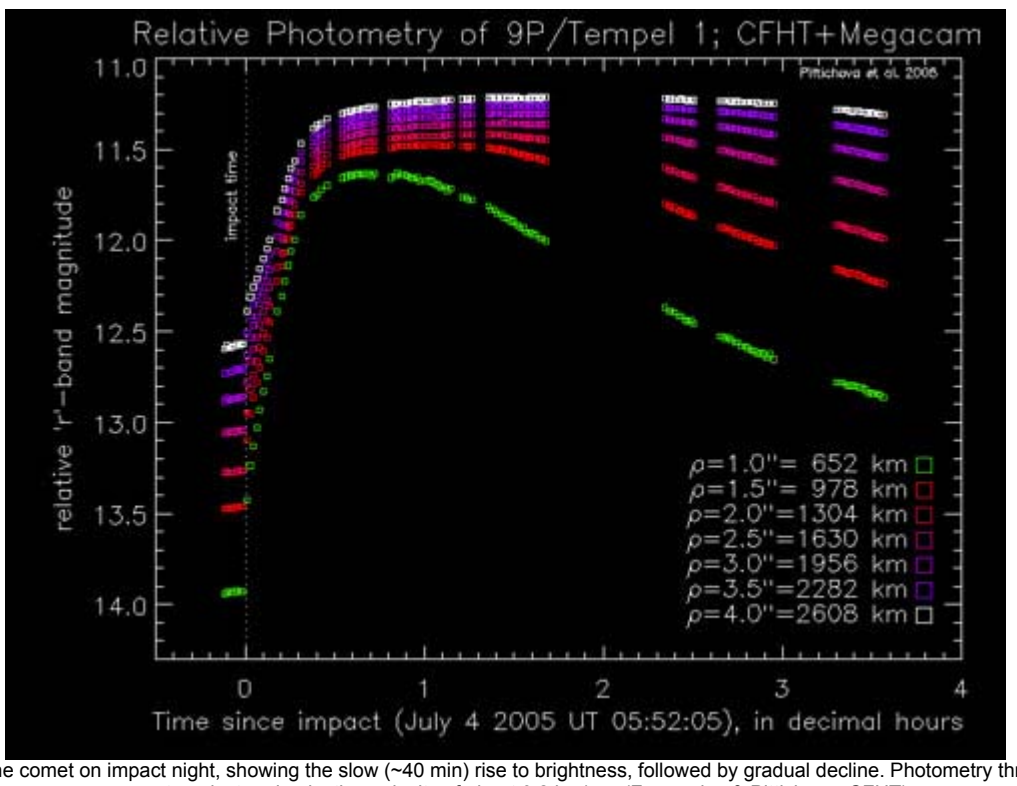


Figure 4. Light curve of the comet on impact night, showing the slow (~40 min) rise to brightness, followed by gradual decline. Photometry through different apertures suggests a dust grain ejection velocity of about 0.2 km/sec (Fernandez & Pittichova, CFHT)

Roadmap Objectives

- **Objective No. 2.2:** Outer Solar System exploration
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts

Mission Involvement

Mission	Mission Name (for class 1 or 2) OR	Type of

Class*	Concept (for class 3)	Involvement**
1	Deep Impact	Co-Investigator

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

The Deep Impact mission has relied heavily upon a ground-based and earth-orbital component to characterize the physical properties of the nucleus prior to encounter. This was both to help in mission planning and to understand the behavior of this comet prior to encounter so we could fully understand the differences post impact and identify the primordial signature of the comet and early solar system materials. Our team has provided the most comprehensive observational data set on this comet and has been collaborating on developing thermal models for its behavior. In addition, we have coordinated the world observing plan for encounter and have participated fully in the encounter observations from Earth and Space.

Integrated characterization of microbial communities associated with aquatic redox gradients

Project Investigator: Brian Glazer

Project Progress

Our investigations of oxic-anoxic transitions are focused on understanding the synergy between geochemical processes and microbial community and metabolic diversity. These studies not only further our understanding of geochemical cycles that have shaped the evolution of Earth but also have the potential to contribute to flight-related missions through the development of *in situ* measurement technologies.

(1) Subseafloor basement (basalt) biosphere studies:

Using UHNAI funds in 2004-2005, we have begun to acquire laboratory equipment and initiate the first environmental electrochemistry research effort at UH making use of solid-state voltammetric sensors **(Figure 1)**.

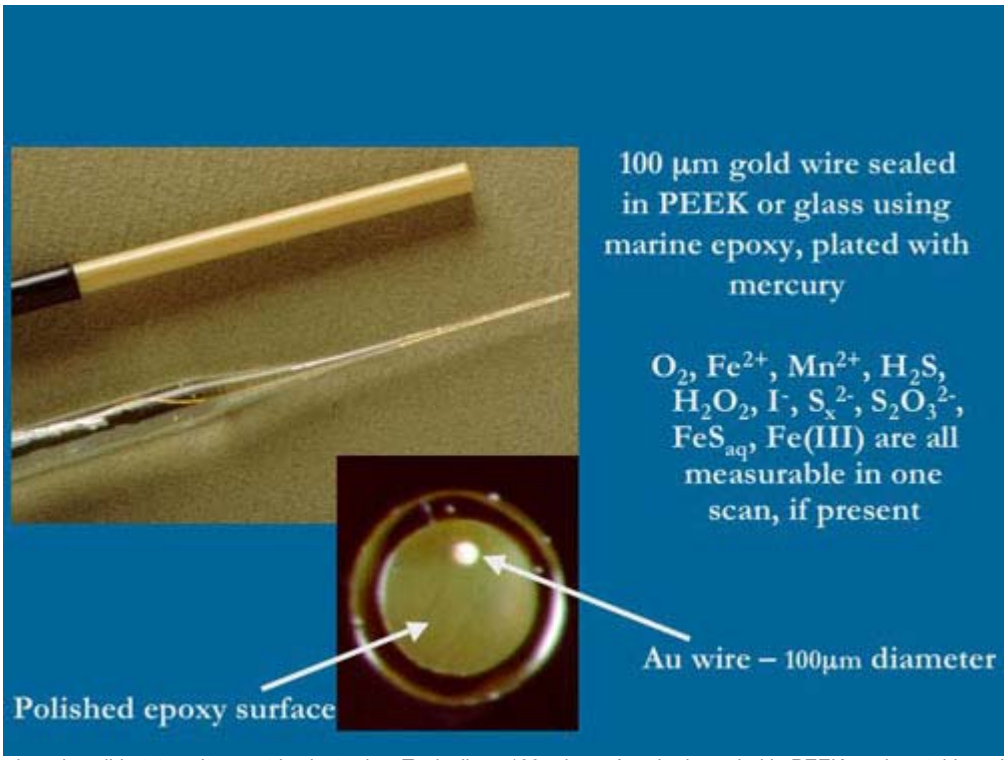


Figure 1. Pictured are the hand-made solid-state voltammetric electrodes. Typically, a 100-micron Au wire is sealed in PEEK or glass tubing with epoxy. The gold surface is then highly polished & an amalgam is made using a mercury nitrate solution.

Voltammetric techniques provide simultaneous, real-time detection of O_2, H_2O_2, HS^-, S(0), S_x^{2-}, S_2O_3, S_4O_6, Fe(II), Fe(III), $FeS_{(aq)}$, Mn(II), and Zn(II). We have leveraged the UHNAI funding with a grant awarded to Cowen and Glazer from NOAA Office of Exploration (NOAA-OE-2005-014) aimed at characterizing subseafloor hydrothermal fluids. We have already acquired and tested an *in situ* voltammetric analyzer capable of seafloor data-logging. A plumbing manifold has been designed and is being fabricated to attach to standard ODP borehole CORKs (Circulation Obviation Retrofit Kits). We are working with UH support engineers to mate the electrochemical analyzer to an *in situ* filtration unit and will deploy the unit from the manned submersible, DSV *Alvin*, during a cruise to the flanks of Juan de Fuca in September, 2005, targeting IODP borehole observatory 1301A, which is in Cascadia Basin. Another key development is that of wireless acoustic and optical communications between the submersible and our analyzer package. **Figure 2** represents a scale schematic of our deployment package at the borehole.

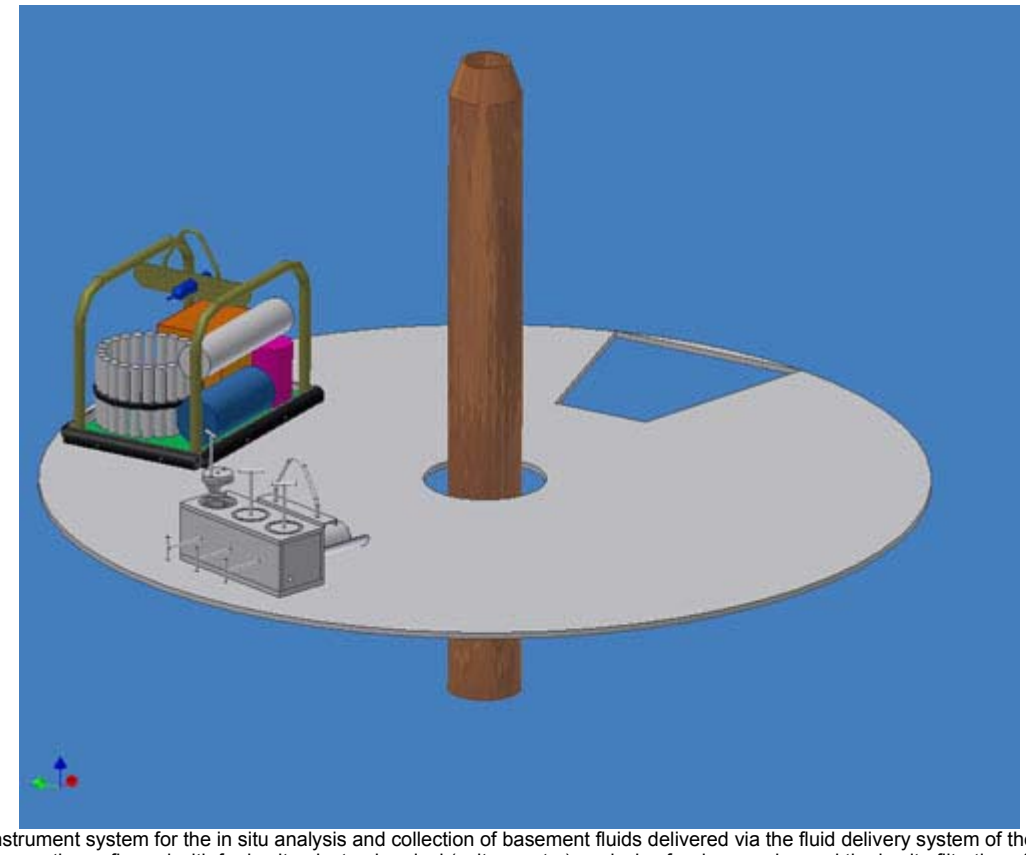


Figure 2. A seafloor instrument system for the in situ analysis and collection of basement fluids delivered via the fluid delivery system of the ODP borehole CORK Observatory. System is currently configured with for in situ electrochemical (voltammetry) analysis of redox species and the in situ filtration of multiple fluid samples for molecular biology, microbial culture and geochemical studies.

(2) Rapid response to remotely detected potential seafloor eruption:

Remote detection of seismic activity on the Endeavour Segment of the Juan de Fuca Ridge prompted a rapid response cruise aimed at detecting any large-scale hydrothermal plume that may have been released from seafloor magmatic events (March 2005). Although the team found no evidence for any seafloor eruption, we did successfully demonstrate evidence for the presence of partially-oxidized sulfur intermediates ($S_2O_3^{2-}$, S_x^{2-}, S(0)) in discrete water samples collected from chronic hydrothermal plumes over the Endeavour Vent Field, Juan de Fuca Ridge **(Figure 3)**.

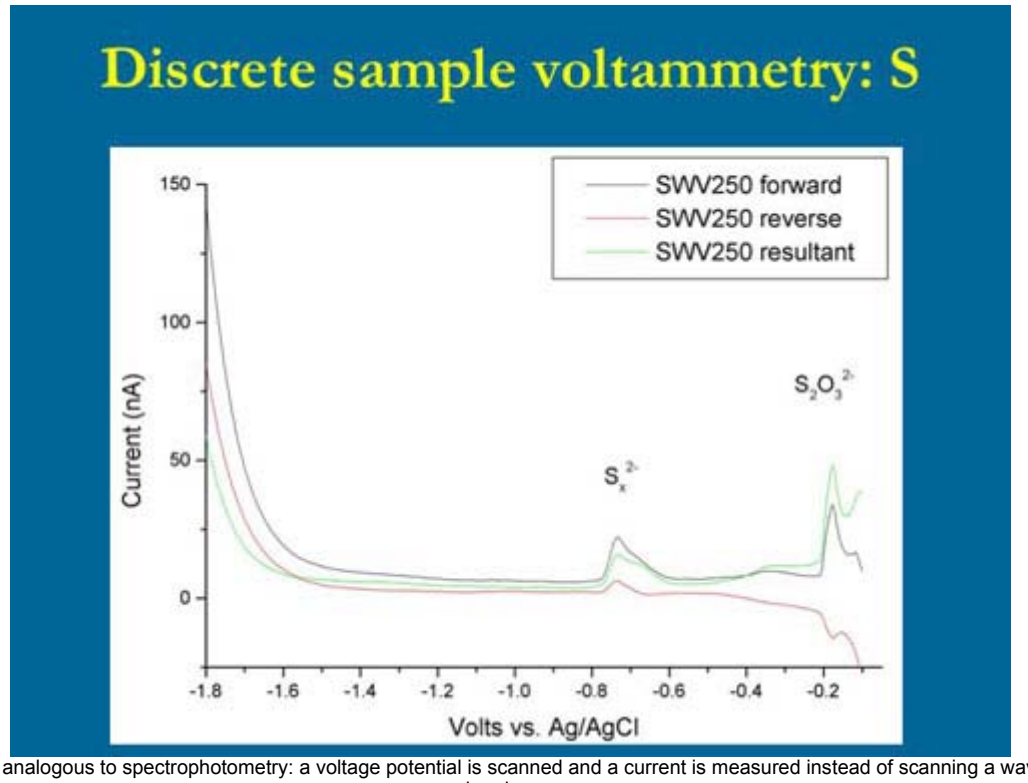


Figure 3. Voltammetry is analogous to spectrophotometry: a voltage potential is scanned and a current is measured instead of scanning a wavelength and measuring absorbance.

The coexistence of thiosulfate and sulfide could be an artifact of temporal changes between water sample collection, or could be a previously undetected signature for significant concentrations of thiosulfate in chronic hydrothermal plumes. We hope to utilize an *in situ* voltammetric analyzer deployed on a ctd to verify the presence of thiosulfate in the plumes.

(3) Geomicrobiology of near-shore porous sandy sediments:

Much of what we know today about sediment geochemistry and redox transitions is based on fine-grained sediments. Typically, studies using traditional wet chemistry methods report reduced concentrations of oxygen in porous sediments, but do not detect any sulfur species. Physical and biological processes are vastly different in porous sediments than in fine-grained sediments, and carbonate reef sediments, in particular, may be important in evolutionary terms, as reef sediments represent an ecological niche that did not exist prior to the rise of coral animals ~500mya. We duplicated an existing design and commissioned the construction of electrochemical flowcells primarily for porewater sampling from sediment microcosms (Gaidos) and natural sediments **(Figure 4)**.

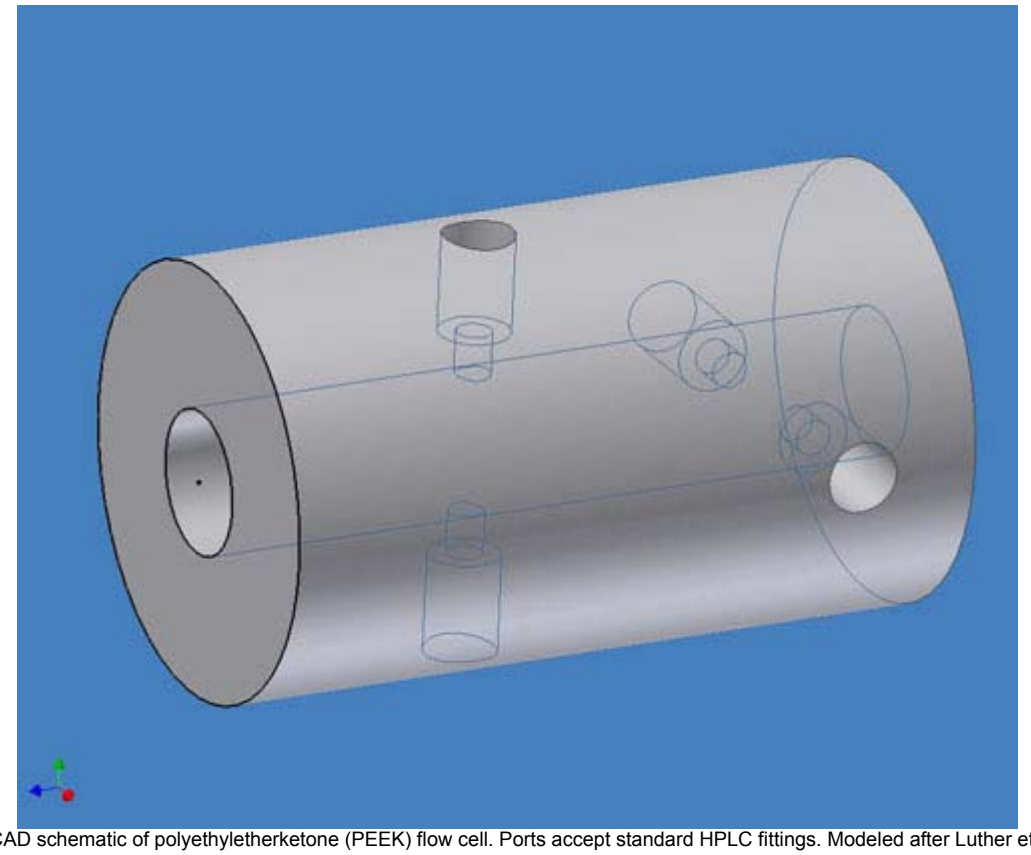


Figure 4. CAD schematic of polyethyletherketone (PEEK) flow cell. Ports accept standard HPLC fittings. Modeled after Luther et al. (2002).

These flowcells will also function in a number of other collaborative studies including microrespirometers (Gaidos), and gastight sampling of discrete water samples from ctd rosette bottles (Cowen). During a recent field expedition, we measured the presence of reduced sulfide and an aqueous form of FeS in natural carbonate sediments as little as 30cm below the sediment-water interface. We intend to follow up these preliminary results with the design of a method for profiling the sediments to map the vertical gradients, as opposed to taking measurements at only discrete vertical horizons. Collaboration with Gaidos & Sorenson has thus far produced clone libraries to describe the constituents of the corresponding microbial communities. We intend to continue with metabolic characterization of particularly the N & S cycle.

(4) A cross-platform software package for efficient data reduction of environmental electrochemical measurements:

Through collaboration with Kim Binsted, we are working toward an automated software package for voltammetric scan analysis, a web-oriented database of electrochemical calibration information, and 'intelligent' data acquisition software capable of making directed sampling decisions during long, unattended data-logging deployments. Binsted has provided summer research credit for two graduate students to work on this project. Kayo Fujiwara has utilized Matlab and is optimizing a peak-identifying and measuring algorithm. Bryan Norman is working on a Java-based graphical user interface. Binsted, Glazer, Fujiwara, and Norman have met weekly to improve design and track progress.

(5) Geomicrobiology of neutrophilic iron-oxidizing bacteria at Loihi Seamount:

Katrina Edwards (WHOI, MBL-NAI affiliate) is leading a team to study the microbiology of iron-oxidizing bacteria at Loihi (NSF Microbial Observatories) and has invited Glazer and Cowen to join their expeditions and efforts. We have just submitted a proposal to NASA to support our involvement. Integrating the team of Cowen (UH-NAI Co-I), Glazer (UH-NAI postdoc), and Binsted (UH-NAI Co-I) with a collaborative effort involving members of the Marine Biological Laboratory NAI (Edwards) and UC Berkeley NAI (Emerson) represents a potentially powerful inter-NAI collaboration.

Roadmap Objectives

- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms

- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems

Field Expeditions

Field Trip Name: Endeavour Rapid Response
Start Date: 3/4/05
End Date: 3/11/05
Continent: Endeavour Segment, Juan de Fuca Ridge, Northeast Pacific Ocean
Country: Canadian territorial waters
State/Province:
Nearest City/Town: Seattle, WA
Latitude: 48.310 N
Longitude: 128.820 W
Name of site(cave, mine, e.g.): Endeavour Segment
Keywords: Mid-ocean ridge; eruption; subsurface biosphere, extreme environment, hydrothermal
Description of Work: This was a rapid response cruise to a remotely detected intense seismic event on the mid-ocean ridge, indicating the possibility of a seafloor eruptive event. In particular, during these events enormous volumes of hydrothermal fluids can be released nearly instantaneously from the seafloor, forming the so-called "event" plumes. We have found unusual chemical signatures in these event plumes as well as hyperthermophiles that have been found no where else. We currently believe that the formation of these event plumes during seafloor eruptive events provides access to parts of the mid-ocean ridge subseafloor biosphere that are not normally accessed via conventional sampling at chronic-style hydrothermal vents.
Members Involved:

Field Trip Name: Kaumana Cave
Start Date: 2/13/05
End Date: 2/16/05
Continent: Hawaii
Country: USA
State/Province: Hawaii
Nearest City/Town: Hilo
Latitude: 19.68 N
Longitude: 155.08 W
Name of site(cave, mine, e.g.): Kaumana Cave
Keywords: cave, lava tube, microbiology, basalt
Description of Work: Initial prospecting trip for potential lava tube geomicrobiology project.
Members Involved:

Cross Team Collaborations

Our subseafloor biosphere work, especially our instrument development efforts (e.g., in situ electrochemical voltammetry) has led to a promising collaboration with Katrina Edwards and team's study on iron oxidation at the Loihi Seamount vents. We have just submitted a proposal to NASA to support our involvement. Integrating the team of Cowen (UH-NAI Co-I), Glazer (UH-NAI postdoc), and Binsted (UH-NAI Co-I) with a collaborative effort involving members of the Marine Biological Laboratory NAI (Edwards) and UC Berkeley NAI (Emerson) represents a potentially powerful inter-NAI collaboration.

Rapid Response to Remotely Detected Potential Seafloor Eruption

Project Investigator: James Cowen

Project Progress

This cruise was prompted by the remote detection of earthquake activity about 34 km north-northeast of the Main Endeavour Vent Field on the Endeavour Segment of the Juan de Fuca Ridge. The earthquakes were detected in real time by an array of hydrophones that are part of the U.S. Navy's Sound Surveilance System and monitored by the NOAA-PMEL VENTS Program's T-Phase Monitory Program. The intensity of the earthquake activity (to >60 earthquakes per hour) and pattern indicate the seismic swarm may have been caused by a magmatic event with the possibility of a seafloor eruption. The purpose of this cruise was to study expression of this presumed magmatic event within the water column (significant 'event' plumes or altered venting intensity or fluid chemistry of known vent sites) or at the seafloor (active venting or new lava flows). We were particularly interested in finding any large "event" plumes. The water column was studied for evidence of temperature and particle anomalies and elevated concentrations of metals, gases and microorganisms associated with any event plumes, as well as any chronic style (continuously venting) plumes found. The chemistry and microorganisms uniquely associated with such 'event' plumes are thought to reflect geochemical and community conditions in the deep-subsurface of the hydrothermally active mid-ocean ridges. We were prepared to 'seed' any event plume with neutrally buoyant RAFOS floats, intended to drift with the plume for several months before rising to the surface and telemetering its drift track and allowing a time series microbial geochemical study of the aging 'event' plume.

Relevance to Astrobiology: A key aspect and justification for this project is the unique access to the subseafloor environment that seafloor eruptive events offer. Astrobiology has strong interests in extreme environments, especially those hosting chemolithotrophic consortia and hydrothermal systems. In particular, the spectacular, enormous volumes of hydrothermal fluids can be released nearly instantaneously, forming the so-called "event" plumes. We have found unusual chemical signatures in these event plumes as well as hyperthermophiles that have been found no where else. We currently believe that the formation of these event plumes during seafloor eruptive events provides access to parts of the mid-ocean ridge subseafloor biosphere that are not normally accessed via conventional sampling at chronic-style hydrothermal vents.

Summary of Findings and Preliminary Conclusions

1. This February/March 2005 earthquake swarm did not induce a corresponding expression at the seafloor (e.g., eruption of a lava flow) or in the water column (e.g., formation of new hydrothermal venting, either chronic or event plumes).
2. The most likely explanation for the absence of evidence of a significant event-related hydrothermal discharge is: The earthquake swarm was likely an intrusive, magmatic event that may **not** have 1) reached sufficiently shallow crustal depths to lead to extrusion (eruptive flows), 2) caused changes in hydrothermal circulation at the seafloor, and/or 3) did not stimulate new venting or changes to existing venting as discernable via surface ship sampling.
3. Preliminary studies during this cruise indicate that electrochemical voltammetry) analysis will be sensitive enough to detect, for the first time, reactive reduced sulfur species within hydrothermal plumes. Further tests will be made in September 2005 with an in situ electrochemical analyzer suspended on a deep-sea hydrowire.
4. This Feb/March event detection and response experience stimulated a constructive exchange of ideas and questions regarding the interpretation of available relevant seismological and geological data and the criteria used in evaluating the appropriate response or lack of response to this event. A paper has been submitted to the weekly journal EOS (Dziak at al., in review) that summarizes the geological, seismological and other geophysical data available at the time of all past SOSUS directed response cruises (1993 Co-Axial; 1996 Gorda Ridge; 1998 Axial Volcano; 2001 Jackon Segment, Gorda Ridge; 2001 Middle Valley; 2005 Endeavour) as well as events detected but not responded to (e.g., 1999 Endeavour). The emphasis of this paper is the correlation of data available during the brief period of time following initial detection of onset of seismic swarm and the decision whether or not to launch a rapid response.

Roadmap Objectives

- **Objective No. 5.3:** Biochemical adaptation to extreme environments

Field Expeditions

Field Trip Name: Endeavour Rapid Response

Start Date: 3/4/05

End Date: 3/11/05

Continent: Endeavour Segment, Juan de Fuca Ridge, Northeast Pacific Ocean

Country: Canadian territorial waters

State/Province:

Nearest City/Town: Seattle, WA

Latitude: 48.310 N

Longitude: 128.820 W

Name of site(cave, mine, e.g.): Endeavour Segment

Keywords: Mid-ocean ridge; eruption; subsurface biosphere; extreme environment; hydrothermal

Description of Work: This was a rapid response cruise to a remotely detected intense seismic event on the mid-ocean ridge, indicating the possibility of a seafloor eruptive event. In particular, during these events enormous volumes of hydrothermal fluids can be released nearly instantaneously from the seafloor, forming the so-called "event" plumes. We have found unusual chemical signatures in these event plumes as well as hyperthermophiles that have been found no where else. We currently believe that the formation of these event plumes during seafloor eruptive events provides access to parts of the mid-ocean ridge subseafloor biosphere that are not normally accessed via conventional sampling at chronic-style hydrothermal vents.

Members Involved:

Subseafloor Basement (Basalt) Biosphere Studies

Project Investigator: James Cowen

Project Progress

This project involves studies of the deep subseafloor basement biosphere. We are utilizing Ocean Drilling Program borehole (CORK) observatories to access the fluids that circulate through the ocean basin wide environment, where temperatures (2-100°C) and chemistry are conducive to a very broad range of aerobic and anaerobic and heterotrophic and chemolithotrophic metabolisms and survival strategies.

Our current efforts are directed at developing equipment and methods to extract high integrity samples from the boreholes for microbial molecular genetic and metabolic experiments and to collect *in situ* geochemical data in order to accurately characterize the redox conditions present within the basement environment. We are currently focusing on two independent efforts:

i) **Seafloor Instrument Sled for Integrated geochemical and microbial characterization:**

We are adapting existing *in situ* electrochemical voltammetric technology and *in situ* multi-sample filtration systems to exploit deep-sea ODP borehole observatory's seafloor fluid delivery systems. The instrument sled, currently nearing field testing, consists of an *In Situ* Electrochemical (voltammetry) Analyzer (ISEA), a modified McLane Water Transfer System, a central controller/computer, optical and acoustic communication links, battery. The entire system has an open architecture to permit addition of other sensors. The sled fluid intake connects to the observatory's fluid delivery line via a specially designed manifold. The only surfaces that the basement fluids will contact during sampling is PVDF, a highly inert, chemically and thermally resistant Teflon-like plastic. This new microbiological sampling system provides the exciting capability of making *in situ* high resolution, real-time, simultaneous measurements of O_2, H_2O_2, HS^-, S(0), S_x^{2-}, S_2O_3, S_4O_6, Fe(II), Fe(III), $FeS_{(aq)}$, Mn(II), and Zn(II) during *in situ* collection of whole borehole basement fluids or the *in situ* filtration and fixation or extraction of fluid particles for molecular biology and other studies.

We will field test this system in September, 2005, at IODP borehole observatory 1301A, which is in Cascadia Basin on the flanks of the Juan de Fuca Ridge. Dr. K. Binsted and graduate students Kayo Fujiwara and Brian Norman are collaborating on this project; their role is to develop software to automate the initial processing of the extensive time-series raw data from the *in situ* electrochemical analyzer.

ii) **Downhole Fluid Sampler and Experimental Incubator for Borehole Observatories:**

We are currently building a Downhole Sampler (DS) for ocean crustal fluids; subsequent versions of the DS will also permit downhole *in situ* incubations. Direct collection of fluids at the bottom of the borehole should avoid any potential changes imposed on the fluid composition during its ascent to the surface. Although access for downhole instruments at ODP observatories is intermittent, it is important to verify the integrity of samples collected using our seafloor sampler and observatory fluid delivery line. Using the DS we will study the microbial community structure in the actual context of geochemical and physical conditions of the basement crust. It is our intention to demonstrate the feasibility of collecting uncontaminated fluids from aging, sediment-buried ocean basement crust. We will: 1) Perform preliminary shore-based borehole simulations (underway now); 2) use dissolved, particle and microbial tracers to test the ability of the inlet system to obtain clean samples(underway now); and 3) compare the chemistry, microbial diversity, and community structure of pristine crustal fluids at the bottom of the borehole with those collected throughout the borehole and with seawater in order to establish the nature and magnitude of any influence of the borehole on the ascending fluids (future cruise to a open borehole observatory).

Relevance to Astrobiology: This project focuses on the deep subsurface basement biosphere. Its relevance to Astrobiology lies in the fact that (i) this represents an extreme environment in terms of temperatures (<2 to >100°C), pressure (200 to >500 bar), and fluid flow, and nutrient supply (from abundant inorganic and organic substrates to severely limiting); and ii) this environment represents a valuable proxy for an extraterrestrial rocky body that is at least liquid saturated within its outer crust. This environment is only recently becoming accessible for studies of its biosphere and the projects summarized

above are at the leading edge of this exploration.

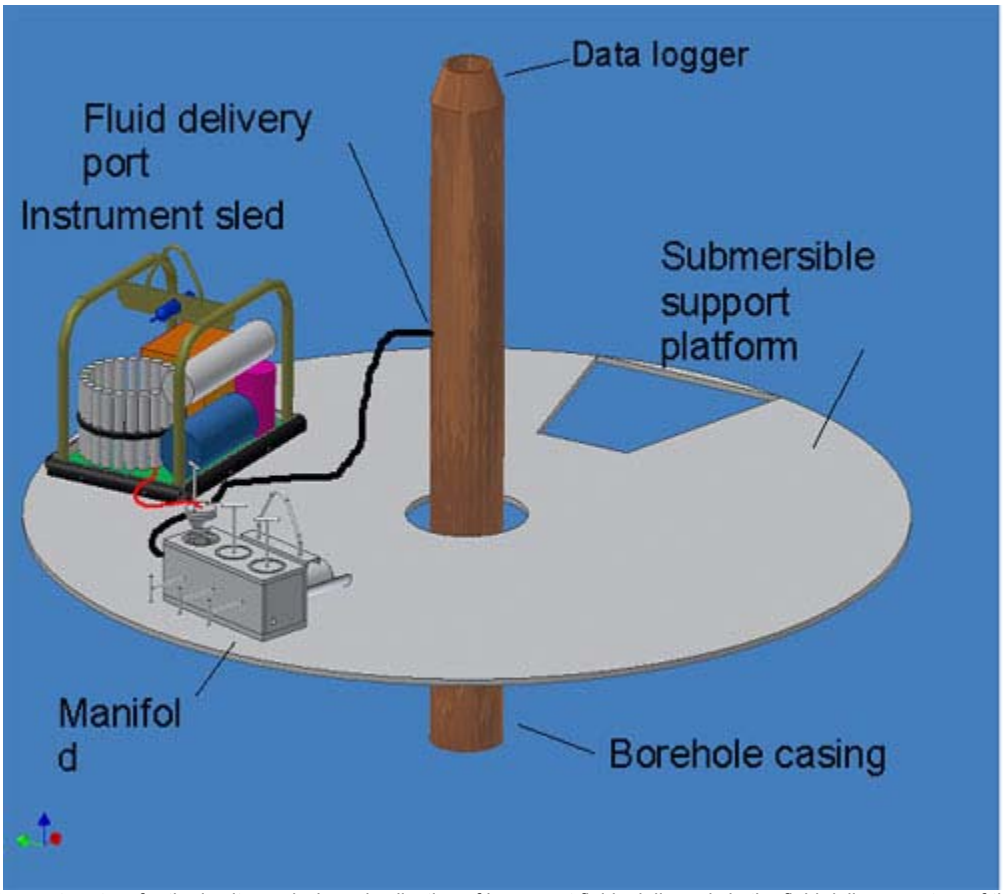


Figure 1. A seafloor instrument system for the in situ analysis and collection of basement fluids delivered via the fluid delivery system of the ODP borehole CORK Observatory. System is currently configured with for in situ electrochemical (voltammetry) analysis of redox species and the in situ filtration of multiple fluid samples for molecular biology, microbial culture and geochemical studies.

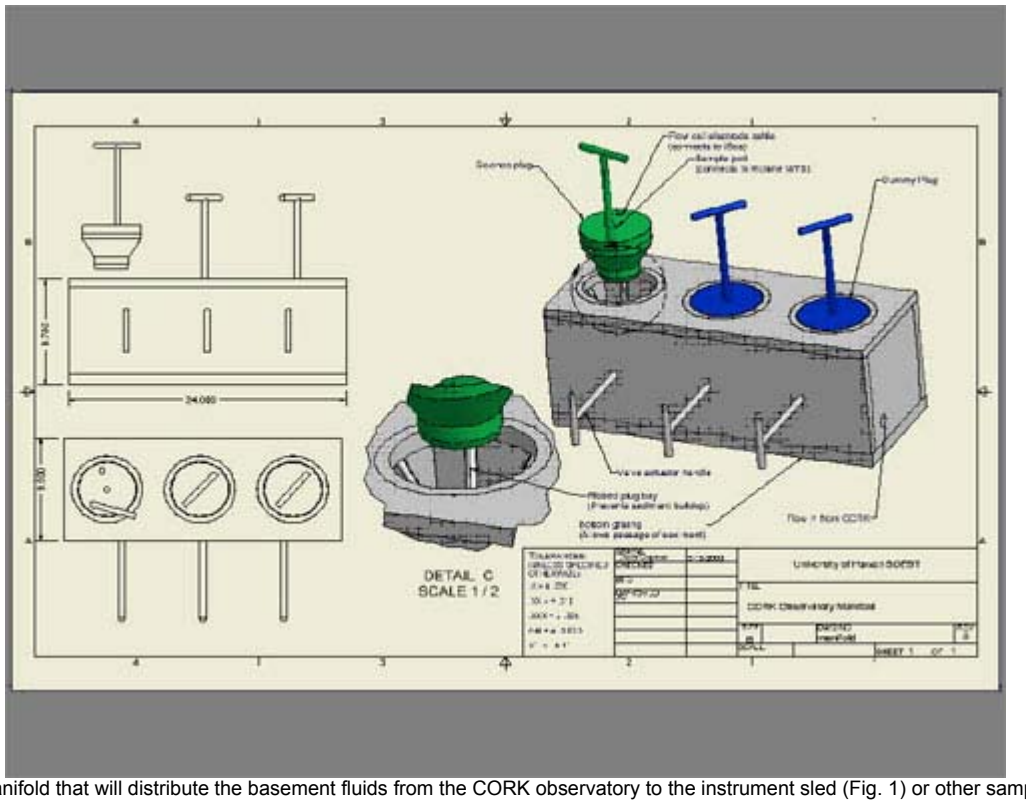


Figure 2. Drawing of manifold that will distribute the basement fluids from the CORK observatory to the instrument sled (Fig. 1) or other sampler or sensor system.

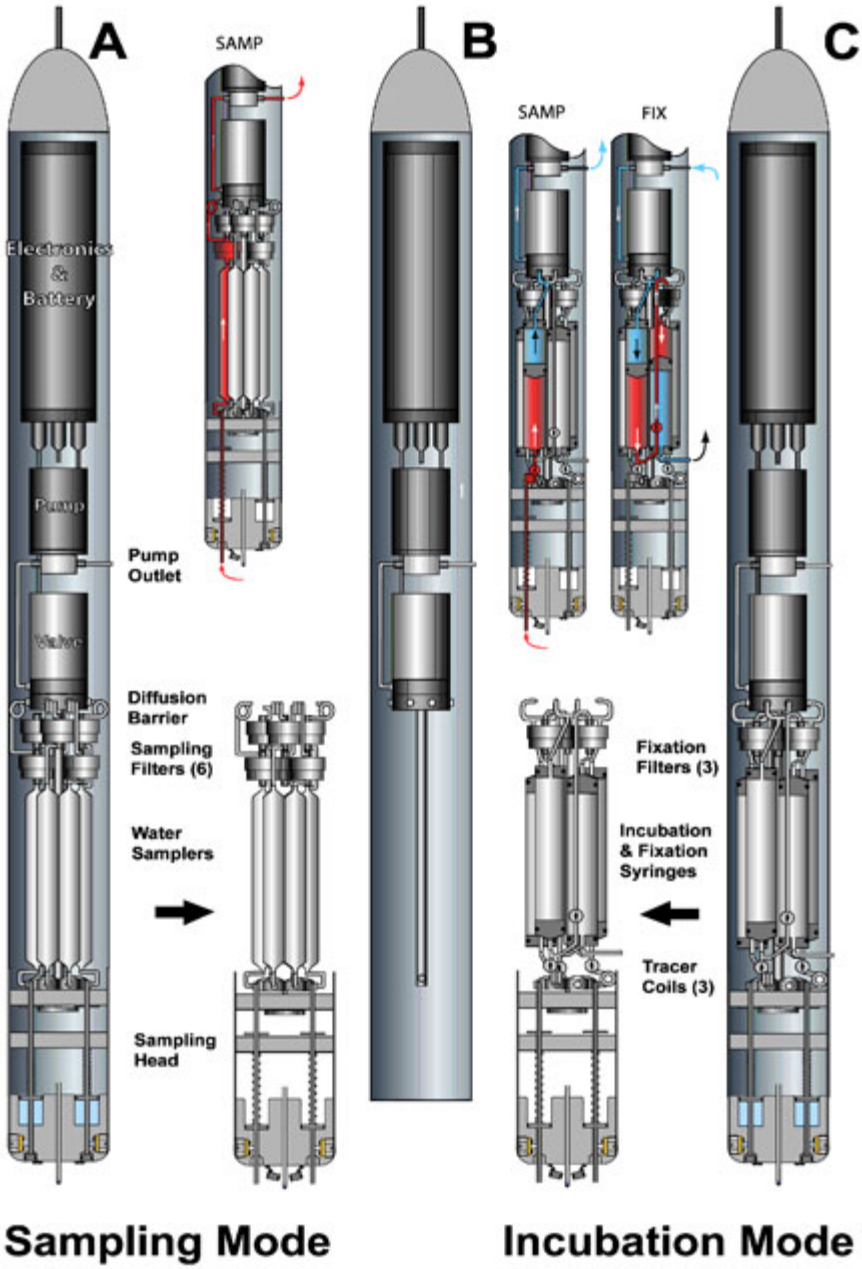


Figure 3. Conceptual drawing of downhole sampler for deployment to bottom of boreholes. Present prototype version is configured for collection of uncontaminated fluids for shipboard studies. Future versions will be configured for either sample collection and/or incubation studies. Sampler allows for in situ fixation or extraction.

Roadmap Objectives

- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Cross Team Collaborations

Our subseafloor biosphere work, especially our instrument development efforts (e.g., in situ electrochemical voltammetry) has led to a promising collaboration with Katrina Edwards and team's study on iron oxidation at the Loihi Seamount vents. We have just submitted a proposal to NASA to support our involvement. Integrating the team of Cowen (UH-NAI Co-I), Glazer (UH-NAI postdoc), and Binsted (UH-NAI Co-I) with a collaborative effort involving members of the Marine Biological Laboratory NAI (Edwards) and UC Berkeley NAI (Emerson) represents a potentially powerful inter-NAI collaboration.

The Aqueous Environment of the Emergence of Complex Life

Project Investigator: Eric Gaidos

Project Progress

We have started a new initiative to study key steps in the evolution of complex life and the potential relationship to aqueous conditions (oxygen, ion concentrations, etc.) at the time of those events. We are studying two "model" systems.

The first are placazoans: Placozoa remains one of the most enigmatic and poorly described groups of the Metazoa (animals). The only officially described species, *Trichoplax adhaerans*, has been assigned its own phylum based on its unique characters. These mm-sized organisms are found in the littoral zone of tropical seas, where they are part of the biofouling community. Although placozoans were first described more than a century ago they were subsequently thought to be a derived cnidarian larva. Most of what is known about placazoans is based on observations of a single strain (Grell) from the Red Sea. They possess a radial symmetry, with upper and lower epithelium cell layers separated by a fiber layer responsible for changes in shape. They possess no nerve cells, yet immuno reaction to neuropeptide antibodies has been reported. In the laboratory, they feed upon the biofilm and can be readily cultured by feeding with Cryptomonad species. In culture, placazoans readily reproduce by fission and budding but it is not known if the organism possesses a complete sexual life cycle: Oocytes have been observed but cell division has never been observed to pass the first 5 divisions. The phylogenetic position of the Placozoa with respect to the Bilateria and the other basal metazoan phyla (Ctenophora, Cnidaria, Porifera) has been controversial. It was earlier suspected that placazoans might be derived cnidarians, but subsequent information does not support this. We are currently carrying out several parallel investigations on these organisms, including (1) constructing and sequencing a cDNA expressed gene library; (2) using PCR and FISH techniques to identify and describe putative endosymbiotic bacteria that have been reported within the placazoans; and (3) measuring and constructing a mathematical model of the motility of these organisms. We are particularly interested in using Ca and Ca-dependent signaling and activity as a probe to understand the interaction and dynamics of the cells in the multicellular system.

The second system is a non-photosynthetic ciliate *(Tetrahymena thermophila)* and cyanobacterium (*Synechocystis* PCC6803). We are studying mechanisms by which feeding by the ciliate on the cyanobacterium might be replaced by a "détente" in which the cyanobacterium avoids digestion and provides oxygen to the ciliate for growth advantage during hypoxic conditions. This is one mechanism by which endosymbiotic relationships – a major step in the evolution of complex eukaryotic life – might have emerged over evolutionary time. Both organisms have had their compete genomes sequenced and have genetic systems already in place, and thus are very tractable. Our preliminary data shows that flow cytometric selection of candidate ciliate-cyano individuals is feasible.

Figure 1. A placozoan isolated from coastal Hawaiian waters. Size is about 300 microns.

Roadmap Objectives

- **Objective No. 4.2:** Foundations of complex life

Kuiper Belt Orbital Studies

Project Investigator: Karen Meech

Project Progress

The discovery of the Kuiper Belt has dramatically changed our understanding of the outer solar system. The KBOs form several dynamical classes: the resonant population and the classical KBOs which are stable over the age of the solar system, the scattered disk objects which are unstable because of close encounters with Neptune, and the extended scattered objects. Recent work has found that there must be a sharp cut off in the mass distribution beyond 50 AU. The inner edge of the Kuiper Belt is believed to be the source of the Centaurs, which eventually evolve into the short-period Jupiter-family comets. While only a small fraction of the total population of KBOs has been discovered, the KBOs studied to date exhibit remarkable physical diversity. The distribution of the orbital parameters of the KBOs provide a fossil record of the dynamical processes which have sculpted the outer regions of the protoplanetary disk over the age of the Solar System. Moreover, the Kuiper Belt is believed to be the vestigial manifestation in our Solar System of the planet-forming dust disks seen around some other stars. The orbits and physical properties of Kuiper Belt Objects (KBOs) provide valuable constraints on dynamical and environmental evolution of the outer Solar System. As the population of KBOs increases, interest is now turning to the characterization of the physical properties of these objects. We are currently at the same point in our understanding of the surfaces and composition of KBOs and Centaurs as we were with the asteroid belt in the early 1970s.

However, a full understanding of this fossil record requires a large and well characterized sample of objects with accurate orbits. We are collaborating on the Deep Ecliptic Survey (Lowell, MIT, IfA, UA, UC Berkeley) which is the largest KBO survey to date. Objects discovered by the survey require addtional astrometric observation to determine accurate orbits. Eight nights on the UH2.2m telescope were used for astrometric follow up of newly discovered objects, and those for which the orbits are not well enough known for classification. All of this data has been reduced and published, and is being used in new dynamical investigations of the outer solar system small body population. This work is complementary to our program of the studies of the physical properties of these small bodies.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 2.2:** Outer Solar System exploration

Analysis of fine scale genetic divergence in oceanic microbial communities

Project Investigator: Mark Brown

Project Progress

The marine environment comprises the largest contiguous "surface" habitat on Earth, but it is far from a continuous, homogenous environment. Spatial variation spans a continuous range from the micrometer (driven by "bottom up" molecular interactions) to the ocean and global scales (driven by "top down" global atmospheric, land, sea interactions) all of which can be highly temporally diverse. Biologically, prokaryotes dominate in terms of abundance, biomass, and biogeochemical processes, however only relatively recently have we begun to define the mechanisms of microbial community structuring and diversification in this environment. We have identified fine scale differentiation within the major microbial groups and our aim is to understand what the driving force of this diversification may be. Using the internal transcribed spacer (ITS) region of the ribosomal operon as a marker we have highlighted two interesting phenomena concerning marine microbial diversification. Firstly, the marine assemblage does not consist of organisms derived from a recent common lineage, but rather a vast array of closely related but discrete co-exiting populations. The mechanisms which maintain this "micro-diversity" are not understood. It may persists because the processes introducing genetic variation are more prevalent than those causing purging of genotypes from the population. However, this microdiversity may also be beneficial by contributing to a systems biological by confounding processes such as viral attack.

Secondly, we observed distinct clusters dominated by sequences retrieved from various depths and geographic regions, possibly indicating adaptation to subtle niche variation. Both these phenomena can be identified from Figure 1.

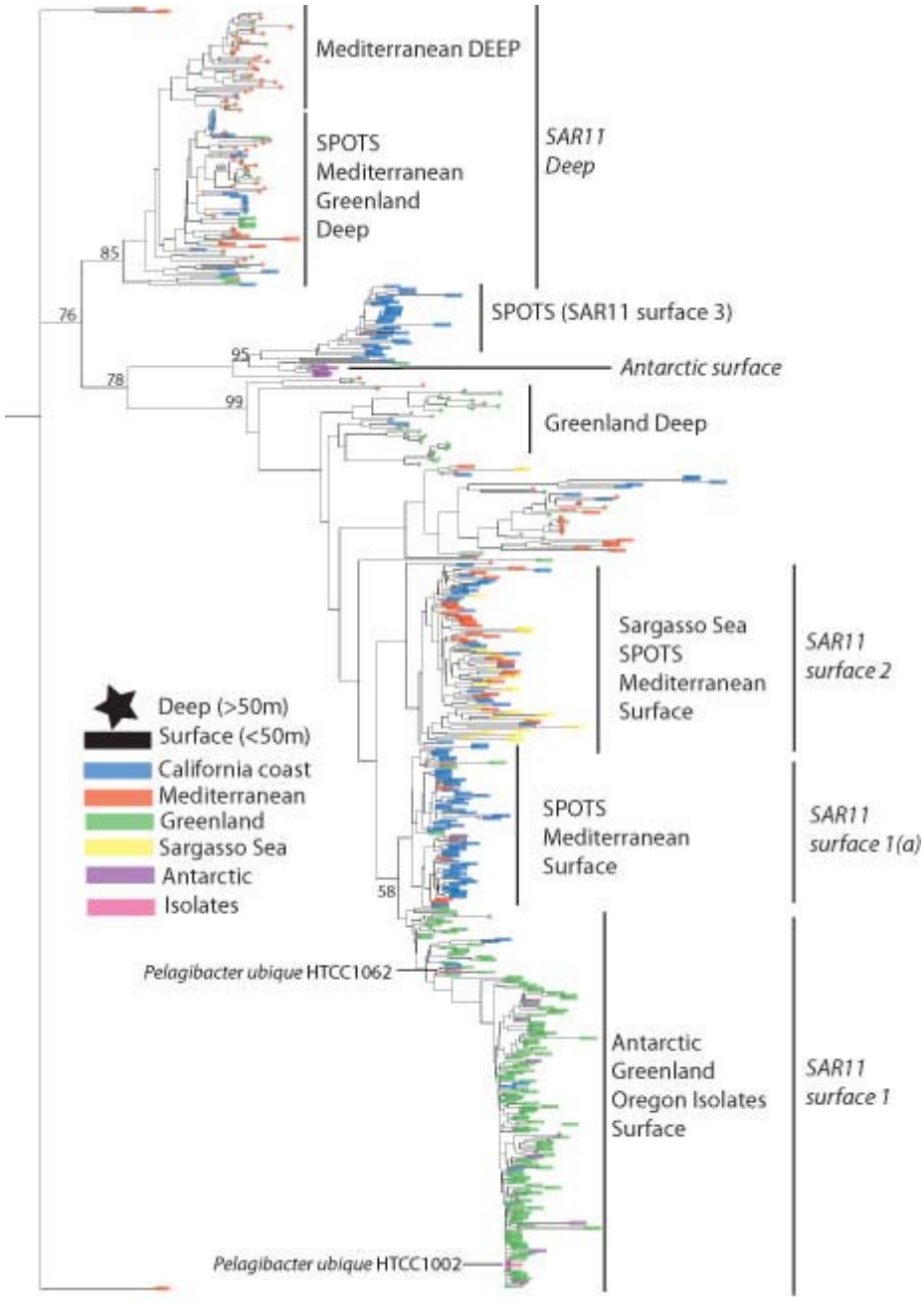


Figure 1. Cluster analysis of SAR11 clade associated ITS sequences showing extensive microheterogeneity within clusters and dominance of clusters by sequences from different geographic locations.

We are collecting large datasets of ITS clusters from public databases, augmenting these with selected sampling, and aim to characterize the data in relation to physical and chemical oceanographic parameters to shed light on the mechanisms driving marine microbial diversification.

Roadmap Objectives

- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.2:** Co-evolution of microbial communities

Field Expeditions

Field Trip Name: HOT169	
Start Date: 5/16/05	**End Date:** 5/20/05
Continent: North America	**Country:** USA
State / Province: Hawaii	**Nearest City / Town:** Honolulu

Latitude: 22.45

Longitude: 158

Name of site(cave, mine, e.g.): Station ALOHA

Keywords: marine time series

Description of Work: Sampling of marine water for extraction of microbial assmebalge DNA

Members Involved:

Origin of Irregular Satellites

Project Investigator: Nader Haghighipour

Project Progress

One of the main features of all giant planets of our solar system is the possession of irregular satellites. Distinguished from their counterparts by their highly eccentric orbits, and/or high orbital inclinations, irregular satellites are thought to have been captured from bodies that were formed elsewhere in the solar system. The accretional process of the formation of regular satellites in a circumplanetary disk cannot account for the high eccentricity and inclination of these bodies. During the past few years, observations have indicated that, (1) irregular satellites exist around all four giant planets, (2) the number of irregulars of the same size around all these planets are almost the same, and (3) there seems to be no irregular satellite in a region around Jupiter, interior to its innermost irregular (~80 Jupiter radii) and exterior to its outermost Galilean satellite (~30 Jupiter radii). During the year 7, we launched an expansive project on the study of the origins and dynamics of irregular satellites. The goal of this project is to arrive at explanations for the three above-mentioned observations. At the first stage our study focuses on identifying regions where irregular satellites can have stable orbits. We are currently carrying out extensive numerical integrations of these objects for a large parameter-space. The results of these simulations, which are to be submitted for publication shortly, will enable us to understand the lack of irregulars at the distances of 30 to 80 Jupiter-radii around this planet. We are also extending our simulations to include the scattering of small bodies with different sizes from a trans-Neptunian planetesimal disk, as a probable source of irregular satellites. The results of this project will make possible identifying the most viable capture mechanism of irregular satellites, and have applicability in furthering our understanding of outer planets formation history.

Roadmap Objectives

- **Objective No. 2.2:** Outer Solar System exploration

Habitability and Water Delivery in Binary-Planetary Systems

Project Investigator: Nader Haghighipour

Project Progress

Study of habitability and water-delivery in binary star systems requires an expansive study of the dynamical evolution of these systems. While habitability requires identifying regions within the habitable zone of the system where a life-harboring planet (such as an Earth-size body) can have a long-term stable orbit, water-delivery requires identifying regions where water-carrying objects such as comets, and water-rich planetesimals and protoplanets, can be unstable. Together these two issues require a detailed and thorough study of the dynamical stability of the binary-planetary system. A vast and systematic study of the formation and stability of planets has begun during this year, both giant and terrestrial, in binary star systems. The motivation behind this study comes from the fact that among more than 150 extrasolar planets discovered to date, approximately 25% are within binary star systems. Some of such systems (*e.g.*, Gamma Cephei), have small separations and also harbor planets – a phenomenon that is not allowed based on the current theories of planet formation. The present research on this topic has been focused on the long-term stability of planets in the binary star system of Gamma Cephei. This system consists of a 1.6 solar-mass star as its primary, an M dwarf, at a distance of 19 AU, as its secondary, and a Jupiter-like planet that revolves around the primary star at 2.1 AU. To study the habitability of this system, the entire parameter-space of this system has been mapped and this shows that the system can, indeed, be habitable as long as the binary eccentricity stays below 0.45 (Figure 1). The results of this project have been submitted for publication in the Astrophysical Journal. Currently, calculations are being expanded to include interactions among planetesimals at different locations in the binary in order to understand the formation of terrestrial planets in that system.

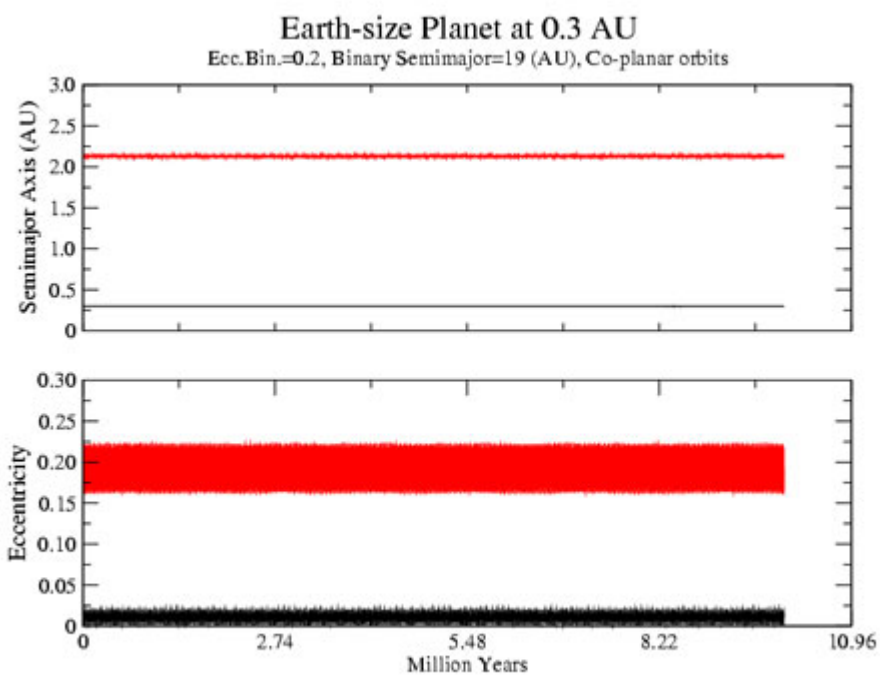


Figure 1. Semimajor axes (top) and orbital eccentricities (bottom) of an Earth-like planet (black) and the Jupiter-like planet (red) of Gamma Cephei binary system. The orbit of the Earth-like planet is stable for 10 million years.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets

Formation of Planetesimals in a Dynamically Evolving Nebula

Project Investigator: Nader Haghighipour

Project Progress

Work on the dynamics of dust grains in the neighborhood of density-enhanced structures in a planet-forming nebula has been continuing. In particular, a new project on the dynamics and coagulations of dust particles in a dynamically evolving nebula has been launched. In such and environment, the physical properties of the nebula, such as its temperature and pressure, constantly vary. This work has shown that such variations will manifest themselves as gas density-enhanced regions and affect the dynamics of small grain in their neighborhood. The presence of pressure gradients on both sides of these structures causes solid objects to undergo inward and outward migrations, and accumulate at the location of maximum gas density. The analysis has been expanded to include the interactions between small dust grains and the background material of the nebula. The results of recent analyses, which will appear in the Monthly Notices of the Royal Astronomical Society, indicate that, in the vicinity of such structures, dust grains grow to a few centimeters by sweeping up smaller objects, and will rapidly accumulate around the location of maximum gas density on the midplane. Recent simulations are allowing for turbulence. It is expected that, once cm-sized particles are accumulated on both sides of the midplane, because of the velocity differences between solids and gas molecules, turbulence will occur and these particles will be removed from the midplane to higher elevations. On the other hand, turbulence will cause particle to collide with one another faster and increases the rates of their coagulation. The results of this project have direct application to the long-lasting issue of planetesimal formation in a solar nebula.

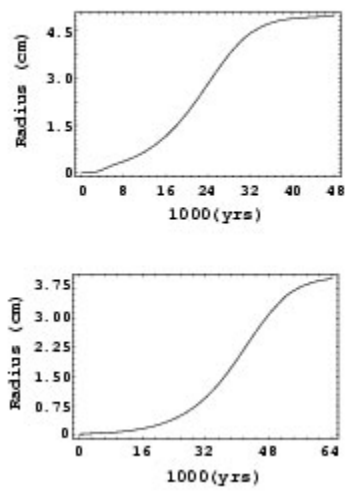


Figure 1. Growth of a 10-micron-sized particle at 2AU (top) and 0.25 AU (bottom) in a nebula with a gas-density maximum at 1 AU. The temperature of the gas is 300 K.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets

A Proteomic View of Adaptations to Extreme Environments

Project Investigator: Andy Boal

Project Progress

Over the past two decades, molecular biology techniques have ushered in a paradigm shift in environmental microbiology. Thriving microbial communities have been discovered inhabiting physical and chemical regimes once assumed limiting to life. These "novel" environments are collectively known as "extreme" environments and the organisms that inhabit them "extremeophiles". As these present day environments are thought to resemble either early Earth environments in niche environments on other planets, the study of extremeophiles is of ongoing interest to several lines of inquiry related to Astrobiology. In this project, we are interested in developing a concise, molecular level understanding of how biomolecular structure allows microorganisms to adapt to various extreme aqueous environments (Figure 1).

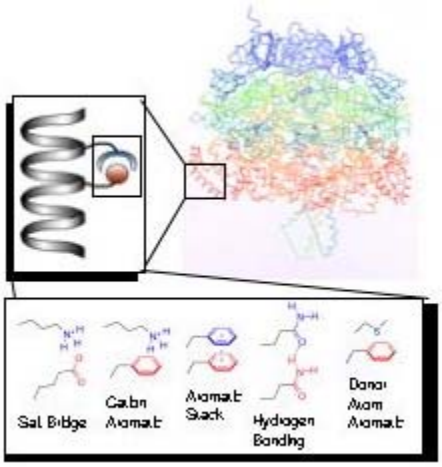


Figure 1. Illustration of the interdependency of environment and the life forms that thrive in that environment. Image credits to NASA and NPS.

The specific question we are asking is: Are there identifiable protein motifs that allow for protein stability, and therefore organism survivability, which are adapted to function in particular environments? We are attempting to answer this question by applying a suite of techniques that include the development of proteomic databases, design and study of protein model molecules, and molecular characterization of extreme environments. A key aspect of protein stability is the stability of the protein structural subunits that make up the whole protein structure, the most common of which is the α-helix (Figure 2).

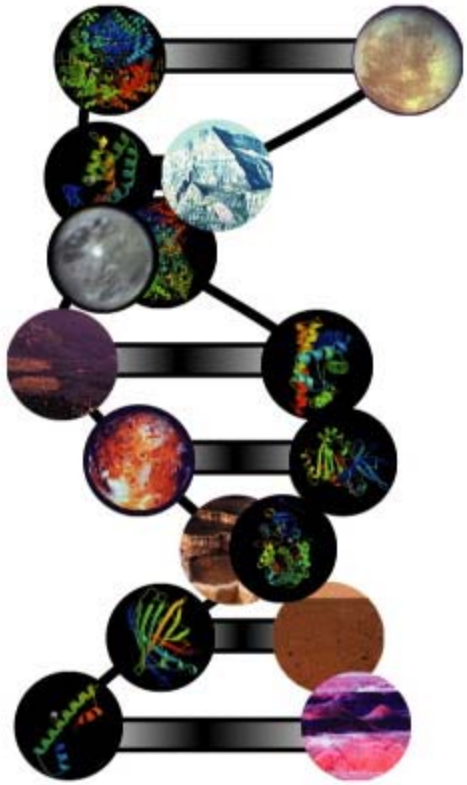


Figure 2. Image illustrating some intrahelical stabilizing interactions found in the helices of proteins.

One of the major ways in which an α-helix can be stabilized is by the formation of *intra*-helical interactions between amino acid side chains of specific compositions and positions within the helix. From the canonical 20 amino acids, there are over 3000 possible combinations that would lead to a stabilizing effect on the α-helix. Since each of these are different in their inherent strengths and response to variation in physical factors such as temperature and salt content, it is expected that organisms from different environments will show a preference for certain subsets of these interactions. We are currently undertaking a structure-function type study to catalog the frequency at which these stabilizing motifs are observed as a function of the environment of the organism from which the genomic information is obtained.

Roadmap Objectives

- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.3:** Biochemical adaptation to extreme environments

Serpentinization, Abiogenic Methane, and Extremophilic Archaea within the Seafloor

Project Investigator: Brian Glazer

Project Progress

We have made significant progress in understanding the origin of methane and extreme high pH (12.5) during serpentinization in the Mariana forearc. Low-chlorinity springs sampled from ten sites on nine serpentinite mud volcanoes show systematic chemical gradients across the outer Mariana forearc that result from progressive devolatilization of the subducting Pacific plate. Sites range from 50 to 90 km from the trench axis corresponding to depths to the top of the plate of ~15 to 29 km. Dissolved sulfate, Na/Cl, K, Rb, Cs, and B in the springs all increase regularly with distance from the trench, leached from the subducting sediment and altered basalt in response to increasing temperature at depth from ~100-300°C. Sites nearer the trench have high Ca (up to 75 mmol/kg) and Sr, low alkalinity, and pH 10.7, whereas sites farther from the trench have almost no Ca and Sr, alkalinity (some carbonate but mostly hydroxyl) as high as 69 meq/kg, and pH 12.5. Springs with high alkalinity also have high methane (>44 mmol/kg) that feeds sulfate-reducing microbial communities in the shallow subsurface and macrofauna at the seafloor. These distal springs form chimneys and crusts of $CaCO_3$, whereas the proximal springs form chimneys of brucite. High alkalinity at the distal sites apparently results from decarbonation at the top of the subducting plate; because serpentinization during ascent generates both high pH and H_2, the resulting dissolved carbonate is reduced to methane such that carbonate alkalinity is replaced by hydroxyl alkalinity: $4H_2 + CO_3^{=} = CH_4 + H_2O + 2OH^-$. This reaction can account for the much higher pH of the distal springs. Chlorinity of the springs varies from 234-546 mmol/kg and is related more to latitude N-S than to distance from the trench. Distal springs have otherwise similar compositions over this entire range of chlorinity, implying that chloride derives from depth rather than from mixing with seawater within the seamounts themselves. The range in chlorinity can readily be explained by serpentinization at reasonable water/rock mass ratios of 0.2-1.0 if 30-40% of the spring water originates as residual pore water in subducted sediment and basalt rather than as $H2O^+$ of dehydration. For convergence at 4.75 cm/y and per km of trench, the rate of subduction under the Mariana forearc is 24 km^3/My or 3.4 x 10^{10} g/y of (dry) sediment 500 m thick, and 95 km^3/My or 2.7 x 10^{11} g/y of altered basalt 2 km thick. For loss from sediment of 1% H2O+ and 2% residual pore water, plus from altered basalt 2% $H2O^+$ and 1% pore water, going from lawsonite-albite to epidote-blueschist facies as in the Catalina schist (Bebout, 1995), this amounts to a water flux of 9 x 10^9 g/y per km of trench, upward into the mantle of the outer Mariana forearc. This water derives 90:10 from basalt:sediment and 63:37 from $H2O^+$: residual pore water. Corresponding vertical fluxes of sulfate, C, Na, K, Rb, Cs, B, Ca, and Sr in the forearc springs represent 0.05-3% of the amounts subducted, consistent with continued supply at greater depths.

Roadmap Objectives

- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 5.3:** Biochemical adaptation to extreme environments

Ice in Sublimation Environments

Project Investigator: Norbert Schorghofer

Project Progress

Ice exists in sublimation environments on many planetary surfaces, including Mars, Antarctica, and possibly the polar regions of the Moon. Schorghofer and Edgett (2005) studied observations of seasonal ice at unusually low latitudes on Mars, where it exists on cold pole-facing slopes (Figure 1).

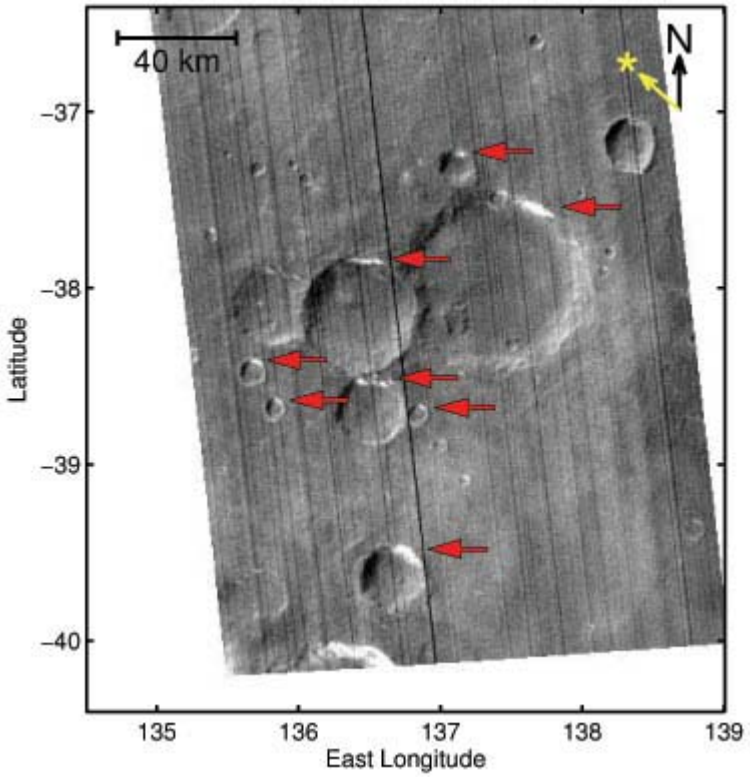


Figure 1. Seasonal surface frost in a Mars Orbiter Camera image acquired on Feb. 13, 2003, during southern Martian winter. Red arrows highlight several of the frost patches on crater walls. The frost appears in early winter and lasts for several months. North is up and illumination is from the upper left.

Although we determined that the observed frost patches consist of CO_2 rather than H_2O ice, the implication is that seasonal water frost exists near equatorial latitudes on Mars. Another study we have completed (Schorghofer, 2005) concerns ground ice in Beacon Valley, Antarctica. Radiometric dating suggests the ice is at least 8 million years old and ranks as the oldest ice ever found on Earth. This age was thought to be incompatible with the theoretical rate of sublimation loss. Our analysis of diffusion processes and meteorological data identified a mechanism by which ground ice can survive indefinitely (Figure 2).

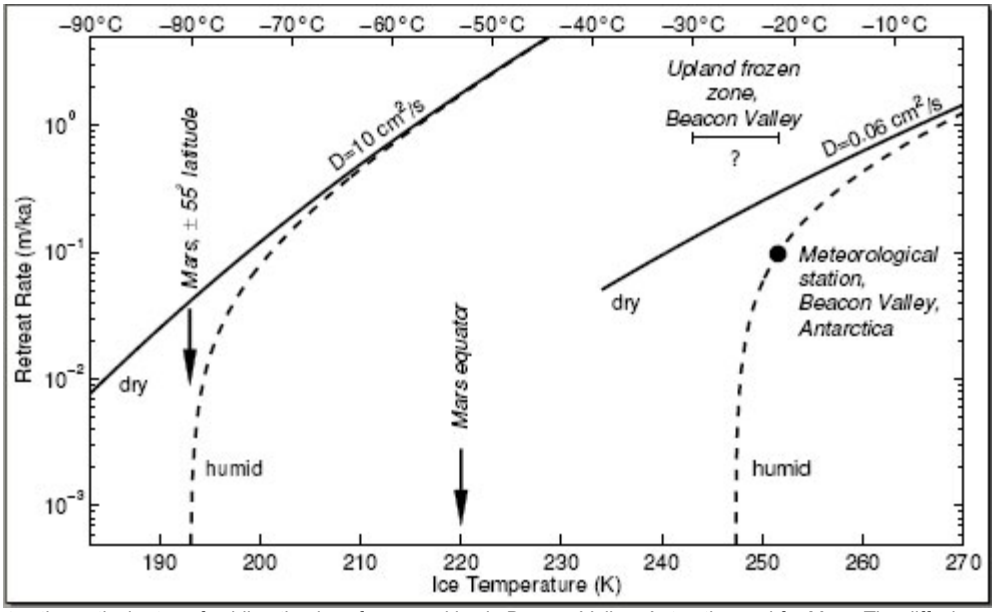


Figure 2. The diagram illustrates theoretical rates of sublimation loss for ground ice in Beacon Valley, Antarctica and for Mars. The diffusion coefficient D is larger on Mars than on Earth, primarily because of lower atmospheric pressure. At sufficiently cold temperatures, the humidity of the atmosphere prevents sublimation loss.

We have also spent a great deal of time planning and designing laboratory experiments in sublimation environments, which should eventually bring together astronomy and biology. A grant proposal has been submitted to NASA-MFR and, with existing equipment and external seed funding, we have recently purchased the first components for preliminary experiments. The envisioned apparatus will simulate lunar, martian, and antarctic temperature and pressure conditions and will be used not only to study ices in sublimation and near-melting environments, but also biological processes, including migration and dispersal of organic material.

Roadmap Objectives

- **Objective No. 2.1:** Mars exploration

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
0	Mars Global Surveyor (MGS)	
0	Mars Odyssey (ODY)	

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Young Low Mass Stars

Project Investigator: Bo Reipurth

Project Progress

Bo Reipurth has continued working on eruptive events in young Solar-like stars, the so called FUor and EXor eruptions. Observations of the prototype eruptive variable, FU Orionis itself, with the 8m Subaru telescope at Mauna Kea, has revealed that a nearby star is in fact a physical companion with characteristics similar to the T Tauri stars. Such events are important not only for the growth it provides to the young star, but also for processes of irradiation of disk material, which may give clues to the short-lived intense heating events that affected chondrites and aqueous alteration products in the early solar system. He and his collaborators have completed a multi-wavelength study of a new object named Persson's Star, after the Swedish amateur astronomer who discovered it, and they demonstrated that it is one of the rare bona fide FU Orionis objects. Reipurth has continued work on the VYSOS (Variable Young Stars Optical Survey) robotic telescope, which will be mounted during August 2005 at the Mauna Loa observatory. Routine monitoring of tens of thousands of young low-mass stars will begin during the coming winter.

Roadmap Objectives

- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets

Astrobiology Winter School

Project Investigator: Bo Reipurth

Project Progress

We have at UHNAI decided to prepare a series of winter schools in astrobiology every other year in collaboration with the University of Arizona NAI team. One of the principal obstacles of astrobiology is the specialization of disciplines. Who would be better than young people to break down the barriers separating the various disciplines? So we set ourselves three goals: First, to provide the coming generation of researchers the opportunity to learn from the best of the current senior researchers in the field. Secondly, our schools should give the young people an opportunity to meet and get to know each other. The personal ties and friendships developed at a young age tend to be strong and long-lasting, and so the schools will with time generate ties within the field of astrobiology across national and cultural boundaries. Third, by a judicious choice of topics the schools should help break down artificial boundaries between narrowly viewed disciplines, foster cross fertilization, and instill a deep rooted understanding of how the many sub-disciplines of astrobiology are all part of one larger question.

The first UHNAI Winter School was organized by Bo Reipurth and Karen Meech. From January 10 to 21, the Institute for Astronomy hosted 39 students or young researchers from across the United States and from several other countries from a large range of disciplines. The first week was spent at IfA in Manoa. Lectures were given every morning, and after lunch the students broke up into smaller groups, which then discussed some of the issues that were brought up in the morning lectures. The lecturers walked from group to group and discussed questions that arose from the discussions. The lectures during the first week dealt with "Water Ice and Chemistry in Circumstellar Disks and the Interstellar Medium" and "Geochemical Processes and Microbiospheres in Hydrothermal Systems". The second week was hosted by IfA in Hilo, where the lecture topics were "Ice on Earth, Mars, and Europa" and "Icy Bodies in the Solar System and the Origin of the Earth's Oceans". All lectures were given by specialists both from UH and from abroad. During the weekend in between lectures, the students could relax by swimming in the ocean, touring the Volcano National Park on the Big Island, and visit a snow-clad Mauna Kea. After two intense weeks, the students once more scattered across the globe, but now bonded by a unique Hawaiian experience.

Roadmap Objectives

- **Objective No. 2.2:** Outer Solar System exploration
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials

Searching for water and organic material in the Outer Solar System

Project Investigator:

Project Progress

A. Delsanti at Institute for Astronomy (University of Hawaii, Manoa)

Minor bodies of the Outer Solar System (Kuiper Belt Objects, orbiting beyond Pluto, Comets, outer planets icy satellites) contain the most pristine material of the Solar System. Studying their surface composition provides relatively direct clues on the conditions of formation of our Solar System. The most fascinating feature is the ubiquitous presence of water ice and organic material. We are therefore trying to map the presence of water ice in the outer Solar System, by performing visible and infrared spectroscopy of the surface of these objects.

So far, we have detected water ice on one of the biggest Kuiper Objects, Orcus (De Bergh. Delsanti et al 2005). A new analysis performed with both the Keck 10m telescope and the Gemini 8m telescopes on top of Mauna Kea (Hawaii) during Spring 2005 will allow us to determine if the water ice is crystalline or amorphous, which has important implications for the outer Solar System thermal history. We might also identify some evidence for aqueous alteration processes displayed in the visible spectra. These studies encompass object Orcus, and several other outer Solar System minor bodies of interest. More spectroscopic observations with the Subaru 8m telescope (Hawaii) are scheduled in September 2005 to study the water content of outer planets icy satellites (e.g. Nereid, Oberon, Ariel, etc).

Chemical modeling of the different sets of data will allow us to provide insights on the surface composition of these objects, and put some constraints on the water and organic material supply to the inner Solar System. A parallel study of the composition of chondritic meteorites and the different aqueous alteration processes will allow us to eventually unveil links between meteorites and outer Solar System material.

Roadmap Objectives

- **Objective No. 2.2:** Outer Solar System exploration

The Lowell Telescope Scheduler

Project Investigator: Kimberly Binsted

Project Progress

The Lowell Telescope Scheduler (LTS) is a system which allows high-school students and other non-professional users to propose research projects and request observations on a 31-inch telescope at Lowell Observatory. At the heart of the system is an automatic scheduler, which allows the principal investigator at the telescope to quickly and easily integrate outside observation requests into his nightly viewing schedule. The system also has a web-based interface which allows inexperienced telescope users to make reasonably sophisticated observation requests.

This year, after many revisions, we have completed both the scheduler and the interface. We will continue to fix bugs and make improvements as necessary over the course of the year.

Analysis software for in situ voltammetry

Project Investigator: Brian Glazer

Project Progress

In situ measurements are necessary to understand dynamic environments where chemical speciation can change within seconds, or millimeters as a result of chemical, biological, or physical processes. Recent efforts have produced reliable techniques for using voltammetric micro-electrodes to measure a variety of redox species in real time from a variety of environments, including hydrothermal vents, microbial mats and biofilms, coastal sediments, estuarine and oceanic water columns and laboratory environments. Each redox species produces a current peak that can be discriminated from others in one potential scan from −0.1 V to −2.0 V (analogous to varying wavelength and measuring absorbance with spectroscopy). Dr. Brian Glazer, a UH-NAI postdoctoral fellow, is an expert on *in situ* electrochemical voltammetric techniques.

Although extremely valuable, these techniques currently require many hours of human analysis. Each micro-electrode must be calibrated over a range of known measurements, requiring a human to identify peaks and measure peak heights for each calibration point. A human must also identify peaks and heights in field data, and weed out any flawed data. All of these processes are time-consuming and prone to inconsistencies due to slight variations in peak identification and measurement heuristics between researchers.

In this project, we are building a system to automate this process as much as possible. The system quickly identifies peaks and peak heights in a consistent manner, and performs micro-electrode calibrations, while also allowing a researcher to intervene and identify flawed data. Two MSc students in the Information and Computer Sciences Department are developing the first version of this software, which will be tested and expanded over the next six months. The next stage is to build *on-board* software, to do a partial analysis of the data during collection, so that the device can automatically re-take problematic data, or focus in on areas of particular interest.

Roadmap Objectives

- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems

The evolution of intelligence under environmental change

Project Investigator: Kimberly Binsted

Project Progress

The Search for Extraterrestrial Intelligence (SETI) is forced to confront the questions of "What is intelligence?", "Under what conditions can it evolve?" and “How can we detect it?”. These questions are related to, but distinct from, questions about the definition, evolution and detection of life. Detecting intelligence can be a difficult task, and instead of testing for intelligence directly, we propose a set of features considered to be sufficient for intelligence, and explore their evolutionary advantages and disadvantages under a range of scenarios. Two features identified in this research are *adaptation to novel situations on individual timescales* (i.e. learning) and *transmission of successful strategies over generations* (i.e. recorded communication), and we focus the adaptiveness of these features with respect to a changing environment. We hypothesize that certain environmental profiles favor the emergence of intelligent species while other environmental profiles favor the non-intelligent life. To date, we have created two distinct simulations that test the effect different levels of intelligence have on a species’ ability to adapt to changing environments. These simulations take into consideration the various characteristics of r and K-strategist organisms and a given environmental profile in order to predict the survival rate for each type of organism. The next step will be to verify the integrity of the simulations by replicating the successes and failures of known organisms such as bird or dolphin species on Earth.

Roadmap Objectives

- **Objective No. 4.2:** Foundations of complex life
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

AFAR: Adaptive Framework for Astrobiology Research

Project Investigator: Kimberly Binsted

Project Progress

In this new project, for which we have recently submitted two funding proposals, we plan to build AFAR (Adaptive Framework for Astrobiology Research), a distributed interdisciplinary collaborative system that allows astrobiology researchers to identify strong research questions and potential collaborators; teachers and students to explore this burgeoning field; and the media and general public to gain an understanding of the motivations behind astrobiology-related research and missions. At the heart of this system will be a knowledge base containing a representation of the state of the field: the questions, hypotheses, data, missions, references, people, and the connections between all of these, that make up the field of astrobiology. The interface to the knowledge base will be highly adaptive, with different representation and navigation techniques depending on the role (e.g. researcher, teacher, student, journalist, etc.), expertise (e.g. PhD in geology, high-school biology, etc.) and focus (e.g. water on Mars, early evolution of life, etc.) of the user. It will be a kind of *knowledge map*, allowing researchers to home in on interesting areas and to add new knowledge quickly, while giving students, educators and the general public an engaging way to explore this exciting field and learn about scientific methodology.

The research method integrates ethnographic fieldwork with participatory design in an iterative multi-phase model. The primary data collection methods will be interviews, observations and analysis of documents and scientific data. We will collect data at NAI centers at UH and the University of Colorado at Boulder (UCB), test the resulting system at UCB, UH and three other NAI centers, and deploy it throughout the NAI. A primary design goal is to make entering and updating knowledge extremely simple and efficient, so that researchers will be willing to take the few minutes necessary to add their knowledge to the system.

Analysis Tools for A Proteomic View of Adaptations to Extreme Environments

Project Investigator: Andy Boal

Project Progress

Another project at UH-NAI, entitled "A Proteomic View of Adaptations to Extreme Environments", is concerned with developing a concise, molecular level understanding of how biomolecular structure allows microorganisms to adapt to various extreme aqueous environments. The specific question we are asking is: Are there identifiable protein motifs that allow for protein stability, and therefore organism survivability, which are adapted to function in particular environments? We are attempting to answer this question by applying a suite of techniques that include the development of proteomic databases, design and study of protein model molecules, and molecular characterization of extreme environments.

We are developing a set of computational tools to support this research. At the most basic level, these tools allow us to quickly perform statistical analyses of proteomic databases; for example, identifying and counting instances of protein motif classes that meet certain contextual constraints. We are also developing a program that uses a genetic algorithm to learn the features associated with protein stability in extreme environments, which we hope will generate novel protein structures to be tested in the lab.

Roadmap Objectives

- **Objective No. 5.3:** Biochemical adaptation to extreme environments

Miniature Mass Spectrometer Development

Project Investigator: F. Scott Anderson

Project Progress

NAI support has contributed to the development of a center for mass spectrometer development at UH, with systems under development for chemical measurements using electron impact (for gases), electrospray (liquids), laser ablation resonance ionization (isotope and elemental abundance in solids), and secondary ionization (a standard for geochemical assays). These instruments will allow us to assess the potential of a habitat to support life and search directly for biomarkers, as well as determine the age of materials these compounds are found in. In addition, we are preparing to propose a new cycloidal mass spectrometer to PIDDP, in combination with an ASTEP proposal, in order to study the fractionation of hydrogen and deuterium, as well as ^{16}O and ^{18}O, in water. This system will be used in deep drill holes and contribute to constraining the true isotopic composition of primitive water on Earth and in the solar system.

Work to date has focused on the development of a nano-electrospray rotating field mass spectrometer (ESI-RFMS) to study heavy compounds commonly associated with life in water directly. The mass spectrometer is <5' in size, is optimized for detecting heavy organic molecules (50-500K Da), can withstand ballistic emplacement (currently demonstrated to 1200g), operates at pressures as high as several milliTorr, and has simple electronics. These traits make the instrument uniquely relevant for astrobiology applications such as the detection of key organic biomarkers derived from cellular components as well as geochemical environmental characterization on wet or icy bodies throughout the solar system. The ionizer uses a modified electrospray introduced directly to vacuum, and the spectrometer operates as a momentum filter using rotating RF fields applied to four poles.

The ESI ion source has now been extensively tested in a wide variety of vacuum conditions and with a wide variety of sample delivery pressures, as well as under a range of electrical conditions and sample chemistries. We have also tested the RFMS mass filter using an off-the-shelf electron impact (EI) gas ionizer **(Fig. 1)**, which demonstrated the new concepts of RFMS mass filtering **(Fig. 2)** and ion beam control, as well as significant advances in noise reduction. Finally, all of the hardware has evolved significantly from the initial designs **(Fig. 3)**. A critical issue that evolved from this work is the importance of a well focused beam of ions in this type of spectrometer versus other similar but less capable spectrometers like the standard quadrupole. Our initial tests show that both the ESI and EI ionizers significantly deviate from a beam **(Fig. 4)**, which we have begun to address using Einzel lenses **(Fig. 5, 6)** and mesh apertures.

ESI-RFMS characteristics are currently undergoing extensive characterization in our laboratory test stand developed in part through support of the NAI. The other mass spectrometers mentioned here will be installed in a second new laboratory being built at UH to support this program. We have leveraged NAI funding with both NASA Mars Instrument Development (MIDP), Planetary Instrument Design and Development (PIDDP), NSF Information & Intelligent Systems (IIS), ONR, & DIA Measurement and Signals Intelligence (MASINT) funds. We have presented our results at numerous conferences, including the American Geophysical Union Fall Conference, and the BioAstronomy Conference. We have nearly completed characterization the electrospray ionizer during the first year of effort, and that in year two we will begin calibration efforts. In later years we plan to test this system in lacustrine and icy environments.

In summary, we anticipate using the ESI-RFMS, as well as the other mass spectrometers spawned by this effort, to aid in searching for and identifying the signatures of life, both on Earth, and potentially on future robotic missions throughout the solar system.

Figure 1: Electron Impact (measures gases) of the RFMS, including (from left to right), detector, mass filter, einzel lens, and off-the-shelf closed ion source (Stanford Research Systems).

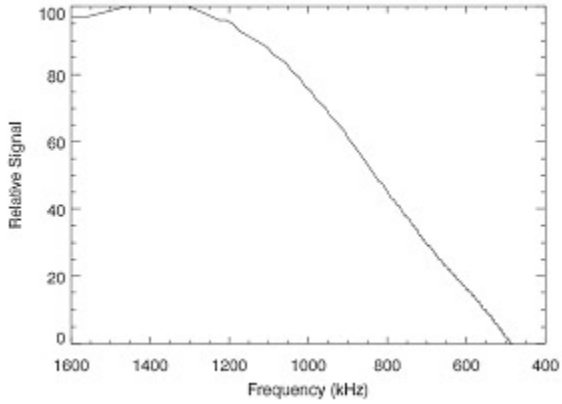


Figure 2: In RFMS, the mass filter sweeps from high to low frequency, causing heavier masses to be removed from the ion beam.

Figure 3: (Left) New mass filter design. (Right bottom) ESI-RFMS components (detector, mass filter, einzel lens, electrospray ionizer). (Right top) Old RFMS design, without ionizer.

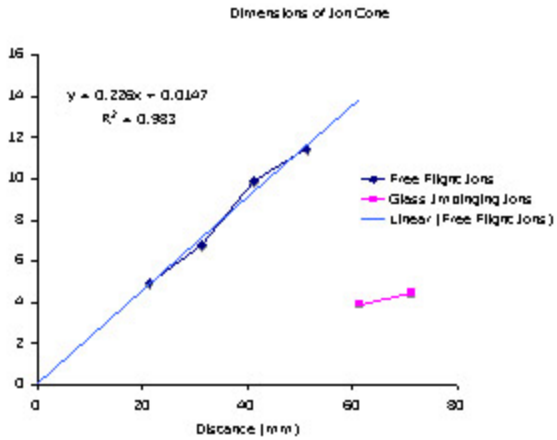


Figure 4: Ions in free flight from the EI source are poorly focused, forming a cone with ~10° of dispersion.

Figure 5: Initial Einzel lens design, capable of narrowing ion dispersion to < 3°.

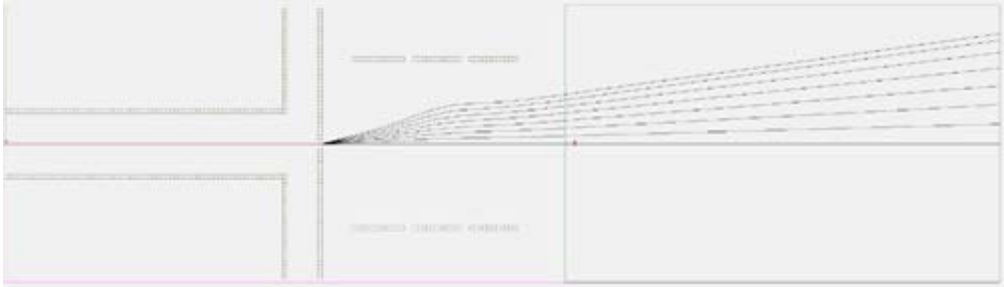


Figure 6: Raytrace of ion flight paths using SIM-ION, demonstrating the initial broad cone, and effects of the lens.

Roadmap Objectives

- **Objective No. 2.1:** Mars exploration
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
0	All	

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

The Mass Spectrometers developed at UH with NAI leverage have the potential to identify habitats,potential biocompunds, and ages of putative fossil or extant environments associated with life.

Cometary Water and Volatile Abundances

Project Investigator: Karen Meech

Project Progress

Many comets have been observed to have activity at large heliocentric distances on their inbound orbital legs at distances too far from the sun to be caused by sublimation of pure water ice. The traditional view that sublimation of water-ice is the driver of activity in comets is changing considerably as observations with new telescope facilities are showing that comets are often active at very large distances from the sun, where the ambient temperatures are much lower than the sublimation temperature of water-ice. Thermal models have been able to explain some of the activity post-perihelion, due to slow transport of the heat from perihelion into the interior, however activity at large distances before the comet is heated has been difficult to explain. It is unlikely that the dominant form of activity at large distances is caused by sublimation of pure ices which are more volatile than water because laboratory experiments have shown that as water vapor in the nebula condensed at low temperatures it would have trapped these more volatile materials as gases in an amorphous water-ice matrix. Release of the trapped gases would then be controlled by the physical properties of the water ice as it warms up. Understanding the causes of activity at large distances can provide information about the chemistry and small scale structure in primitive bodies, and this relates to constraints on the chemistry, physical conditions and planetesimal formation processes in the young solar nebula.

NAI team member Meech, and postdoc Pittichova have been collaborating with Akiva Bar-Nun and Gila Notesco (Univ. Tel-Aviv) to understand the role of water ice in the activity of comets on their inbound orbital trajectories at large heliocentric distances. A thorough understanding of cometary activity has implications for delivery of volatiles and organics to the terrestrial planets. Work carried out on amorphous, gas-laden ice samples suggests that the cause of distant cometary activity is from gas release during annealing processes in the water ice between 35 and 120K. The experimental set up involves flowing different mixtures of gases onto a cryogenically cooled plate at 50K in a pumped chamber at 10^{-8} torr, forming 5 to 200 micron thick ice layers. The ice deposition plate is then heated while monitoring the emanation of trapped gases, water vapor and ejected ice grains. The experiments show that the gases trapped in the amorphous ice during its formation are partly released from the ice during its annealing as it warms up.

We have been comparing model results to activity in comets at large distances, in particular on their first inbound passage into the inner solar system. Work has continued this year on the observing and calibration of the comet data.

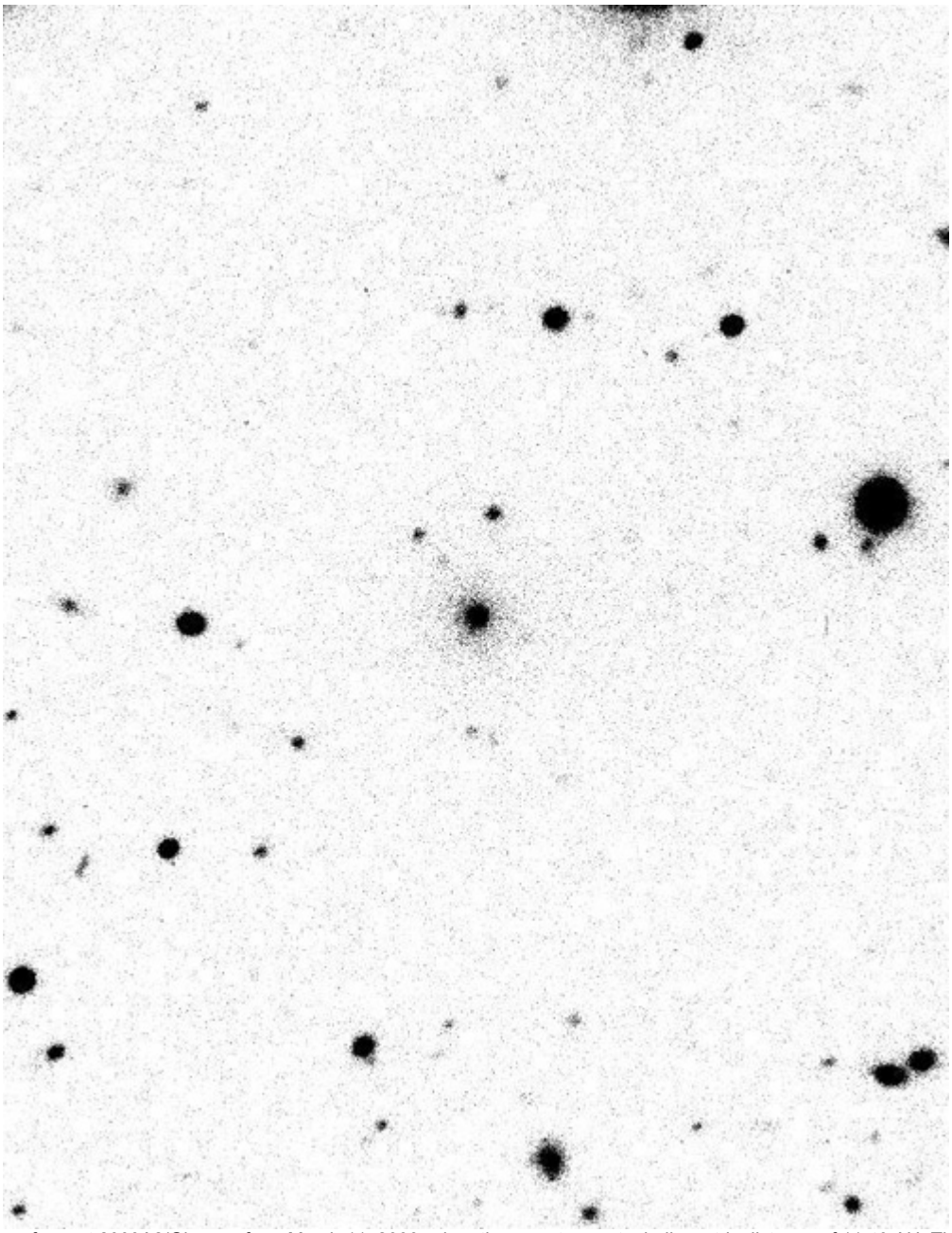


Figure 1. Preperihelion image of comet 2003A2/Gleason from March 11, 2003, when the comet was at a heliocentric distance of 11.49 AU. The image is 180x180 arcsec, which corresponds to 1.4x10^6 km at the comet. N is up and E to the left in this image.

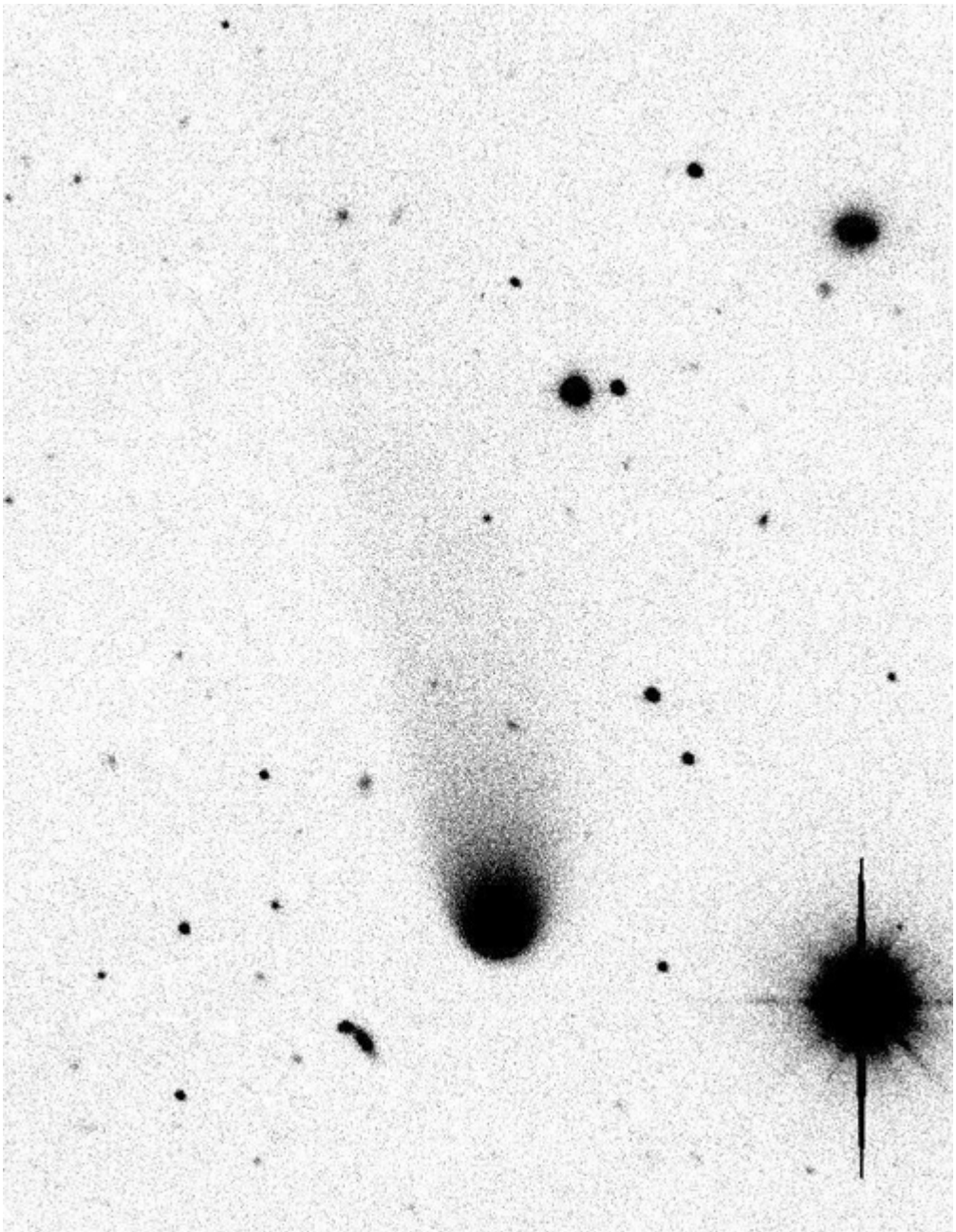


Figure 2. Image of comet 1999J2/Skiff from February 24, 2000 at a heliocentric distance of 7.11 AU pre-perihelion. The image is 180x180 arcsec, which corresponds to 9x10^5 km at the comet. N is up and E to the left in this image.

Roadmap Objectives

- **Objective No. 2.2:** Outer Solar System exploration
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts

Characterizing Extrasolar Planets through Planet-Star Interactions

Project Investigators: Eric Gaidos, Evgenya Shkolnik

Project Progress

The magnetic field of a planet plays a critical role as a shield against the irradiation of the planet's atmospheric molecules through cosmic rays and the energetic particles from the stellar wind. A planetary magnetic field is a key factor in the search for possible life, since on the Earth it is considered a necessary condition. Theorists require this information to model planetary structure, formation and evolution as well as the tidal and magnetic heating of their parent stars.

Previous to my arrival to the NAI, our findings represented the first evidence for planet-star magnetic interaction as well as the first ever detection of an extrasolar planetary magnetic field on the planet orbiting Sun-like star, HD 179949 (Shkolnik et al., 2003, 2005a). A magnified example of such planet-star interactions exists in the tightly orbiting binary star system, ER Vulpeculae, presented in my first NAI paper (Shkolnik et al. 2005b)

Since starting at the NAI on February 1, 2005, I executed two observing programs in collaboration with UH-NAI Co-I, Eric Gaidos, and his graduate student, Nick Moskovitz. The first was a three-night run at the NASA Infrared Telescope Facility (IRTF%) in Hawaii in February to search for $H^3{}_+$, a brightly emitting molecule in Jupiter's aurorae, from the surfaces of Jupiter-massed extrasolar planets. The second program was with Phoenix, a high-resolution infrared spectrograph at the Gemini-South 8.1-m telescope in Chile. Unfortunately, Chile's winter weather in June 2005 provided complete cloud cover for 85% of the four-night run. However, I can compare the small amount of data I have with previous years' to search for chromospheric and coronal variations in HD 179949 due to the planet's magnetic field. We are also looking for $H^3{}_+$ from this star as well as from AU Mic, a young star with a kinked debris disk indicative of planet formation. High signal-to-noise spectra were obtained of these two stars during one night. The first data set has been process and limits on the amount of $H^3{}_+$ from those stars have been set. I am currently halfway through the data reduction process in order to answer the sought-after questions of the second observing run.

Also, during the telescope proposal deadlines of March 2005, we submitted three successful proposals to be executed this fall: a) 3 nights with IRTF again to look for $H^3{}_+$ but with a revised experimental strategy, b) a multi-wavelength search for planet-star interactions in old and new targets during 6 nights with the Canada-France-Hawaii Telescope's new high-resolution echelle spectrograph and c) 4 nights on the Keck I Telescope to do the same but with much fainter stars.

Another project we are working on studies the effects of ultraviolet and extreme-ultraviolet radiation from a star on planet formation, evolution and migration. Over the course of a Sun's lifetime, its UV emission drops by many orders of magnitude. My role in this project is to use archived data of stars at various ages and spectral types to map the change in UV emission and stellar activity to be used as environmental parameters in planetary atmospheric models.

Roadmap Objectives

- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets

Formation of astrobiologically important molecules in water-rich environments

Project Investigator: Ralf Kaiser

Project Progress

Our goal ultimate goal is to investigate the formation of biological molecules in water-rich environments. Water ice serves as the energy-transfer medium and active participant in a variety of radiation-driven chemistry reactions thought to be important in either the interstellar medium or the primordial solar nebula. The processes for formation of biological molecules in space are fairly complicated. In order to understand the detailed mechanism behind it, we have to do experiment step by step. As the first step for understanding the formation of those molecules in water-rich environments, we choose to investigate the irradiation of pure water ice itself and the formation of bio-molecules without water involved. Our project progress includes three parts: (1) commission of an ultra high vacuum experimental apparatus; (2) investigation of pure water ice; (3) formation of small biologically important molecules in water-free environments.

Since our last report, we have improved our experimental apparatus significantly (Figs. 1 and 2). The lowest pressure in the main chamber can be pumped down to 5.0_10^{-11} torr. This can minimize the impurities in the low temperature ices. It is extremely important for mechanism study of chemical reactions in low temperature ices under clean conditions without surface contaminations.

Figure 1. Experimental Setup.

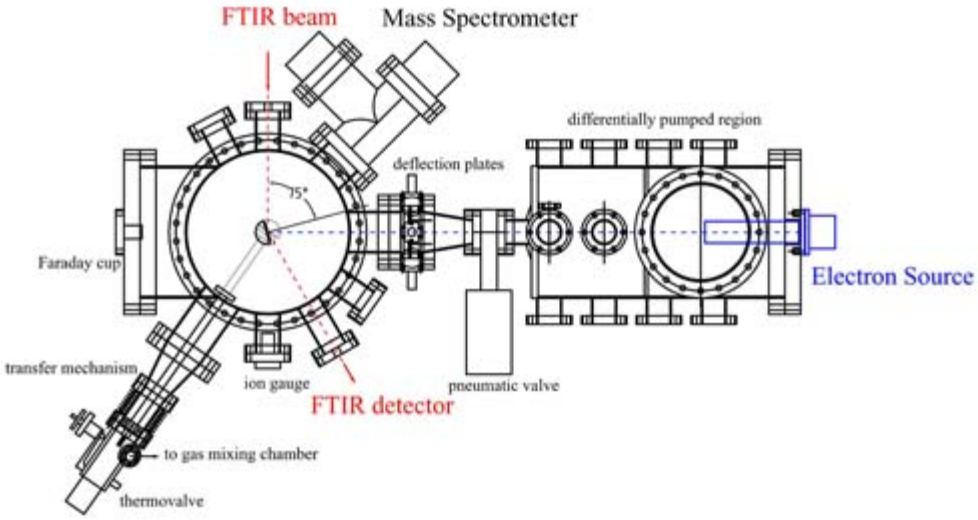


Figure 2. Top view of the experimental setup.

We have conducted a systematic study on electron irradiation of pure water ice. The formation of molecular hydrogen, molecular oxygen, and hydrogen peroxide together with hydrogen and oxygen atoms had been investigated in the experiments (Figs. 3 and 4). We also proposed mechanisms how these molecules are formed. The experimental results of pure water ice might also help the understanding of the cosmic ray processing of water ices in the interstellar medium as well as the cosmic ray and solar wind processing of water ices in Kuiper Belt Objects, comets, planetary surfaces and satellite surfaces.

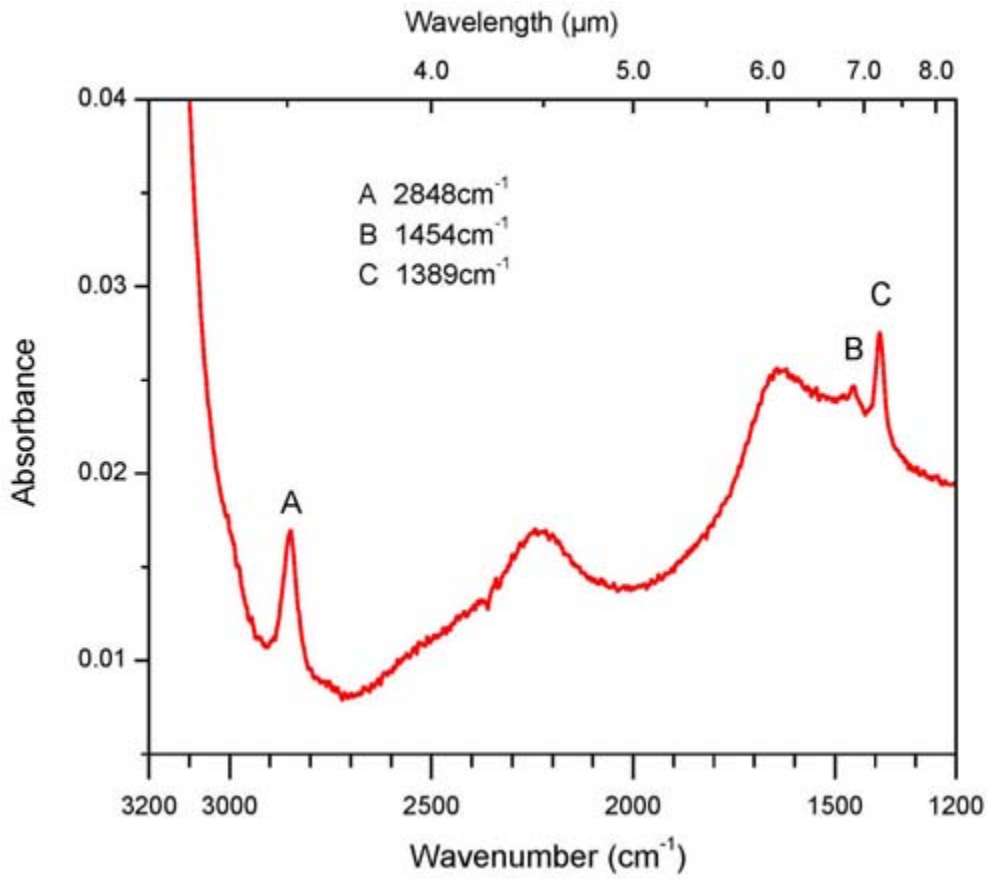


Figure 3. Infrared spectrum of the sample after an irradiation with electrons at 12K for 180 minutes and warmed up to 170K with most of the water sublimed. Peak A, B and C correspond to hydrogen peroxide's v2+v6 combination mode (v2 symmetric bending and v6 asymmetric bending, respectively). The remaining absorption features belong to water ice.

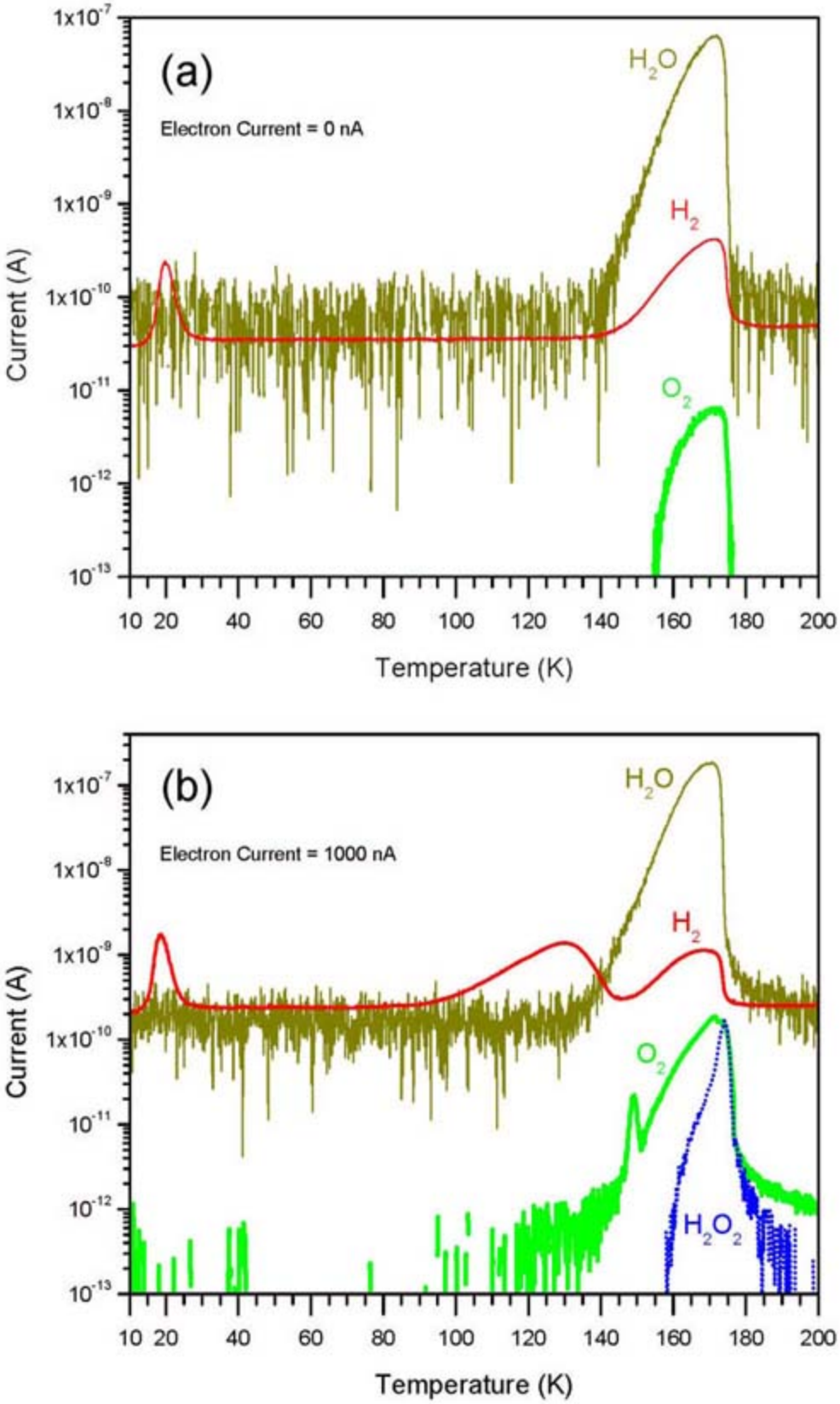


Figure 4. The release of gases by warming up crystalline water ice samples after 180 minutes irradiation. (a) Blank experiment, electron current = 0, (b) Irradiation experiment, electron current = 1000 nA.The comparison of the blank experiment and irradiation experiment shows that H2, O2 and H2O2 were generated and trapped in water ice during the irradiation. The H2 was released from water ice when the samples were warmed up to 100 - 140 K; the H2 peak at 19K and was confirmed to be the desorption of H2 from ice surface. The O2 was released at 147 - 151 K. The H2O2 was released at 160-190 K.

In the experiments of water-free ices, we investigated the formation of the amino acid glycine (NH_2CH_2COOH) and its isomer ($CH_3NHCOOH$) in extraterrestrial ices (Fig 5 and Fig 6). We studied also the formation of acetaldehyde (CH_3CHO), ethylene oxide (c-C_2H_4O), and vinyl alcohol (C_2H_3OH) in interstellar and cometary ice analogs by electron irradiation of carbon monoxide (CO) and methane (CH_4) mixture (Fig 7 and Fig 8) as well as carbon dioxide (CO_2) – ethylene (C_2H_4) mixtures. We also studied the formation of

nitrous oxide (N_2O) which might be important the interstellar medium and on the surfaces Pluto and Triton (Fig 9). Nitrogen-oxides are also important as electron transfer molecules in biological processes.

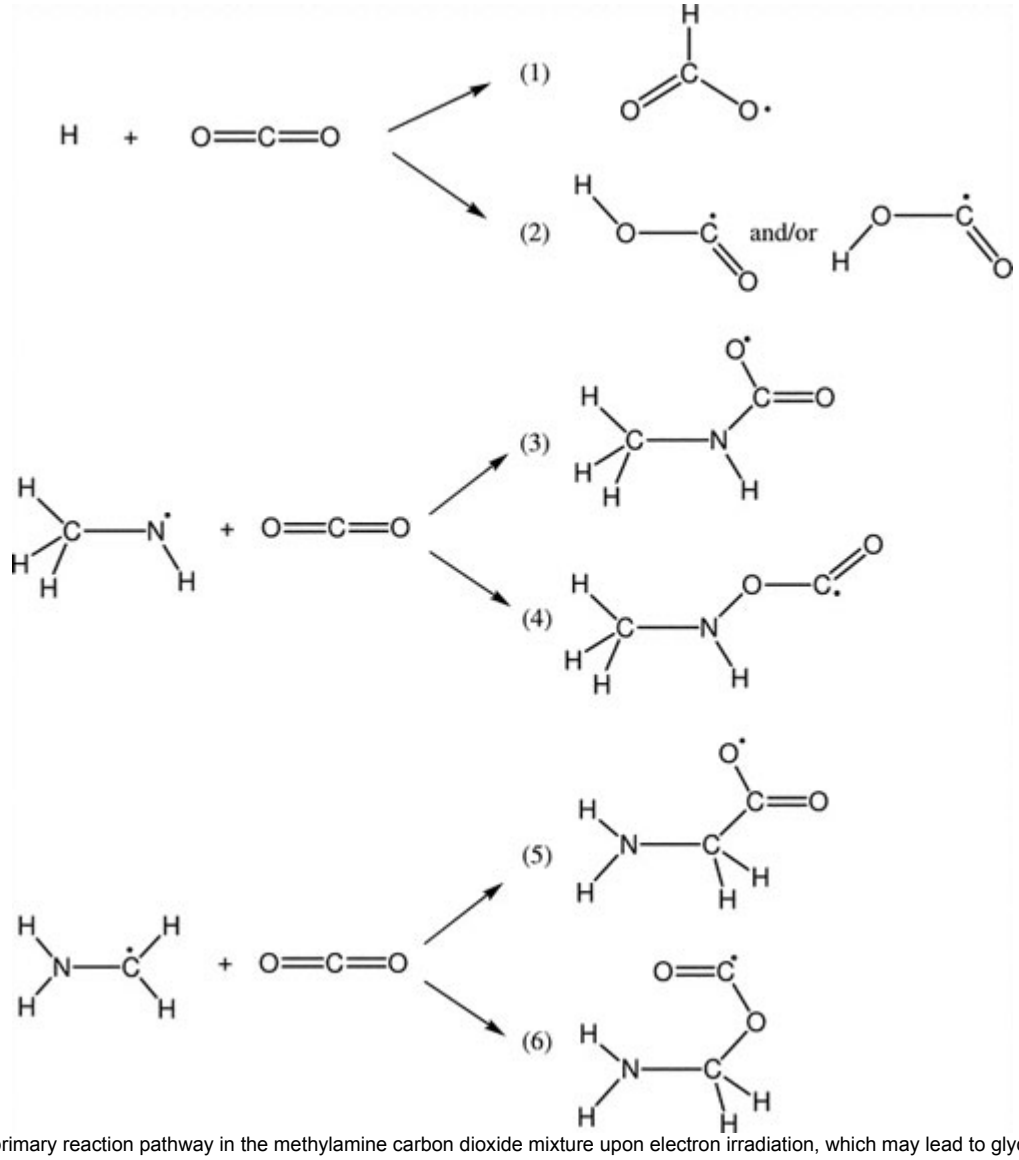


Figure 5. Feasible primary reaction pathway in the methylamine carbon dioxide mixture upon electron irradiation, which may lead to glycine and its isomers.

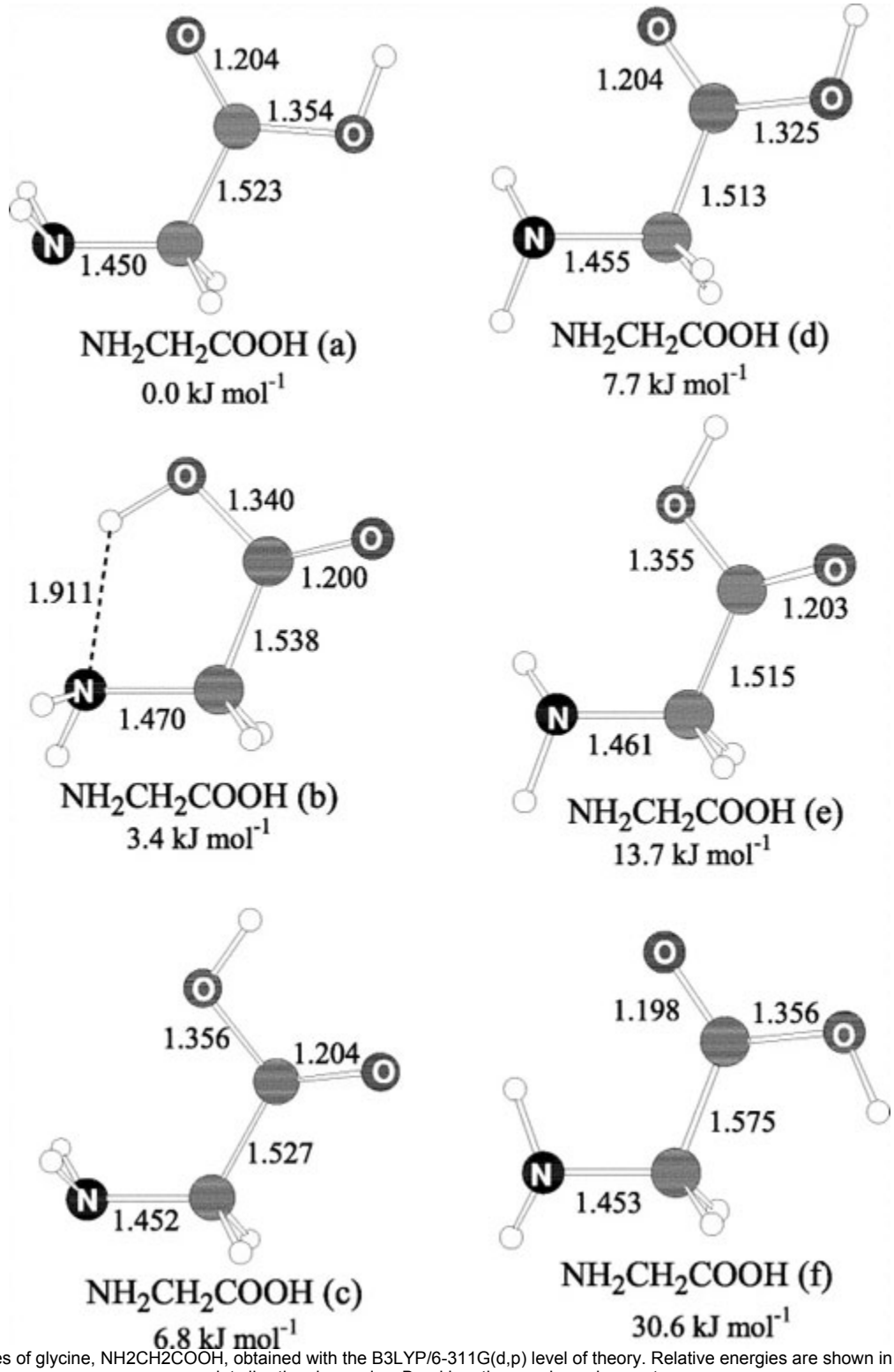


Figure 6. Optimized structures of glycine, NH2CH2COOH, obtained with the B3LYP/6-311G(d,p) level of theory. Relative energies are shown in kJ mol-1 corrected with zero-point vibrational energies. Bond lengths are shown in angstroms.

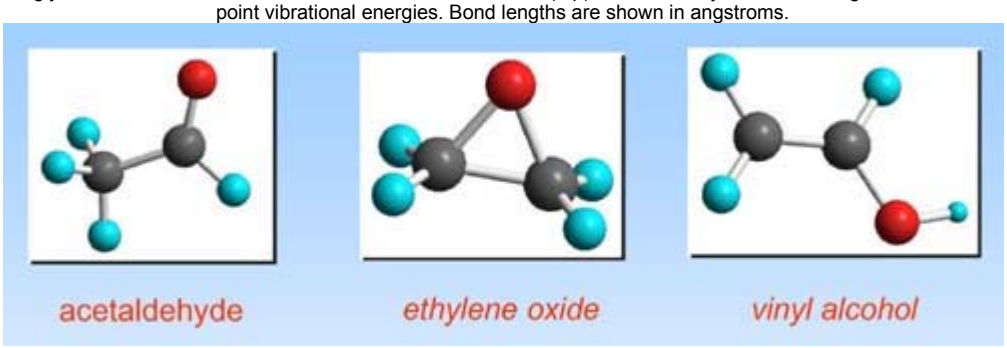


Figure 7. Structures of three C2H4O isomers acetaldehyde, ethylene oxide, and vinyl alcohol (most stable cis conformer shown).

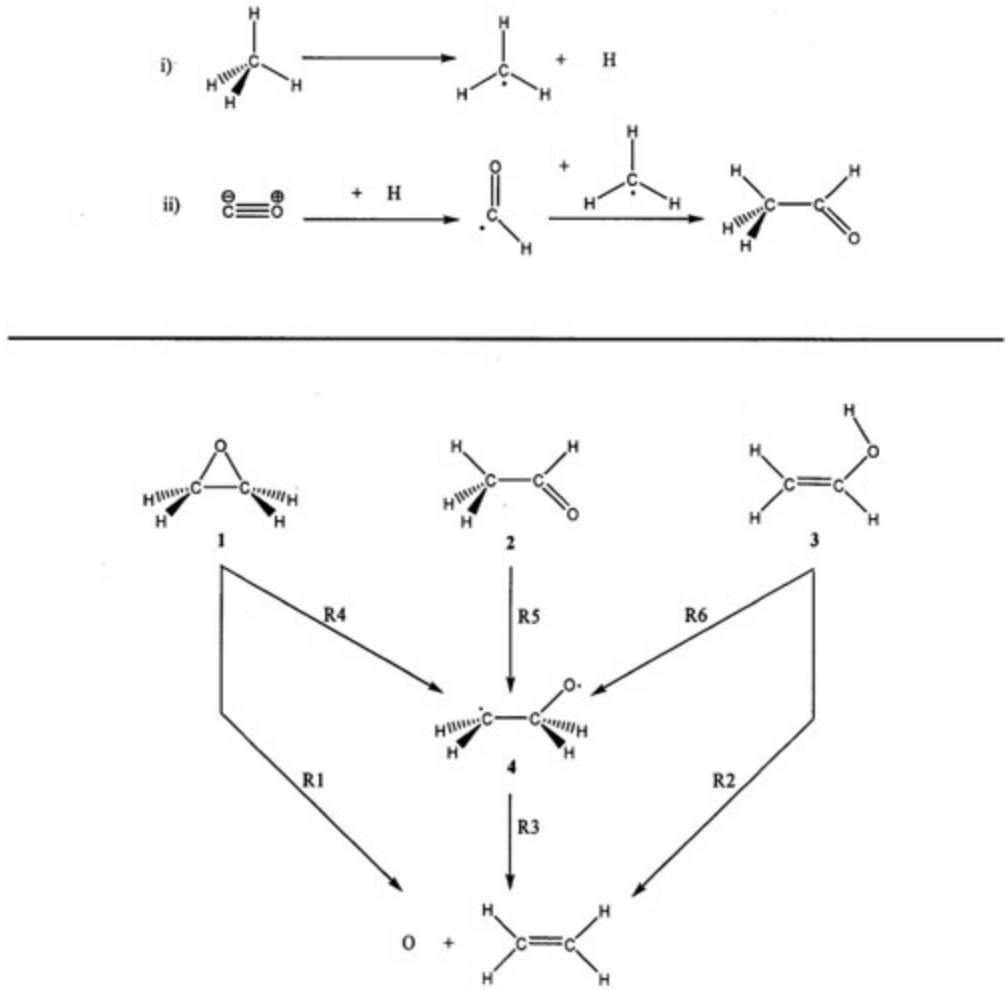


Figure 8. Synthetic routes to acetaldehyde in carbon monoxide-methane ices (top; i) and ii)) to ethylene oxide "1", acetaldehyde "2", and vinyl alcohol "3" in the oxygen-ethylene system (bottom).

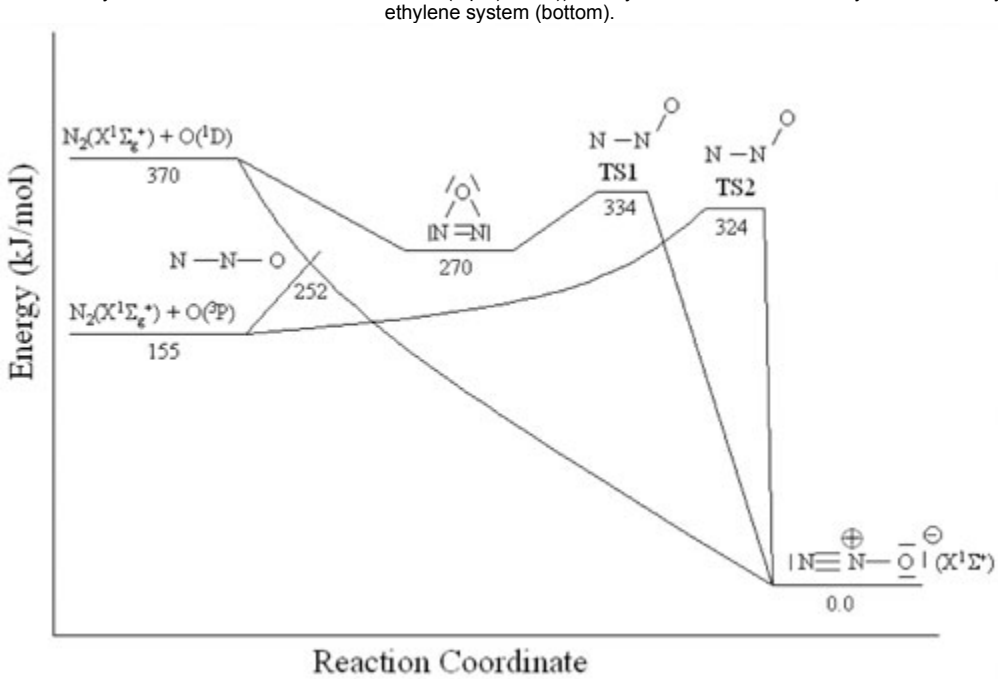


Figure 9. Potential energy surface of the reaction between molecular nitrogen and an oxygen atom in the electronic ground state (3P) or in the first electronically excited state (1D) to the linear nitrous oxide product on the triplet and singlet manifold.

Roadmap Objectives

- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 3.2:** Origins and evolution of functional biomolecules

Icelandic Subglacial Volcanic Habitats

Project Investigator: Eric Gaidos

Project Progress

1. Sampled subaerial Iceland lakes and performed direct cell counts for comparasion to subglacial lakes
2. Set up long-term microcosm experiments using pristine glacial ice and volcanic tephra to study rates of microbial colonization
3. Retrieved samples of glacial margin outflow water for direct cell counts and analysis as possible method of indirect sampling of subglacial lakes
4. With Icelandic collaborators, redesigned hot-water drill for improved performance and reliability and included filtering and UV sterilization

5. Successful field test of drill in June 2005. We expect drill to be fully operational for planned June 2006 expedition.

Figure 1. One of several outflow points of water draining the Vatnajokull ice sheet west of the Skaftarkatlar subglacial lakes.

Figure 2. Solheimarjokull glacier near the site where volcanic tephra and glacial ice samples were obtained. The dark bands of the tephra deposit can be seen.

Figure 3. Sampling the volcanic tephra layer.

Figure 4. The Askja volcanic caldera lake (background), one of several sampled for comparison with subglacial lakes. The smaller foreground lake is strongly influenced by both geothermal input and a large number of bathing tourists.

Figure 5. Hot spring along sure of Askja lake. The microbial mat covering the rocks is probably dominated by colorless sulfur bacteria that oxidize sulfide to sulfur.

Figure 6. New portable hot-water drill rig developed by the Icelandic National Energy Authority in consultation with UHNAI. The entire system is housed in the cart and can be transported onto the ice by a single 4WD vehicle.

Figure 7. Sampling hot water from the drill head during the field test.

Roadmap Objectives

- **Objective No. 2.1:** Mars exploration
- **Objective No. 2.2:** Outer Solar System exploration
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
1	Mars Exploration Rovers	Background Research
0	Mars Odyssey	Background Research
0	MRO	Background Research
0	MSL	Background Research

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Field Expeditions

Field Trip Name: Iceland 2004
Start Date: **End Date:**
Continent: **Country:**
State/Province: **Nearest City/Town:**
Latitude: **Longitude:**
Name of site(cave, mine, e.g.): **Keywords:**
Description of Work: Following the 2004 Bioastronomy conference in Reykjavik Gaidos and Thorsteinn carried out two sets of sampling in Iceland. The first was of various subaerial crater lakes in north and central Iceland to be used as a comparison to the subglacial examples. The second was a trip to the Vatnajokull ice sheet margin to sample outflow waters that run directly from the Skaftarkatlar subglacial lakes. Sampling outflow waters may provide complementary time-series information that cannot be obtained by other means. We also visited the Solheimarjokull glacier to retrieve pristine glacial ice and volcanic tephra that was deposited onto the glacier from the eruption of the nearby Hekla volcano. These materials were shipped frozen to Eric?s UH laboratory and incorporated into microcosm incubation experiments. The purpose of these experiments was to measure the rate of colonization of initially abiotic tephra sediments by microbes from the glacial ice. The tephra was baked at 500 deg. C for 48 hours to sterilize them and remove all organic carbon. Glacial ice whose surface had been cleaned by 98% ethanol and sterilized with 254 nm radiation was melted and added to the tephra in multiple serum vials, which were sealed and incubated at 2-4 deg. C in the dark. Vials are frozen at periodic intervals for final analysis in August of this year, which will include direct cell counts and DNA analysis using DGGE and RISA.
Members Involved:

Field Trip Name: Iceland 2005
Start Date: **End Date:**
Continent: **Country:**
State/Province: **Nearest City/Town:**
Latitude: **Longitude:**
Name of site(cave, mine, e.g.): **Keywords:**
Description of Work: In June of this year a new hot-water drilling system developed by the Icelandic National Energy Authority was tested in the field by a team led by Thorsteinn. This new drilling system operates at higher temperatures (90 deg. C) and higher throughput than the previous system. It also incorporates filters and a UV light that clean and sterilize the drilling water prior to heating. The drill was demonstrated to be capable of drilling through 40-50 meters of clean ice in an hour. Samples of the ice, snow used as the source of the hot water, and the drilling water were taken for biological analysis with collaborators at the Icelandic company Prokaria.
Members Involved:

Lava tube microbiology

Project Investigator: Mark Brown

Project Progress

The extreme nature of the surface environments on Mars appear to exclude extant biological habitation. However, the recent discovery of a subsurface biosphere on Earth has focused attention on the possibility that life on Mars may have retreated to subsurface "oases" when surface conditions became unfavorable. Major projects, some involving UHNAI team members, are examining the deep-subsurface environment (into and below the crust), however there are alternative, cheaper and equally relevant, subsurface habitats deserving of attention. Lava tubes form during differential cooling of flow during volcanic activity. Clear photographic evidence exists of lava tubes on Mars, e.g. on Ceraunius Tholus. Analogues are common on earth and in particular in Hawaii, where over 20 lava tubes exist. Six of the eight longest tubes in the world are found on the Big Island. An initial sampling trip to Hawaii targeted Kaumana Cave near Hilo. A transect was taken following a light intensity gradient and additional samples collected at visually geologically diverse sites up to 1km into the cave interior. DNA extraction and PCR amplification using conserved bacterial specific primers has been carried out and initial sequence data will be available shortly, providing an overview of the dominant microbial community members. More specific investigations will follow, including the molecular detection of light harvesting enzymes (chlorophyll, bacteriochlorophyll, proteorhodopsin) to determine how substrate (light) availability impacts on microbial diversity. This information will be important in our understanding of the community independence of surface energy sources. We have identified and contacted potential collaborators with access to lava tubes on the mainland USA and aim to work with them to determine the correlations of community composition with respect to light, organic substrate and water availability in geographically disparate lava tube ecosystems.

Figure 1. Twilight zone of Kaumana Cave.

Figure 2. White/grey silvered or shiny mats coating walls and ceilings are evidence of microbial communities

Roadmap Objectives

- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth

Field Expeditions

Field Trip Name: Kaumana Cave	
Start Date: 2/13/05	**End Date:** 2/16/05
Continent: North America	**Country:** USA
State/Province: Hawaii	**Nearest City/Town:** Honolulu
Latitude: 19.5N	**Longitude:** 155W
Name of site(cave, mine, e.g.): Kaumana Cave	**Keywords:** lava, cave, microbiology
Description of Work: Collection of cave rock samples for microbiological analysis	
Members Involved:	

EPO Reports: University of Hawaii

Astrobiology Laboratory Institute for Instructors

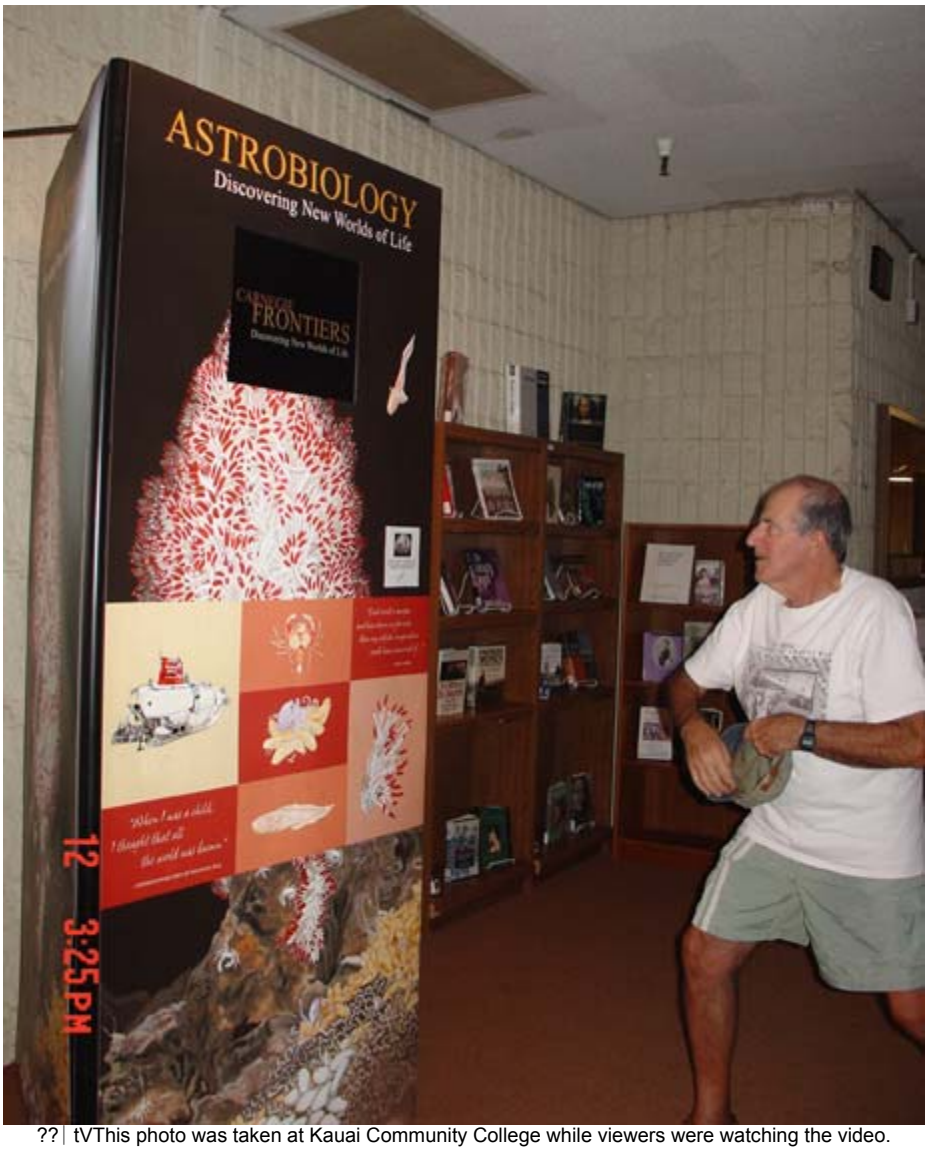
High school science teachers were introduced to the integrative nature of astrobiology through lectures by thirteen UH NAI team scientists, lab tours on adaptive optics, spectrometer, cryogenic synthesizing of hydrocarbons, and NSF-SETI Voyages Through Time curriculum. From reviewing materials in the computer lab to making comets for better understanding of NASA's Deep Impact preliminary results to developing astrobiology concept maps, these teachers will take all these activities to their classrooms. To earn 2 graduate credits, they will implement the VTT modules into their courses. Six teachers were sponsored by the Space Science Network Northwest (S2N2), one of the seven regional broker/facilitator programs. They will also be conducting secondary teacher workshops in their states. Out of 15 educators, the Native American shared how he would integrate astrobiology with his Blackfoot culture and the Native Hawaiian teacher gave a presentation on the history of water rights in Hawaii. A college of education professor participated to see how VTT can be used in his preservice teacher course.

Deep Impact/Faulkes Telescope Projects

In June, students attended sessions to develop their project plans and learn image processing on laptop computers. This was in preparation for NASA Deep Impact encounter in July. From July 2-6, they participated in a workshop on Maui to remotely observe Comet Tempel 1 on the Faulkes Telescope North under the guidance of a professional astronomer. They honed their skills during this workshop by working on astrometry and photometry of the comet images taken before, during and after the encounter on July 3, Hawaii time. The goal for these students is to complete a comet research project for entry in the 2006 science fairs. More sessions are planned to follow up with their progress. Students from Iceland with their teacher mentors also attended this workshop to collaborate with Hawaii students. UK Faulkes Telescope education manager and a UK student also participated and shared their technical and image processing expertise.

Astrobiology: Discovering New Worlds of Life

This traveling exhibit loaned from NAI team at Carnegie Institution was displayed on Oahu, Maui, Kauai, and the Big Island of Hawaii, the four major islands in the state of Hawaii, for two weeks each from January 13, 2005 to March 31, 2005. This was used to introduce the people of Hawaii to astrobiology.



??| tVThis photo was taken at Kauai Community College while viewers were watching the video.

Astrobiology/Deep Impact Workshops

Half-day teacher workshops were held on a Saturday on Oahu, Maui, Kauai, and the Big Island of Hawaii. The applications of comet research for the Deep Impact mission were related to origin of earth's oceans, an astrobiology topic for the UH NAI team. There was a diverse group of forty teachers, from those teaching kindergarten children to community college astronomy, participating. The purpose was to expose teachers to astrobiology, to have them learn about Deep Impact mission in preparation for encounter visibility in Hawaii on July 3, and inform them about project possibilities using the Faulkes Telescope. There was a goal of reaching out to teachers in the rural communities on other islands. A mother home schooling her son confined to a wheelchair attended in Hilo.

Astrobiology Lecture Series

Public lectures entitled, "Astrobiology and Deep Impact", and "Extremophiles" were held on three islands while the traveling exhibit from Carnegie Institution was being displayed there. The attendance depended upon the extent of the publicity and public exposure. When radio spots are made and the population has been privileged to have monthly astronomy talks in Hilo, the largest audience for these lectures was on the Big Island. It will take more effort and time to stimulate the other rural islalnds. Total of 100 people attended these lectures.

2005 Winter School

Graduate students and postdocs attended this program instructed by four primary instructors for the winter school, in addition to an assortment of invited speakers. The theme for the 2005 Winter School is "Water on Earth and in Space". The format used was 4 lecture series in the mornings and afternoon group sessions. Participants had to focus on the major concepts conveyed to produce documents to serve as proceedings of this winter school to be put on the UH NAI website.

Space Grant Undergraduate Fellowship

David Gremminger, a junior in Geology & Geophysics, will use images from Viking Orbiter and Mars Orbiter Camera to study the surface of Mars; in particular, the physical characteristics and rates of formation and fading of slope streaks. David's project, titled "Decadal Variability in Slope Streak Activity on Mars" will be conducted under the guidance of mentor Dr. Norbert Schorghofer of the Institute for Astronomy.

Kristine Ayson, a senior in Biology and Physics, will continue to work with mentor Dr. Karen Meech of the Institute for Astronomy on a project utilizing a large database of comet images. Kristine's project, titled "The Effects of Aging on the Morphology of the Dust Comae of Periodic and Non-periodic Comets with Regards to the Formation of Jets" includes the collection and processing of images from the UH 2.2 meter telescope at Mauna Kea.

William Carrier, a freshman in Physics, will perform experiments under the guidance of his mentor, Dr. Ralf Kaiser of the Department of Chemistry, to characterize infrared spectra of germanium-carrying molecules in low temperature ices. His project titled, "Chemistry of Germane and Methane in the Atmospheres of Jupiter and Saturn," will aid our understanding of the origin and evolution of the atmospheres of giant gas planets, and the data will be useful for future astronomical searches with infrared spectroscopy.

UH REU Program

Two of our NAI scientists mentored REU students for the summer of 2005.. 1) Name - Desiree Cotto-Figueroa Univerity of Puerto Rico at Humacao "Habitable extrasolar planetary systems; the case of 55 Cancri" 2) Name - Adrienne Dove University of Missouri-Columbia "Habitability and planet-planet interaction in 47 Uma" Both plan to have posters at the AAS conference , January 2006, Washington DC 3) Student's name: Claire N. Bendersky University: Mount Holyoke College Title of Project: Using AOIs to Document Aqueous Alteration in the CO3 Parent Body Asteroid

Publications: University of Hawaii

There are **94** publication entries for the University of Hawaii

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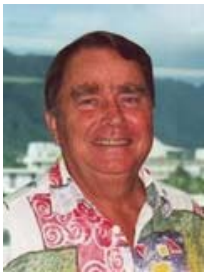

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Executive Summary: Indiana University, Bloomington

Executive Summary: Indiana University, Bloomington
Principal Investigator: Lisa Pratt
Reporting Period: 2005 (7/04-6/05)

Future exploration for life on Mars and icy bodies in the outer region of our solar system necessitates rapid development of innovative instruments and techniques for life-detection that can be field tested in analogue environments on Earth. With this goal in mind, IPTAI scientists are leading a highly collaborative effort to core, sample and characterize the microbial ecosystems present within regions of persistent permafrost in northern Canada. We intend to core a sequence of bore holes using aseptic procedures and starting from lichen-encrusted rocks at the ground surface (Figure 1), extending through hundreds of meters of rocky permafrost, and penetrating into deep sub-permafrost brines contained in fractured bedrock. We seek direct evidence of microbial biomass and activity, as well as indirect evidence of microbial metabolism in the form of distinctive chemical and isotopic anomalies in gases, aqueous species and minerals. Instrumental and assay techniques that prove to be effective for detecting biosignatures in permafrost will be modified for flight deployment on future orbiting and roving Mars missions.

Figure 1. Lichen covered rocks blanketing the landscape in northern Canada at Wolfden's Ulu gold mine.

A research site has been established at Kinross/Echo Bay Lupin gold mine, Nunavat Territory of Canada by collaborating scientists from the Geological Survey of Finland and the University of Waterloo in Canada. At this site the permafrost rock is 500 m thick. During 2001 and 2002, the Finnish/Canadian Lupin Project drilled a borehole array, which is accessible at a depth of 880 and 1130 meters. Packers and valves were installed in the boreholes, allowing for multi-year monitoring of biogeochemical reactions (Figure 2). IPTAI scientists from Princeton University, Indiana University and the University of Toronto have analyzed chemical and isotopic compositions of numerous water and gas samples from the Lupin borehole array. Funding is being pursued aggressively to drill a second borehole array at a gold mine located to the north of Lupin mine. Parallel proposals for funding the second array are being submitted to Canadian and Finnish funding agencies as part of an unusual collaboration involving universities, research institutions, regulatory agencies, and commercial mines. Biological, chemical, and physical study of core samples from permafrost will provide crucial scientific insights and engineering constraints for future exploration drilling on Mars. In addition to conventional drilling, IPTAI scientists at University of Tennessee and Oak Ridge National Laboratory are preparing to conduct laboratory drilling tests using N_2 and CO_2 as drilling fluids. Laboratory results will be used to refine technologies that are best suited for acquisition of rock, ice, water and gas samples from regolith-covered permafrost terrains on Mars and from ice-covered terrains on Mars and other planetary bodies. Future drilling tests in the laboratory and field will target strategies for removing

rock material from boreholes, stabilizing borehole walls and managing changes in fluid pressures during intersection of fractures or cavities.

Figure 2. Tullis Onstott from Princeton University and Monique Hobbs from Ontario Power and Light measure rates of gas discharge from a brine intersection at a depth of 1130 meters below the surface in the Lupin gold mine, Nunavat Territories Canada.

Three geomicrobiological field campaigns have been successfully conducted at the Lupin gold mine by IPTAI scientists. Microbial diversity at Lupin is being assessed and rates of microbial reactions are being measured in subsurface settings extending from about 200 to 1500 m below the surface. Laboratory investigations of psychrophilic (cold loving) and psycho-tolerant microbial communities recovered from water intersections at Lupin are strengthened by collaboration with astrobiologists at Michigan State University, University of Rhode Island, and Woods Hole Oceanographic Institutes. Culturing of both aerobic and anaerobic microbes from sub-permafrost brines at Lupin has been successful. Cell counts in the range of 350 to 97,000 cells/ml have been determined for Lupin bines (see details in Annual Report Year 7 from the University of Rhode Island). Harvesting deep-subsurface microbes (Figure 3) by filtering thousands of liters of sub-permafrost brine has yielded sufficient DNA for amplification and phylogenetic classification of ribosomal gene sequences. These environmental DNA samples will also be analyzed using the ribosomal gene microarray technology at Lawrence Berkeley National Laboratory and large-insert genomic sequencing using the high throughput sequencing capabilities at Diversa Corporation.

C and H stable isotopic analyses of the light C_{1-4} hydrocarbons) and H_2 are being determined at the University of Toronto for the purpose of constraining estimates of *in situ* microbial activity in the deep subsurface. Isotopic study of carbon and hydrogen are a priority because of the recent discovery of CH_4 in the Martian atmosphere. Inferring biotic versus abiotic origins and mapping distributions of natural gases in deep permafrost and sub-permafrost brine systems is a long-term goal of IPTAI research at sites in northern Canada. Development of instruments capable of C and H isotopic analyses on trace-level methane in surface seeps or in bore holes is being pursued at Princeton University. A series of box experiments will be deployed on the ground surface above cryopegs and other types of permafrost fractures in order to identify CH_4 and other gases emanating from the subsurface. These field tests will allow IPTAI scientists and collaborators to determine which gases are readily detectable and which are reliable indicators of subsurface microbial activity.

Passage of ionizing radiation through water or ice produces a complex mixture of short-lived ions, free radicals, and electronically excited molecules that can participate in a wide range of chemical reactions involving solutes and solids. Reactions between radiolytically produced radicals and aqueous or solid media can accelerate water-rock interaction in ways that mimic groundwater in contact with atmospheric O_2. If radiolytically generated oxidants react with sulfide minerals or elemental sulfur then partially to fully oxidized sulfur species could be available for microbial metabolism in unexpected subsurface environments. Almost no data are available to assess the role of naturally occurring radionuclides on oxidation of sulfide minerals and subsequent formation of sulfate plumes in groundwater. Fractionation of sulfur isotopes has not been determined during radiolysis of water coupled to oxidation of sulfides or elemental sulfur. Consequently, IPTAI scientists at Indiana University have analyzed gaseous, aqueous, and solid products of abiotic pyrite oxidation in millimolar solutions of hydrogen peroxide (H_2O_2) as an analogue for oxidizing molecular products formed during the radiolysis of liquid water. Small amounts of O_2 can form during radiolysis but at the salinities representative of subpermafrost brines, the O_2 is probably insignificant. Mineralogical, chemical, and stable isotopic data are used to infer multiple pathways for pyrite oxidation during reaction with H_2O_2. These types of laboratory experiments will lead to technology for exploration of Mars where H_2O_2 is expected to be a catalytic species in the atmosphere and a significant oxidant in regolith.

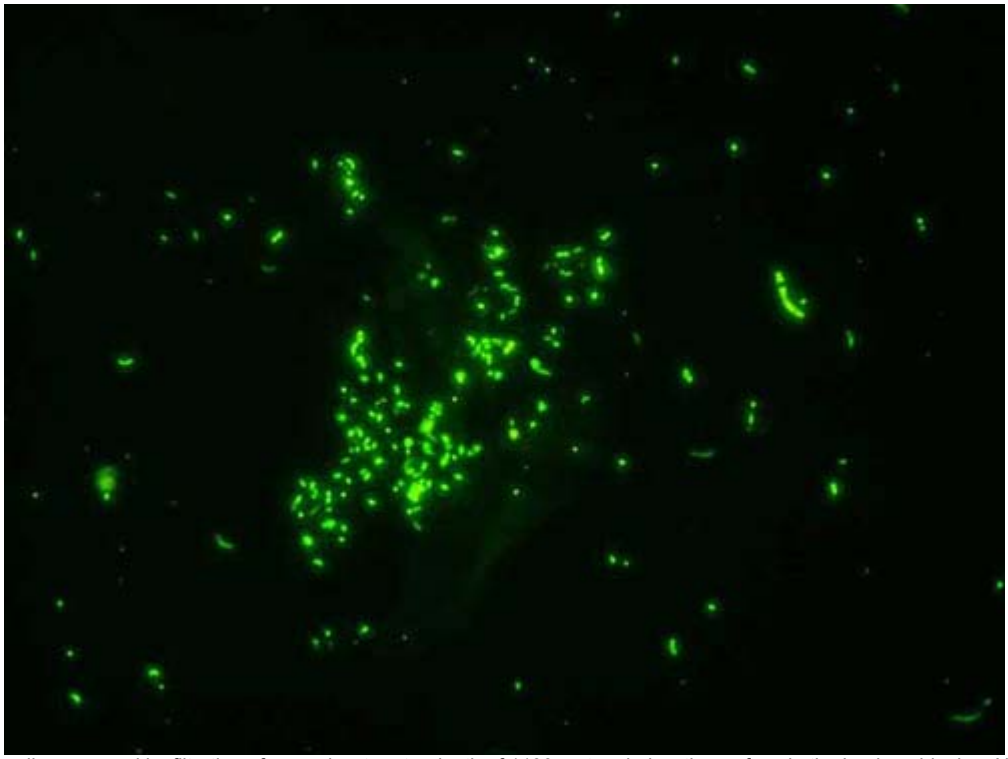


Figure 3. Intact prokaryotic cells recovered by filtration of ground water at a depth of 1130 meters below the surface in the Lupin gold mine, Nunavat Territories Canada. Cells occur in clumps and exhibit diverse morphologies. Cells were enumerated using a green fluorescent dye.

Project Reports: Indiana University, Bloomington

Synergism, evolution, and functional ecogenomics of deep-subsurface microbial communities based on molecular analyses

Project Investigator: Terry Hazen

Project Progress

Samples for genome analysis were collected at a depth of about 8,000 ft below the surface from a South African gold mine in the Witwatersrand Basin. DNA was extracted from fracture water that is inferred to be 3 million years old based on noble gas contents. DNA was extracted also from microbial biofilms that were collected from within a borehole previously exposed to oxygenated mine air. Analysis of 16s rDNA (Figure 1) in the groundwater samples demonstrated the dominant presence of a sulfate reducer and a methylotroph with a few other thermophilic microbes. The borehole biofilm sample showed a number of other species including methanogens and oxidizers of sulfur, ammonia, and methane, a finding consistent with contamination during exposure to mine air. In addition, DNA was extracted from groundwater after concentration of biomass on filters and was subjected to metagenome analysis by complete direct sequencing of all of DNA in the sample or community DNA sequencing. This deep-subsurface metagenome is currently being annotated for comparison to the 16s rDNA analyses. The dominant *Desulfotomaculum*-like organism in the Witwatersrand community appears to represent a new species and new family. This deep-subsurface organism contains a number of differences from other thermophiles and sulfate reducers which may be related to biosustainability in deep-subsurface environments. The microbial community analyses using 16s suggest that Witwatersrand microbes have synergistic energy flux relationships allowing them to collectively use a broad array of electron donors and electron acceptors. This synergism may contribute to microbial biosustainability in deep-subsurface environments.

Figure 1. Analytical sequence used by Terry Hazen at Lawrence Berkeley Livermore National Lab for amplification, fragmentation, and hybridization of DNA.

Highlights:

- 16s rDNA analysis of deep subsurface microbic community
- Metagenome sequence of deep subsurface microbic community

Roadmap Objectives

- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
3	Long-lead future mission	

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Microbial and biogeochemical characterization of a terrestrial analogue site for Mars.

Project Investigator: Tullis Onstott

Project Progress

Vertical and horizontal excavations at the Lupin gold mine in northern Canada allow access to a 500-meter thick permafrost/rock environment overlying a methane-bearing brine/rock environment. Groundwater, gas, and rock samples were collected by IPTAI scientists during two field trips to Lupin (Figure 1). Filtered groundwater samples collected in 2004 did not yield sufficient biomass for DNA characterization via polymerase chain reaction (PCR) amplification of small subunit ribosomal DNA (16SrDNA). Consequently, filtered samples collected in 2005 employed in-line filters capable of handling higher flow rates and exposure for longer periods of time (3 days). As a result, we now have successfully amplified the 16SrDNA from two of the boreholes and are continuing to work on samples from four other boreholes. Initial results indicate a diverse bacterial community. PCR products have been submitted for sequencing. Archaeal 16SrDNA is not as abundant as bacterial, but we're continuing to work on extraction of any archaeal signal. We have hopefully succeeded in filtering sufficient biomass for metagenomic analysis of the deep-subsurface environment at Lupin.

Figure 1. Tullis Onstott from Princeton University innoculates a sterile tube with brine from 1130 meters below the surface at Lupin Mine, Nunavat Territories, Canada.

Microbiological samples from 2004 yielded a diverse population of aerobic (possibly facultative) bacteria and a sulfate reducing anaerobe, but no Archaea. Samples from 2005 have yielded several sulfate reducing anaerobes and fermentative anaerobes. The enrichment cultures appear to be monophyletic and their PCR amplified 16SrDNA have been submitted for sequencing.

Stable sulfur isotope analyses have been performed at Indiana University for both dissolved sulfate and sulfide. Initial isotopic results indicate that most of the brine samples exhibit little microbial fractionation with the exception of brine from one borehole which also yielded a sulfate reducing anaerobic enrichment.

Carbon and hydrogen isotopic analyses have been completed for gas samples collected in 2004. It appears that methane, ethane, propane and butane (C_{1-4} hydrocarbons)have a thermogenic signature, although a mixture of methanogenic and abiogenic cannot be excluded. Additional samples were collected in 2005 in order to verify isotopic characterization of Lupin gases. If the origin is thermogenic, then the C_{1-4} hydrocarbons at Lupin are Archean/Proterozoic in origin and their formation coincides with the timing of the last major orogenic episode. A thermogenic origin is quite unusual as previously published analyses of C_{1-4} hydrocarbons from the Canadian Shield all suggested an abiogenic origin. Isotopic analyses indicate that microbial methane is not dominant in the Lupin gases.

Helium gas analyses indicate subsurface residence times that are on the order of ~100 million years at least. Complete noble gas isotopic analyses have been completed by Ian Clark of the Univ. of Ottawa and his analyses will be able to provide a more accurate determination of isolation time. This age, however, is much greater than the 10 kyr estimated age of the permafrost.

Anion and cation analyses of last year's and this year's samples are consistent with analyses performed by the Finnish Geological Survey for the past 4 years and indicate that the geochemical environment, in particular the redox state, has remained stable over this period of time. We infer that mining activities have not perturbed the brines isolated in fractures at Lupin. When these results are compared with extensive data set collected from South African gold mines in the Witwatersrand Basin, the similarities are quite remarkable, particularly considering that the depth range of the Lupin boreholes is relatively shallow (less than 1.5 kilometers) compared to mines as deep as 4 kilometers below the surface in South Africa. It is significant, however, that the brines at Lupin are 35°C colder than the deep brines sampled in South Africa. It will be intriguing to see if the microbial communities at the Lupin mine are similar to those recovered from the South African gold mines.

A graduate student at Princeton University, Mark Davidson, is performing a "retentostat" experiment on a subsurface, thermophilic sulfate reducing bacteria, *Desulfotomaculum putei*. This experiment is designed to reproduce nutrient and energy levels of *in situ* conditions and then to slowly decrease these levels and examine the changes in the genes expressed, the changes in lipid composition and the changes in the sulfur isotope fractionation. We plan to continue these types of experiments using microbes cultured from sub-permafrost brines in northern Canada.

We have initiated discussions with mining officials at Wolfden concerning the acquisition of permafrost rock cores at the Ulu gold mine which is located ~100 km further north of Lupin. The Ulu mine is situated in a mafic/ultramafic Archean greenstone belt and has ~500 meters of permafrost. Wolfden is planning an extensive exploration drilling campaign for 2006 and it is our hope to piggy back on their effort with the acquisition of pristine permafrost/rock samples for microbial and geochemical analyses. Penetrate into the underlying environment is necessary to determine if a gas-bearing brine is present beneath the permafrost at Ulu and to assess if biogeochemical signatures of sub-permafrost brines are similar at Ulu and Lupin. To this end we have prepared and submitted a proposal to NAI where we are requesting funds to cover the cost of this drilling campaign.

Highlights

- Successful recovery and culturing of aerobic and anaerobic microbes from brines at depths from 800 to 1100 meters below the surface in northern Canada.

- Brines present beneath 500-meter thick permafrost were filtered and yielded sufficient DNA for PCR and sequencing of cold-tolerant, deep-subsurface microbes.

Roadmap Objectives

- **Objective No. 2.1:** Mars exploration
- **Objective No. 2.2:** Outer Solar System exploration
- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials

Field Expeditions

Field Trip Name: Lupin Au Mine	
Start Date: March 2, 2005	**End Date:** March 11, 2005
Continent: North America	**Country:** Canada
State/Province: Nunavut Terrotory	**Nearest City/Town:** Yellowknife

Latitude: 65o 47?
Longitude: 111o 15?
Name of site(cave, mine, e.g.): Lupin
Keywords: Permafrost, Brine, Methane, Microorganisms
Description of Work: Collection of DNA and Lipid samples, collection of anaerobic and aerobic enrichment cultures, determination of in situ hydrogenase activity and H2 concentrations, measurement of methane isotopes
Members Involved:

Cross Team Collaborations

In the previous year's expedition, Corien Bakersman (Michigan State University) participated by collecting bio samples for aerobic enrichments. In this year?s expedition additional bio samples were collected that were delivered to Ms. Bakersman and to other members of the Michigan State University NAI team. The University of Rhode Island NAI team joined this year's Lupin expedition by sending Bruno Soffientino, a biogeochemist specializing in the development of a tritiated hydrogenase activity assay. Jon Telling, a postdoctoral research fellow who joined the University of Toronto team this year, also participated by collecting gas samples for analysis of stable carbon and hydrogen isotopes for C1-4 hydrocarbons. Telling also collected water samples for stable carbon isotopic analyses of carboxylic acids, especially acetate.

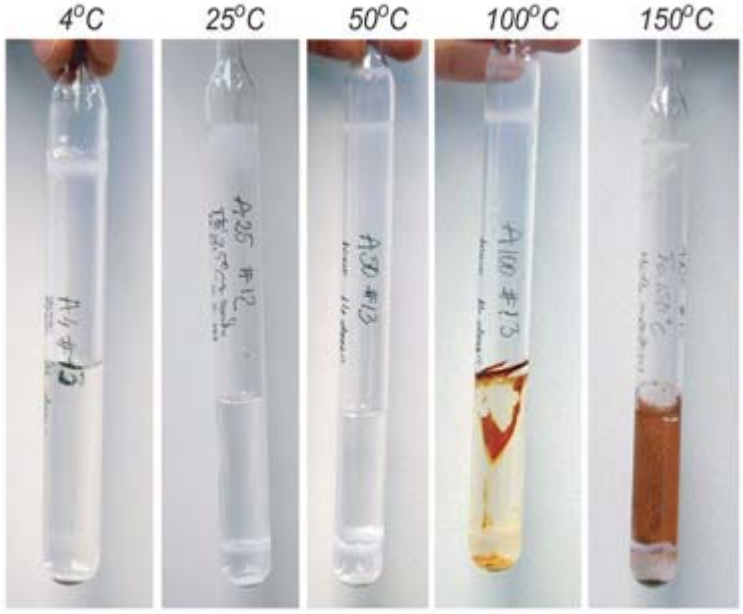
Radiolysis as a source of chemical energy for microbial metabolism in the deep subsurface

Project Investigator: Edward Ripley

Project Progress

Radiolysis of water can accelerate water/rock interaction through production of radicals (e.g., hydrogen, hydroperoxyl, hydroxyl), ions (e.g., superoxide, protons, hydroxide), and reactive molecules (e.g., hydrogen, hydrogen peroxide, oxygen). Radiolytic oxidation can be observed in modern groundwater associated with uranium ore bodies and can be inferred for ancient groundwater based on the composition and isotopic signature of minerals. Prior to development of an oxygen-rich atmosphere on Earth, radiolytically generated oxidants could have reacted with pyrite and provided local plumes of partially to fully oxidized sulfur species suitable for microbial metabolism.

We evaluated sulfur isotope effects associated with reactions between pyrite and radiolytic oxidants using a series of sealed-quartz-tube experiments run with 60 mg of acid-cleaned pyrite, 10 milliliters of deoxygenated water, and concentrations of hydrogen peroxide (H_2O_2) at millimolar levels (Figure 1). Experiments ranged in temperature from 4 to 150 degrees Celsius with durations from 1 to 10 days.



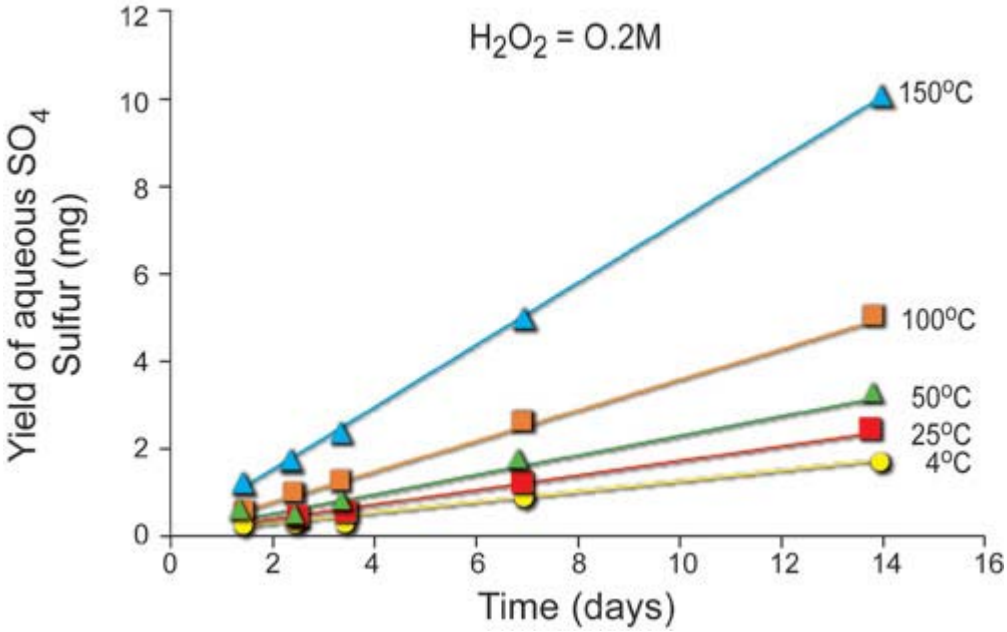


Figure 1. Photographs of the sealed-tube experiments after reacting at temperature from 4 to 100 degrees C. The amount and type of reaction products is dependent of temperature.

In initial experiments, primary oxidation products were dissolved sulfate, elemental sulfur, iron sulfate minerals, and iron oxyhydroxide minerals. X-ray diffraction patterns and images from scanning electron microscopy reveal anhedral to subhedral hydrated iron sulfates in globular clusters of about 10-30 micrometers in diameter forming on pyrite surfaces (Figure 2). Sulfur isotopic compositions remained unchanged for pyrite but showed distinct enrichment of ^{34}S in produced sulfate and elemental sulphur. The isotopic difference between sulfate and pyrite was 0.5-1 permil and between elemental sulfur and pyrite was 1-2 permil. Our results indicate that pyrite oxidation by H_2O_2 induces greater fractionation that has been recognized in previous studies. Although difference in isotopic composition for produced sulfate and elemental sulfur compared to starting pyrite are not large but compensating depletion of ^{34}S in undetected products could be substantial if proportional yields are small. Preliminary isotope results from high-temperature experiments indicate that the missing ^{34}S-depleted fraction might be held in iron sulfate and/or iron oxyhydroxides. Similar fractionation in ancient terrestrial samples or in extraterrestrial samples could be mistaken as evidence for microbial activity.

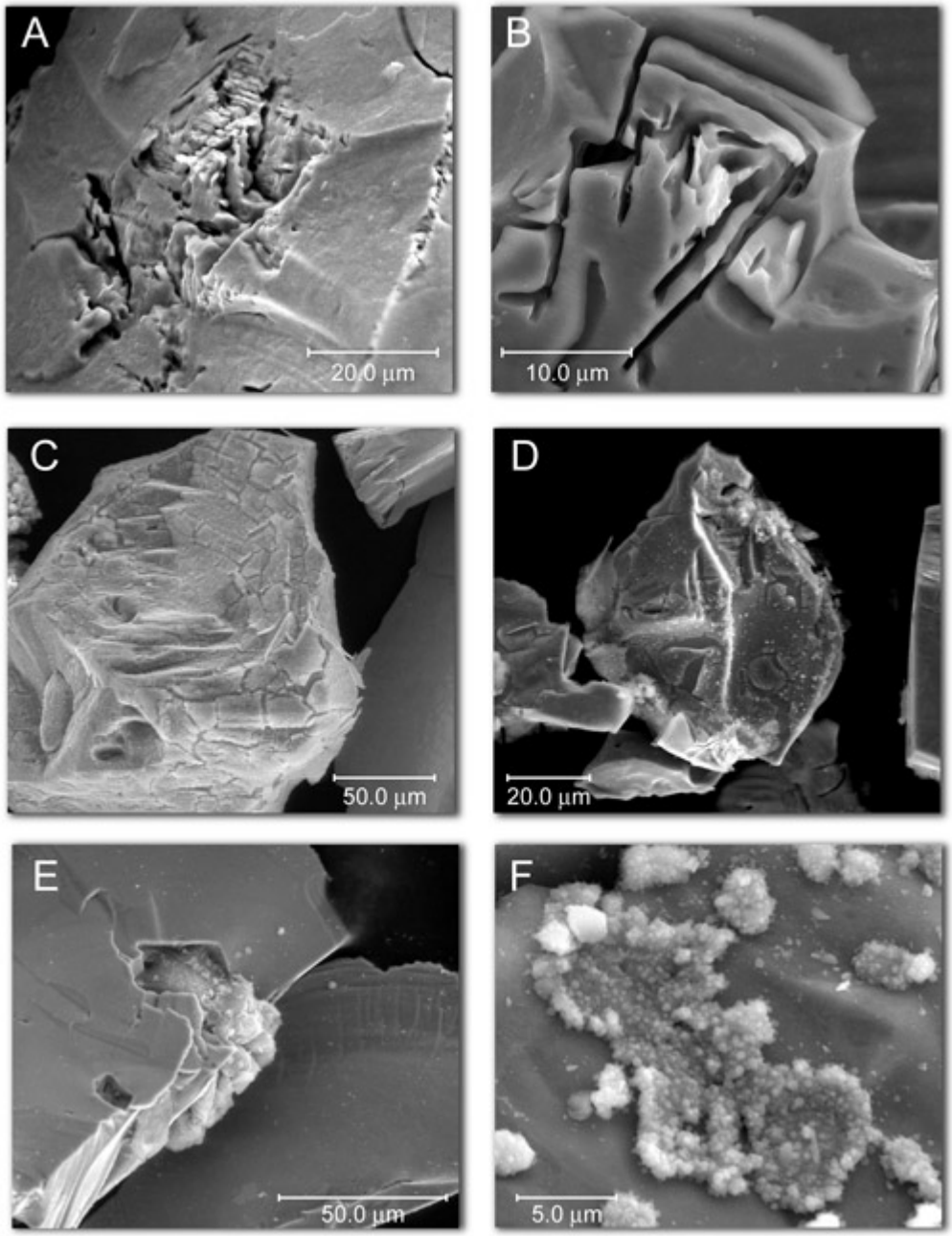


Figure 2. SEM photomicrographs of the final solid residue from the pyrite-hydrogen peroxide solution experiments: (a) and (b) dissolution features within pyrite crystal faces; (c) and (d) multilayered sulfate crust on individual pyrite crystals; (e) and (f) aggregates of micron-size, polyphase mixtures of sulfate minerals grown within and on the pyrite surface.

Highlights:

- Recently published paper by Lin and others (Geochemistry Geophysics, and Geosystems, 2005) presents an exciting and controversial hypothesis for the crucial of radiolytic hydrogen production in sustaining deep-subsurface microbial communities on Earth and, potentially, on other planets.

- Laboratory experiments simulating radiolysis in the deep subsurface yield distinctive non-biogenic isotope signatures for sulfate and elemental sulfur produced by oxidation of pyrite.
- Radiolysis of groundwater in uranium-rich deposits can provide oxidized and reduced chemical species suitable for sustaining diverse communities of microbes.

Roadmap Objectives

- **Objective No. 3.3:** Origins of energy transduction
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.2:** Foundations of complex life
- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms

- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Field Expeditions

Field Trip Name: Lupin Au Mine	
Start Date: March 2, 2005	**End Date:** March 11, 2005
Continent: North America	**Country:** Canada
State/Province: Nunavut Terrotory	**Nearest City/Town:** Yellowknife
Latitude: 65o 47'	**Longitude:** 111o 15'
Name of site(cave, mine, e.g.): Lupin Mine	**Keywords:** Permafrost, Brine, Methane, Microorganisms
Description of Work: Collection of DNA and Lipid samples, collection of anaerobic and aerobic enrichment cultures, determination of in situ hydrogenase activity and H2 concentrations, measurement of methane isotopes	
Members Involved:	

Laser fluorometry for remote detection of oxygenic phototrophs on Earth and, potentially, on Mars

Project Investigator: Charles Dismukes

Project Progress

The innovation of oxygenic photosynthesis is argued to have transformed the Earth's atmosphere and been the driving force that led to the evolution of O_2-based respiratory metabolisms. At the heart of this biological innovation is the photosystem II (PSII) enzyme complex with ability to split water into O_2. Previously, it was postulated that the first oxygenic PSII may have originated from an anoxygenic phototroph that lived on ferrous metal complexes for an electron source and later bound and photo-oxidized Mn^{2+} in the form of bicarbonate complexes. To test this hypothesis, both electrochemistry and electron paramagnetic resonance (EPR) spectroscopies were used to characterize Mn^{2+} bicarbonate complexes that form in solution and their efficacy as electron donors to Photosystem II. The charge and structure of these complexes together with the greatly reduced oxidation potential to Mn^{3+} explains why bicarbonate stimulates the rate of photo-assembly of the Mn_4CaO_x-cluster during biogenesis of Photosystem II in whole cells (Dasgupta et al.., submitted to *J. Phys.Chem B.*). This work supports the hypothesis that carbonate is essential in some Photosystem-II organisms and could have played a key role in the evolution of oxygenic photosynthesis in the CO_2-rich Archean era.

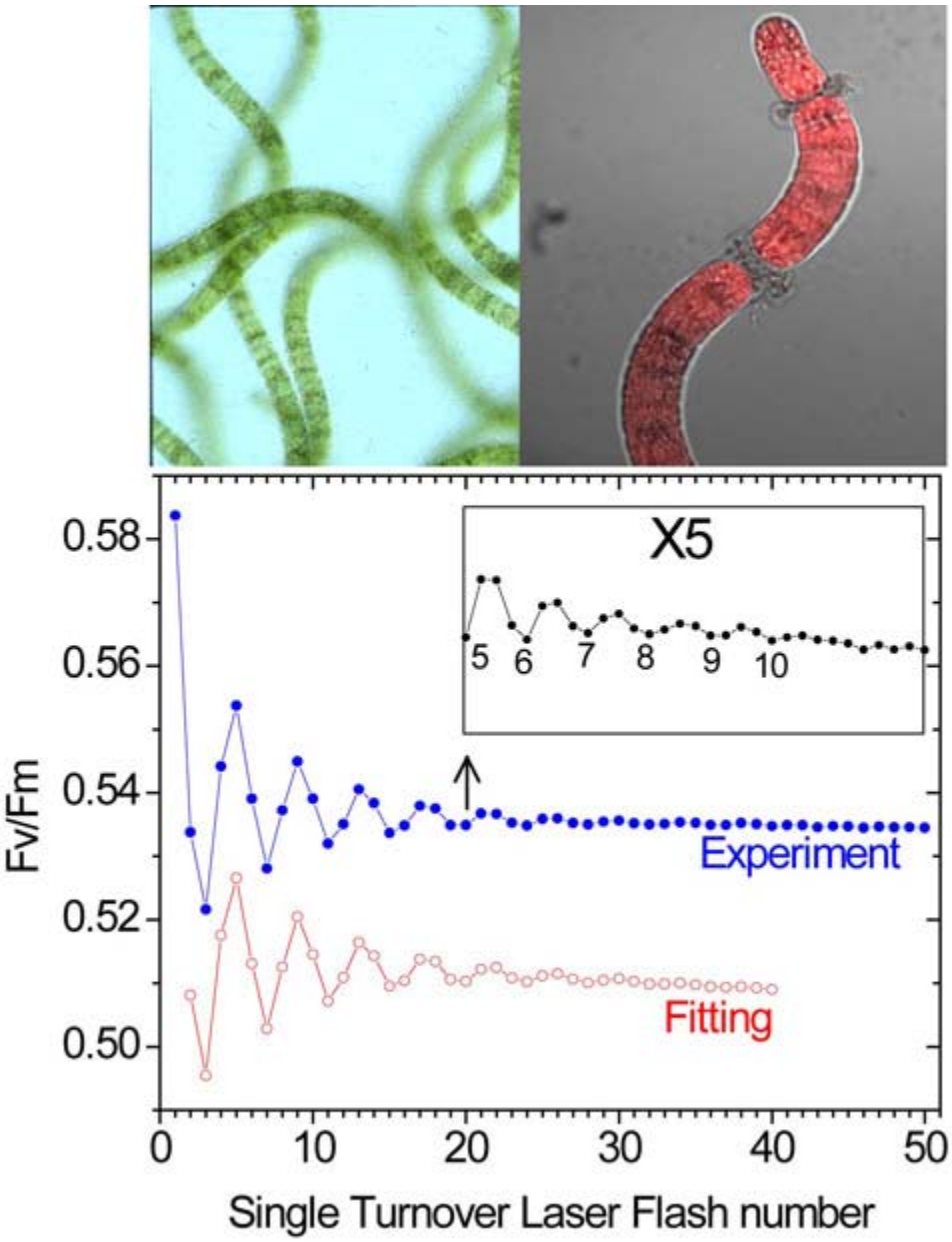


Figure 1. The graphic illustrates an oxygen-producing cyanobacterium that was isolated from an alkaline soda lake where volcanic carbonate levels reach 1 molar concentration. Red emission intensity was collected from live cells using a pulsed laser fast repetition rate fluorometer. Cells are initially dark-adapted and exhibit oscillations in yield of a few percent that damp away owing to light adaptation. These oscillations reflect the cycling of the oxygen-evolving enzyme which weakly modulate the recombination reactions of the fluorescing chlorophyll pigments. This instrument has applications in identifying photosynthetically active organisms in extreme environments, such as future Mars missions.

Highlights

- A pulse-laser flat-repetition-rate fluorometer (FRRF) was successfully used to characterize photosynthetic function for *in situ* biofilms and planktonic cells in hot spring settings.
- An astrobiology course was taught at Princeton University, including a field trip to LaDuke hot spring near Yellowstone National Park in Fall 2005.
- A modified design was completed for a fluorometer that measures quenching of the variable portion of chlorophyll fluorescence emission from the Photosystem II reaction center by the O_2-evolving enzyme.

Roadmap Objectives

- **Objective No. 3.3:** Origins of energy transduction
- **Objective No. 4.2:** Foundations of complex life
- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.3:** Biochemical adaptation to extreme environments

Field Expeditions

Field Trip Name: Yellowstone National Park, Princeton GEO 255 Astrobiology Course	
Start Date: Fall, 2005	**End Date:**
Continent: North America	**Country:** USA
State/Province: Wyoming	**Nearest City/Town:** West Yellowstone
Latitude:	**Longitude:**
Name of site(cave, mine, e.g.):	**Keywords:** hot spring, microbes, fluorometer, students
Description of Work: A pulse laser flat repetition rate fluorometer (FRRF) was used to characterize photosynthetic function in biofilms and planktonic cells sampled during a class field trip to the LaDuke hot springs near Yellowstone in Fall 2005.	
Members Involved:	

Cross Team Collaborations

We are currently seeking ollaborations with other NAI members to apply this instrument to the detection of photosynthetic life in remote environments such as Yellowstone National Park and the Atacama desert in Chile.

Origins and signatures of biogenic and abiogenic hydrocarbons.

Project Investigator: Barbara Sherwood Lollar

Project Progress

Radiolysis experiments. Completed experimental results showed δ^2H of H_2 can only be used as an indicator of *in-situ* water radiolysis for groundwater with relatively young ages and low temperatures. However, radiolytic H_2 yields derived from theoretical estimates for several natural settings seem sufficient to support lithoautotrophic microbial communities in continental crusts or enriched ore bodies, which have more abundant radioactive elements than those of oceanic crusts.

Hydrocarbon Yielding Water/Mineral Reactions. Substantial progress was made in three different sets of experiments under this Objective. Experiments generating abiogenic hydrocarbons under hydrothermal conditions (400°C, 500 bars) were conducted using gaseous sources of H_2 and CO_2, as well as the traditional method of using formic acid (in order to compare and contrast the influence of simple organic acids in the experiments). In addition, experiments were conducted to produce abiogenic hydrocarbon via Fischer-Tropsch synthesis using iron powder catalysts instead of magnetite, since mineral surfaces appear to introduce an additional source of carbon into the experiments due to residual carbon sorbed to the mineral surfaces even after careful cleaning. The initial results of the synthesis of abiogenic hydrocarbon via spark discharge experiments were also very positive. Initial results show that ethane produced from methane by polymerization in the spark discharge experiments do indeed show the pattern of inverse carbon isotope depletion and hydrogen isotope enrichment hypothesized by Sherwood Lollar et al. (2002) and first identified for the Kidd Creek mine gases in that paper in *Nature*.

The spark discharge results suggest that indeed production of abiogenic hydrocarbons via polymerization may have a characteristic isotopic signature that could be an important criteria for distinguishing abiogenic from biogenic sources of hydrocarbons. Recently there has been substantial interest in this approach as a more definitive means of resolving the abiogenic versus biogenic origin debate over methane in the Martian atmosphere. This issue is addressed in a manuscript in submitted to the *Astrobiology Journal* by T.C. Onstott, B. Sherwood Lollar and others. In addition, B. Sherwood Lollar was asked to discuss this research and its implications for Mars exploration at the NASA Astrobiology Institute sponsored workshop on "Methane on Mars" at NASA Goddard Space Flight Center in May 2005. The results of these experiments make an important step forward in trying to define a criteria for unambiguous identification of abiogenically produced hydrocarbons versus biogenic hydrocarbons and hence for establishing isotopic signatures of life.

Evolution of the C Cycle From Abiotic to Biotic Processes. As planned, comparison of results from Canadian Shield sites to results from the South Africa mines was used to develop a model to distinguish between microbial gases and abiogenic end-members in Precambrian Shield field settings. Most importantly, the geochemical, isotopic and microbiological data suggest that the methanogens might in fact be utilizing the abiogenic gases, specifically H_2, as an energy source in the deep subsurface. The association of high concentrations of H_2 with ^{13}C-enriched CH_4 end-members, and H_2 depletion in the ^{13}C-depleted methanogenic end-members suggests the possibility that abiogenic gases may support H_2 autotrophy linked to methanogenesis in the deep subsurface.

With continuing effort to increase the sensitivity of our analytical techniques, we have been able to observe details of the isotopic composition of the Shield gases not possible in previous research. In particular we are now building a data base documenting isotopic signatures for higher hydrocarbons (C5 and C6) and both the straight chain and branched chain forms of C4-C6. These observations have been used to develop a mass balance model, which adds substantially the evidence for an abiogenic origin via polymerization for the Shield gases.

Evolution of the N cycle from Abiotic to Biotic Processes. Nitrogen isotope values for South African samples ranged from -2‰ to 7‰ AIR, similar to that observed for the Canadian Shield and consistent with N_2 derived during devolatilization reactions associated with metamorphism. The Canadian sites had

somewhat more enriched values $\delta^{15}N$ (as high as 16‰AIR) and we are presently investigating whether these differences are a function of mixing with air, or whether they reflect differences in the thermal metamorphic histories.

Field Sites for Biosustainable Subsurface Environments.

Two field sampling trips were conducted by the Deep-Subsurface Life Team to Lupin Mine in May 2004 and March 2005 (Figure 1). The gases were predominantly methane with C1/C2+ ratios typically between 50-200 indicating a substantial component of C2+ (ethane, propane and butane) in these gases. Although the carbon and hydrogen isotope values for the Lupin methane samples appear to fall close to the field expected for microbially-produced gases, the high concentrations of C2+ in these boreholes argues against the gases being entirely microbially-derived. Gases produced by methanogenesis are typically dominated by methane, with C1/C2+ ratios > 10^3-10^5. In addition, abiogenic Shield gases found at other sites in Canada and South Africa have been shown to fall in a similar range as the Lupin samples – reflecting a predominantly abiogenic origin due to water-rock interaction, but with carbon isotope depletion and hydrogen isotope enrichment due to mixing with a component of microbially produced methane.

The study of deep subsurface, ecosystems in ancient groundwater is directly relevant to the exploration for extant life in the subsurface of Mars. In addition we are interested in the study of geological terranes where thermal overprinting is sufficient to eradicate microbial life and where tectonic processes keep the terrane isolated from Earth's surface. We are planning to determine the types of prebiotic compounds that are formed or available in these thermally overprinted terranes, allowing assessment of the potential for life to be spawned and evolved beneath Earth's surface.

Figure 1. Jon Telling from University of Toronto uses a syringe to sample dissolved gases during the 2005 field trip to Lupin Mine, Nunavat Territories Canada

Highlights

- Ecosystems based on H_2 autotrophy are proposed as a possible basis for microbial life on Mars in a manuscript submitted to *Astrobiology Journal.*
- Abiogenic gases supporting H_2 autotrophy are linked to deep-subsurface methanogenesis in a paper by Sherwood Lollar et al. that has been accepted for publication in *Chemical Geology.*
- Results of stable hydrogen isotope experiments suggest a new criteria for unambiguous identification

of abiogenically produced hydrocarbons versus biogenic hydrocarbons and hence for establishing isotopic signatures of life. Sherwood Lollar was invited to discuss this research and its implications for Mars exploration at the NAI sponsored workshop on "Methane on Mars" at NASA Goddard Space Flight Center in May 2005.

Roadmap Objectives

- **Objective No. 2.1:** Mars exploration
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.2:** Foundations of complex life
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
2	Mars Sample Return	Instrument/Payload Development,Research or Analysis Techniques
3	Far-Future Mars or Europa	Background Research,Instrument/Payload Development,Research or Analysis Techniques

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Resolving abiogenic versus biogenic sources of methane has important implications for Mars exploration. Techniques for collection of gas samples in deep subsurface mines will be modified and tested for flight application.

Field Expeditions

Field Trip Name: The Geochemistry of Deep Subsurface Gases, Lupin Mine, Nunavut, Canada

Start Date: March 5, 2005 | **End Date:** March 10, 2005
Continent: North America | **Country:** Canada
State/Province: Nunavut Terrotory | **Nearest City/Town:** Yellowknife
Latitude: 65deg 46'N | **Longitude:** 111deg 15'W
Name of site(cave, mine, e.g.): Lupin Mine | **Keywords:** permafrost, deep terrestrial biosphere, gases, biosignatures, methane, stable isotopes

Description of Work: Sampling and stable isotopic analysis of gases associated with deep subsurface brines to distinguish abiogenic versus biogenic signatures.

Members Involved:

Cross Team Collaborations

1. Collaboration with Dr. T. McCollom of the University of Colorado, Boulder team is underway to measure

13C and 2H isotopic signatures of abiogenic hydrocarbons produced via F-T synthesis. Technique developments made for this analysis were the subject of an invited presentation to the Goldschmidt conference in Idaho in May 2005. 2. Collaborations with the Pennsylvania State team include collaborative experiments with Dr. William Seyfreid on synthesis of abiogenic hydrocarbons (see resulting publications list) and communications with Dr. Kate Freeman regarding isotopic analysis of low concentrations of organic acids in deep groundwaters. The results of the work with Seyfried?s group and U of Toronto were the subject of two presentations to the Goldschmidt conference in Idaho in May 2005. 3. Collaboration with Dr. George Cody and Dr. Marilyn Fogel of the Carnegie team involves 2H isotopic characterization of hydrothermal fluids and gases. These experiments are in their initial phases, with experimental development being carried out by Carnegie PDF P. Morrill (a recent PhD graduate from the Toronto group).

EPO Reports: Indiana University, Bloomington

IPTAI EDUCATION AND PUBLIC OUTREACH EFFORTS, JULY 2004 - JUNE 2005: Course Development

Indiana University - Lisa M. Pratt

Course Development:

Geomicrobiology G690: Geomicrobiology is a new course taught by Professor Lisa M. Pratt. This class provides an introduction to environmental microbiology and astrobiology for graduate students and advanced undergraduates with interests ranging from biogeochemistry to extremophile adaptation to origins of life. The first six week focus on textbook readings with supporting lectures on microbial phylogeny, growth, metabolism and genetic sequencing in order to build a conceptual framework and a technical vocabulary. During the second six weeks, dialogue and debate are incorporated into lecture through discussion of recent journal articles. The final two weeks of the semester are reserved for student presentations. Students write a three-page executive summary on a topic selected in consultation with the instructor. Each summary is supported by an annotated bibliography with a minimum of 20 journal references. Each student presents a 20-minute oral summary of their term paper to the class. Thirteen students representing four different departments (Biology, Geological Sciences, Public and Environmental Affairs, Science Education) enrolled in the first offering of Geomicrobiology. The course will be offered a second time in Spring 2006.

Princeton University - T.C. Onstott

Course Development:

Life in the Universe Ge/As/EBB 255. Instructors: T.C. Onstott, Ed Turner, Laura Landweber, Chuck Dismukes and Ed Stiefel Teaching Assistants: A. Youdin, M. Davidson, K. Sigloch

This course introduces students to a new field, Astrobiology, where scientists trained in biology, chemistry, astronomy and geology combine their skills to discover life's origins and to seek out extraterrestrial life. Students will experience first hand the diverse techniques used to study extremophiles in hot springs during an excursion to Yellowstone National Park over fall break. The course also covers the technologies being used to explore for life on Mars, Europa, Titan and extra-solar planets. Overall we believe we accomplished the impossible in the first year of this course, which was to teach about life in the universe from the perspective of an astrophysicist/ astronomer, a molecular/evolutionary biologist, two bio/inorganic chemists, and a geologist/microbiologist. Our goal for next semester is to make some minor adjustments in the field trip, to modify the course material by removing the less relevant content and to make it more digestible, change the assignments by adding exercises that relate to the assigned reading. The course is now cross-listed in the Chemistry department. The MER's (Mars Exploration Rovers) will continue to roam and Cassini will have several more flybys of Titan next fall, a new 7-9 Earth mass planet has been discovered around a M star, so plenty of new observations will present themselves for discussion in fall '05. We also plan to promote speakers invited by PABC in our classes, invite members of last years class who spent the summer doing NASA research interns to class and invite Prof. Chris Chyba, a world-renowned astrobiologist recently hired by Princeton University, to join our final discussion period. If next semester's students are as enthusiastic as was this semester's, then we believe this course should become part of the undergraduate curriculum and perhaps with increased enrollment. This could be accomplished by offering a two track version 255 and 255a where the latter satisfies the ST requirement by making the YNP trip mandatory. We set the enrollment cap at 21 this year and this was reached in the first day of SCORE. We let an additional 7 students enroll under the assumption that some attrition will occur prior to the Yellowstone field trip. A proposal has been submitted for an AST/MAE course science/engineering on life detection on exoplanets and Mars. This is part of a proposal to the undergraduate dean for a certificate in Astrobiology that is being submitted this semester. Onstott and colleagues have put together sample courses of study for 5 departments. University of Tennessee - Susan M. Pfiffner

Public Outreach Coordinated with the University of Tennessee's Institute for Assessment and Evaluation to evaluate the effectiveness of the 2003-2004 "Research Experience for Undergraduates (REU): Biogeochemical Education Experience - South Africa." Interviews and surveys of students and mentors were used to assess how well the goals and objectives of the REU were met and the impacts of the REU on

students (e.g., academic and career aspirations, tracking of progress, and science literacy) and mentors (e.g., teaching/mentoring skills, research experiences, and international collaboration of benefit to the home institution). This information was used for the final report, submitted to the National Science Foundation in July 2005.

Planning is underway to continue the E/PO begun under the 2003-2004 REU through the Deep Underground Science and Engineering Laboratory (DUSEL) a developing multidisciplinary program at the National Science Foundation. DUSEL would be a logical next step for transfer and extension of the REU technology from the mines in South Africa. We are emphasizing the REU goals of increasing diversity in the sciences and education arenas, enhancement of multidisciplinary science, and providing opportunities for cultural exposure. Anticipated education projects would emphasis K-16 curriculum development, research experiences for undergraduates, career development for teachers, and inreach and exchange activities for undergraduate and graduate students. Outreach projects would include the use and development of digital media, remote access, and a hands-on visitor center or museum.

IPTAI EDUCATION AND PUBLIC OUTREACH EFFORTS, JULY 2004 - JUNE 2005: Public Outreach

Indiana University - Lisa M. Pratt Phi Beta Kappa Fellows Lecture, Eastern Illinois University. Talk entitled, "If we encounter life on Mars, will we recognize it as living?" Approximately 200 people attended this evening lecture which was open to the public. September 2004.

Interview for NOVA miniseries, "Origins." PBS broadcast September 28, 2004

Invited presentation to Cook Corporation executives. Cook is a biotechnical corporation with headquarters in Indiana. Talk entitled, "Detection of biosustainable energy and nutrient cycling in the deep subsurface of Earth and Mars.?" October, 2004

National Science Teachers Association Regional Convention Indianapolis IN. Talk entitled, "If we encounter life on Mars, will we recognize it as living?" November 5, 2004

Department of Geological Sciences, Indiana University, Colloquium Series. Talk entitled, "If we encounter life on Mars, will we recognize it as living?" November 15, 2004

Interview with Earth and Sky Radio series, "Inspiring curiosity about science and nature in the 21st century." April, 2005

National Academy of Science Lecture, "Biosustaining Energy and Nutrient Cycles in the Deep Subsurface of Earth and Mars NASA Astrobiology Institute." Presentation to Committee on the Origin and Evolution of Life. 31 May 2005 J. Erik Jonsson Center Woods Hole MA

Website managed by Ruth Droppo: http://www.indiana.edu/~deeplife

Princeton University - T.C. Onstott Princeton Astrobiology Club: www.princeton.edu/~pabc

TIGER talk to a high school teacher training workshop run by the molecular biology department at Princeton; there were about 40 teachers in attendance.

Website managed by James Wray http://deepbio.princeton.edu/

IPTAI EDUCATION AND PUBLIC OUTREACH EFFORTS, JULY 2004 - JUNE 2005: Multimedia

IPTAI team members at Indiana University are developing an interactive DVD teaching module for use in middle and high school classrooms as well as in science museums. The Deep-Subsurface Life DVD allows

students to see how scientists explore the deep subsurface of Earth to search for microbes adapted to extreme environments. Interviews with senior scientists and graduate students reveal the excitement, challenges, and risks associated with working in deep mines. Digital photographs were taken during field trips to deep gold mines in South Africa and northern Canada.

Videotaped interviews were conducted by Peter Suchecki (independent videographer) during visits to laboratories at Princeton University, Michigan State University, and Indiana University. Peter is now working on post-production and animations. Glenn Simonelli (PhD candidate in School of Education, Indiana University) and Wayne Britton (science teacher at Columbus North High School in Columbus, Indiana) are writing lessons, support materials, and laboratory exercises. Each lesson plan is provided in three versions: open-ended, moderately structured, and highly structured. Michael Mattner (independent musician) is composing and performing an original score. Ruth Droppo directs the development of the DVD and is the graphic designer for layout and pre-press. We have completed two classroom assessments of student reactions to the first-generation DVD. Based on student and teacher comments, we have substantially revised and enlarged the introduction in order to provide more connections to terms and concepts used in conventional biology and geology. We anticipate having a second-generation product ready for field testing in classroom during November and December 2005.

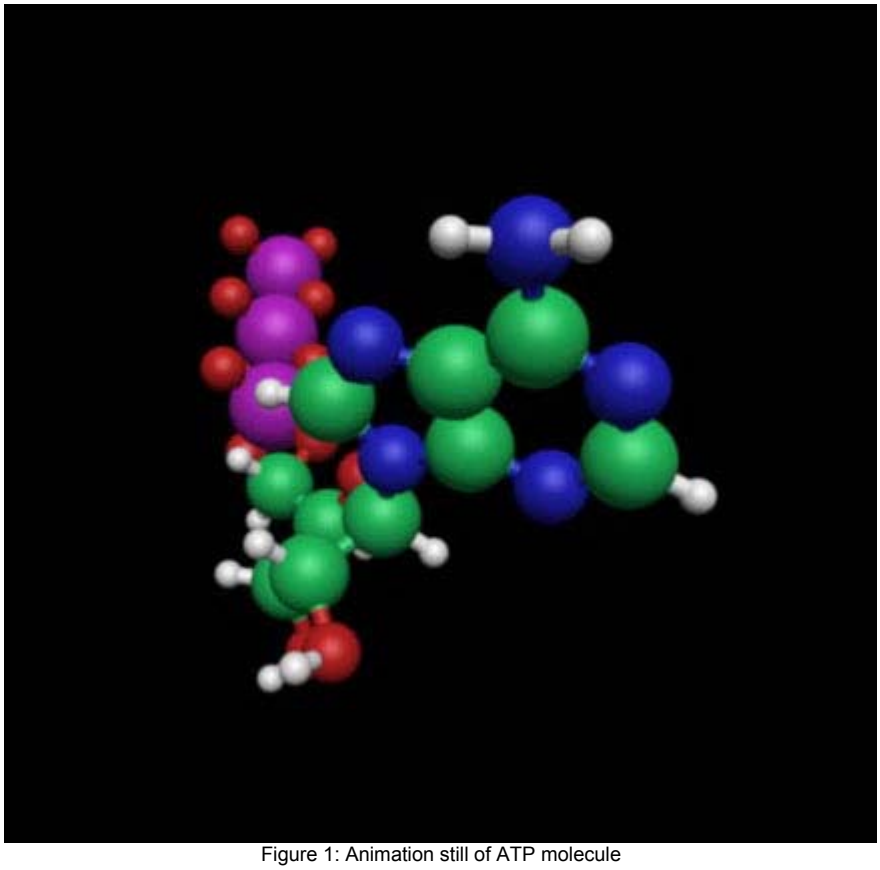


Figure 1: Animation still of ATP molecule

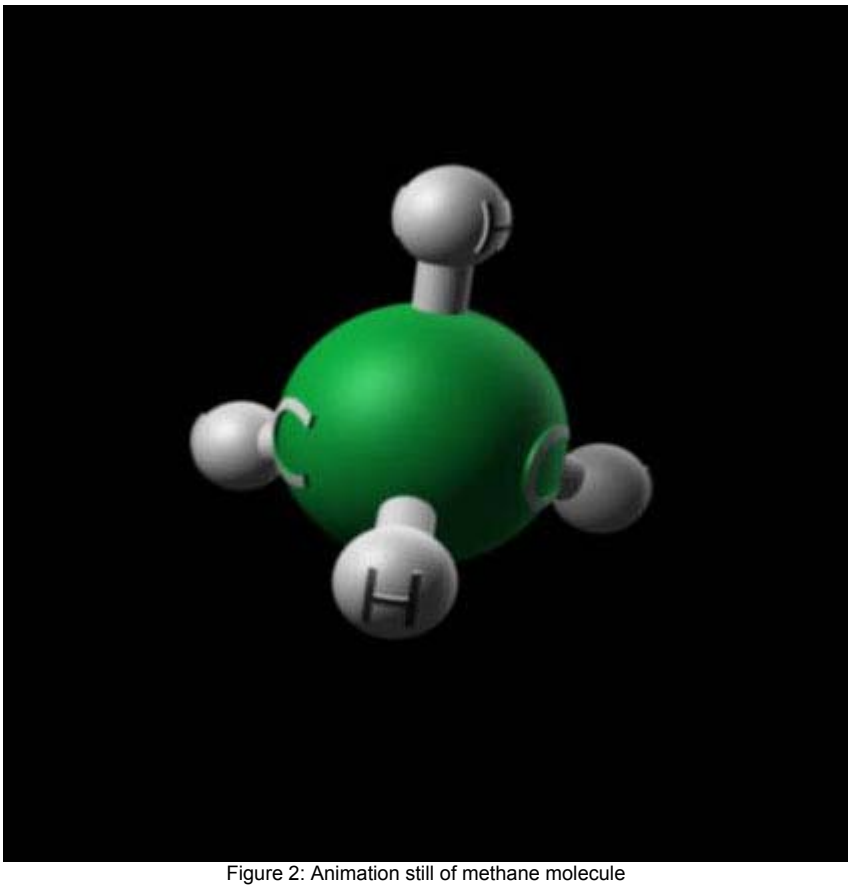


Figure 2: Animation still of methane molecule

Figure 3: Animation still of bacteria in a deep-subsurface fissure. A microbial community is shown colonizing mineral surfaces adjacent to a gas and water seep.

IPTAI EDUCATION AND PUBLIC OUTREACH EFFORTS, JULY 2004 - JUNE 2005: Teacher Development

We organized and participated in a teacher workshop providing an Introduction to Astrobiology with hands-on activities at Tennessee Science Teacher Association Meeting in Franklin TN (November 2004). Presenters included the three regional high school science teachers from Tennessee and Virginia who attended the Astrobiology Laboratory Institute for Instructors (ALI'I) at the University of Hawaii, Manoa during the summer of 2004.

Dr. Pfiffner led the workshop for the Knox County In-Service Training for 6-12 grade science teachers (February 18, 2005). We are working with Monty Howell and Becky Ashe, who are the science supervisors for the Knox County Schools, to set up tester classrooms for testing the IPTAI educational products.

Sent six teachers from the Chattanooga, Tennessee area to two different workshops during 2005. Three teachers attended the Evolution of a Planetary System: Exploring Our Origins workshop at Pennsylvania State University July 24-29, 2005 and three teachers attended the Astrobiology Laboratory Institute for Instructors (ALI'I) at the University of Hawaii, Manoa July 18 - 22, 2005. This fall these teachers will meet with Davis and Pfiffner to plan activities for dissemination of information and methods learned in the workshops.

Figure 5. At the Tennessee Science Teacher Association in Franklin, TN, middle and high school teachers are making comets as part of an introduction to Astrobiology.

IPTAI EDUCATION AND PUBLIC OUTREACH EFFORTS, JULY 2004 - JUNE 2005: Informal Education

University of Tennessee We presented an astrobiology session at SHaring ADventures in Engineering and Science (SHADES), an interactive colloquium with hands-on science activities for 100 girls ranging in age from 11-12 years old. The colloquium is designed to attract middle-school aged girls to careers in math and science. Presenters included the three regional high school science teachers from Tennessee and Virginia who attend the Astrobiology Laboratory Institute for Instructors (ALI'I) at the University of Hawaii, Manoa during the summer of 2004.

Indiana University Water On Mars, Indiana University Brownie Math and Science Day, November 2004. Hands-on science activities for 260 girls ranging in age from 6-8 years old.

Figure 4. Middle school girls make comets and learn about Astrobiology during an interactive colloquium called SHaring ADventures in Engineering and Science (SHADES).

Publications: Indiana University, Bloomington

There are **45** publication entries for the Indiana University, Bloomington

Analyev, G. & Dismukes, G.C. (2005). Laser Fluorometer for Remote Detection of Photosynthetic Life. *NASA Astrobiology Institute Annual Meeting*. Boulder Colorado.

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Executive Summary: Marine Biological Laboratory

Executive Summary: Marine Biological Laboratory
Principal Investigator: Mitchell Sogin
Reporting Period: 2005 (7/04-6/05)

The relevance of microbes to NASA's exploration program.

The stage for life was set billions of years ago and we are on the verge of knowing what happened to its characters. Two convergent lines of evidence raise expectations that biological systems could occur beyond the confines of Earth. The first is the detection of microbial life forms in terrestrial environments that may be similar to those on other solar system bodies. The second is NASA's spectacular discoveries of significant water reservoirs on Mars and Europa, and evidence of liquid organic environments on other solar system bodies such as Titan. Knowledge about the diversity and evolution of life on Earth will provide important inputs for the design of future astrobiology missions in NASA's exploration program.

During the initial 2-3 billion years of Earth's history, the only form of life was microbial and it generally consisted of complex consortia. The effects of the microbial biosphere, driven by metabolism and expressed as biogeochemical processes, have imposed an overwhelming force on planetary change and have shaped Earth's habitability. They are the essential catalysts for all of the chemical reactions within the biogeochemical cycles. From an evolutionary perspective, microbes are important because they share an ancient common ancestry with lineages that ultimately evolved into more complex organisms such as fungi, plants and animals. The primary objective of the Astrobiology Program at the Marine Biological Laboratory is to study microbial diversity and evolution. We seek to understand the evolution of key enzymes in ancestral metabolic pathways and the diversity of microbial life in acidic environments, in hydrothermal vent environments, in the deep subsurface, and in anoxic, high-pressure environments. Whenever possible we integrate this information with studies of biogeochemical processes and interpretation of geological data from remote sensing activities. Several of our investigations target genomes in order to understand the evolution and diversity of organisms that carry out neutraphilic iron oxidation or which play a role in shaping the evolution of genomes in more complex organisms via formation of endosymbiotic relationships. We also participate in the development of technology and instruments for *in situ* life detection and planetary protection.

Microbially mediated iron metabolism.

Because iron plays a key role in all biological systems, the study of environments enriched in iron may provide insights into the biochemistry and metabolisms of the early Earth and putative life that might have existed on ancient Mars. We are currently investigating the microbial diversity and mineralogy of the iron-rich Rio Tinto of southwestern Spain, the metabolic diversity of neutraphilic iron oxidizers from the deep sea as revealed through genome-based investigations, and iron isotope investigations of ancient pyrites. The Rio Tinto studies include collaborations between Linda Amaral Zettler and Carmen Palacios (MBL), Jack Mustard and Aline Gendrin (Brown University and the MBL Astrobiology team) and Ricardo Amils and Elena Gonzalez-Toril (Centro de Astrobiología / Universidad Autónoma de Madrid). The iron and sulfate mineralogy of the Rio Tinto serves as an analogue for Mars. Dr. Mustard is building a database of field measurements that will provide a predictive framework for interpreting remote sensing measurements. The database includes diversity measurement of minerals and analysis of airborne hyperspectral data. It will ultimately be coupled to the biological and biogeochemical measurements made by Drs. Amaral Zettler and Amils. The biology measurements employ a novel technology (SARST-V6) to define microbial diversity at several sites (Origin, Anabel's Garden and Berrocal) in the iron rich (22 mg ml^{-1}) and acidic (pH ranging from 1.7-2.3) Rio Tinto. Earlier studies based upon characterizations of ribosomal RNA genes isolated from the Rio Tinto suggested that eukaryotic diversity is much greater than prokaryotic diversity, which in this watershed includes fewer than a dozen kinds of bacteria. The SARST technology samples short homologous hyper-variable regions in rRNAs. It has the advantage of being at least an order of magnitude more efficient than traditional DNA sequence analyses of PCR amplicons from rRNAs in molecular characterizations of microbial population structures. This allows for more thorough sampling of microbial populations and the detection of minor components in microbial populations. Figure 1 is a rarefaction study of rRNAs based upon SARST analysis of several different sites in the Rio Tinto. It reveals that the microbial diversity of the Rio Tinto as measured by the presence of different rRNAs is much greater than previously

appreciated. From one study of 4545 tags, Amaral Zettler and her colleagues identified 126 bacterial phylotypes. They also obtained many additional tags with less than 100% similarity to a reported sequence in GenBank for which we are designing primers to extract full-length sequence data. These sequences await further phylogenetic analyses. An analysis of a total of 11,951 tags is underway which is likely to significantly increase the total number of phylotypes known to date.

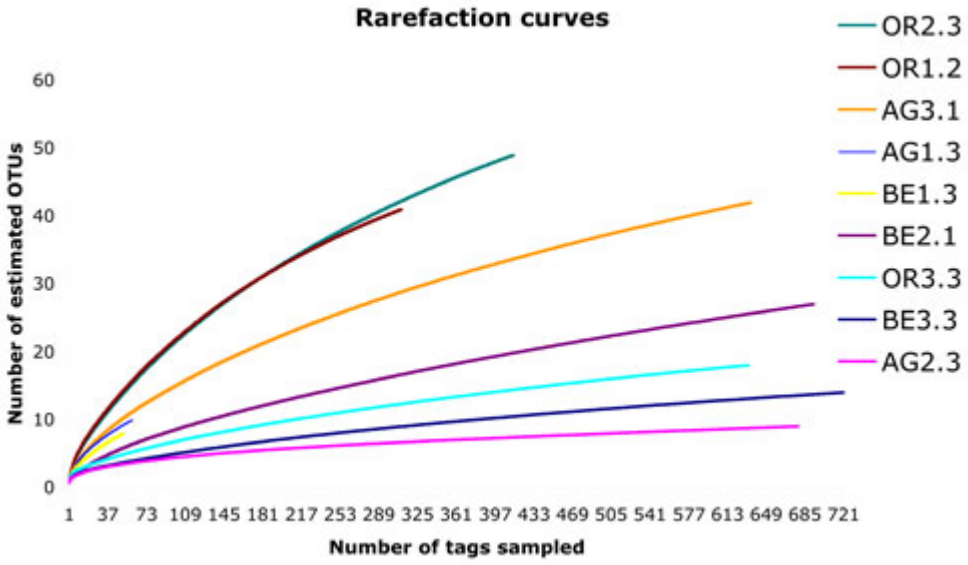

Figure 1. Rarefaction curves of microbial populations from three sites in the Rio Tinto based upon SARST-V6. DNA was extracted from three locations nicluding the Origin (OR), Anabel's Garden (AG) and Berrocal (BE) from the Rio Tinto. Using conserved primers that flank hypervariable region V6 in Bacterial rRNA genes, we generated PCR amplicons approximately 65 bp in length. Concatemerized sequences of the short PCR amplicons (SARST-V6) were parsed into invidual tags and compared to rRNAs in GenBank. The number of different kinds of microbes (Organism Taxonomic Units - OTUs) in each sample are plotted vrs. the number of sampled tags.

Dr. Edwards, working with Ashita Dhillon in Dr. Sogin's laboratory, has been investigating the genomics of *Marinobacter aquaeolei*, which is a cultured neutraphilic iron oxidizer from the deep sea. The genome sequence of this organism is nearly complete and we have constructed fosmid expression libraries. Using a simple plate-based assay we have identified fosmids that express genes required for Fe-oxidation in *E. coli* and production of *HemA*. Sequence analysis of these fosmids has allowed Edwards and Dhillon to identify an operon in *M. aquaeolei* that plays an important role in iron oxidation. The next phase of this project will explore the diversity of iron oxidation pathways in neutraphilic iron oxidizers from the sea. The traditional approach is to prepare large DNA insert libraries and employ molecular probes or PCR techniques to identify clones that contain a conserved protein associated with a metabolic activity. However screening strategies that rely upon conservation of nucleotide sequences frequently overlook highly diverged coding regions. Our solution is to use a functional assay such as the plate assay for Fe-oxidation. We will determine sequences for any fosmid that expresses genes required for Fe-oxidation. This will provide information about the genomic context and diversity of pathways responsible for iron oxidation under neutraphilic conditions. The final project related to iron is an iron isotope study of banded iron formations. The rise of atmospheric oxygen which began by ~2.3 Ga was a profound event in Earth's history. The oxidation state of Fe, along with C and S, is linked to the redox state of the surface environment. It is very likely that the concentration and isotopic composition of Fe in seawater was linked to such global changes, yet deposition of banded iron formations (BIFs) indicates that the deep ocean remained anoxic until ~500 million years after the initial rise of atmospheric oxygen. Using Fe isotope evidence, Edwards provides evidence that the change in the ocean iron cycle occurred at the same time as the change in the atmospheric redox state (Figure 2). Variable and negative iron isotope values in pyrites older than about 2.3 Ga suggest that an iron-rich global ocean was strongly affected by the deposition of iron oxides. Between 2.3 and 1.8 Ga, positive iron isotope values of pyrite probably reflect an increase in the precipitation of iron sulfides relative to iron oxides in a redox stratified ocean. This data provides new insights into the Archean and Paleoproterozoic ocean chemistry and redox state. Fe isotopes suggest that the Archean oceans were globally Fe-rich and that their Fe isotope composition and Fe content were variable in response to the episodic establishment of an Fe-rich pool supplied by hydrothermal activity and the deposition of Fe oxides, either in BIFs or dispersed throughout sediments on continental shelves and in the deep sea. After the rise of atmospheric oxygen by about 2.3 Ga, the Paleoproterozoic Ocean became stratified and characterized by an increase of sulfide precipitation relative to Fe oxide precipitation. During this period, BIFs were likely deposited by upwelling of Fe(II)-rich plumes and rapid oxidation in the

oxygenated layer of the ocean.

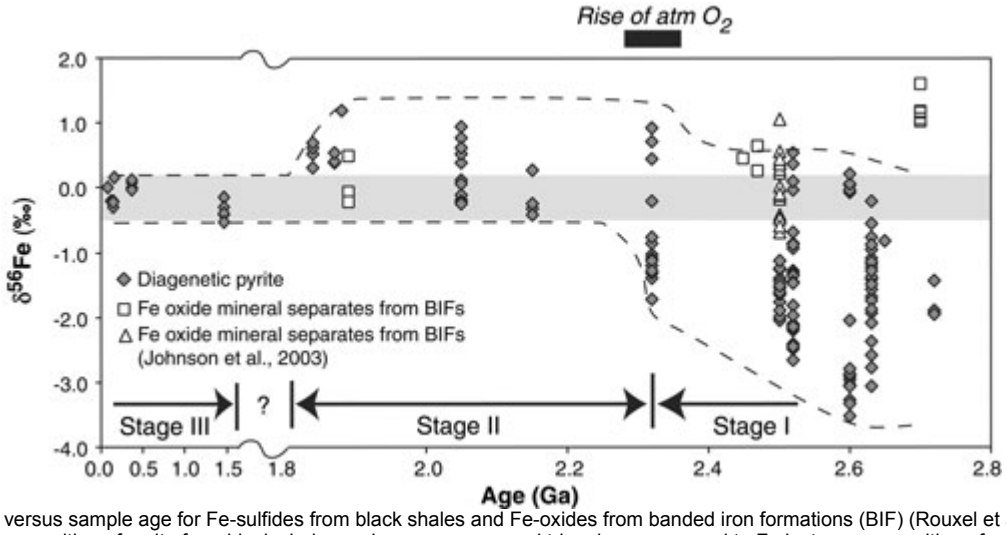

Figure 2. Plot of del 56Fe versus sample age for Fe-sulfides from black shales and Fe-oxides from banded iron formations (BIF) (Rouxel et al, 2005). Gray diamonds correspond to Fe isotope composition of pyrite from black shales and open squares and triangles correspond to Fe isotope composition of magnetite and hematite-rich samples from BIFs. Gray area corresponds to del 56Fe of Fe derived from igneous rocks (at 0.1 del) and hydrothermal sources (ca. -0.5 del). Dashed lines represent the contour lines of maximum and minimum Fe isotope compositions of sedimentary sulfides used to define Stages I to III.

Studies of microbial diversity and ancient metabolism in anoxic marine environments.

One of the remarkable discoveries of the last decade is the occurrence of deep subsurface life. Microbial communities exist in habitats that support exclusively chemotrophic communities. In a study carried out in collaboration with the URI Astrobiology team, Teske has been characterizing the rRNAs of deep subsurface sediments from sites containing very low levels of organic matter. The archaeal lineages represented in the PCR amplicon libraries from rRNA molecules are related to rDNA genes amplified from other deep subsurface sites. There is no evidence of remineralization, sulfate reduction or methanogenesis in this environment, but we infer that these sequences correspond to active organisms. Since the rRNA content of microbes is to the first approximation proportional to metabolic activity, detection of PCR amplicons templated from rRNA molecules provides presumptive evidence of active microbial communities.

Two other studies of microbes from deep sea, anoxic sediments address questions about the evolution of pathways that may be very ancient. The first is a comparative study by Teske, Dhillon, and Sogin of dissimilatory (*dsr*) and assimilatory sulfite reductases (*asr*) including new environmental sequences from Guaymas Basin. Sulfite reductases play a key role in the global sulfur cycle. Comparative amino acid sequence analyses of the dissimilatory sulfite reductase genes (*dsr*AB) from cultured isolates and environmental PCR amplicons have provided insights about the evolutionary history of anaerobic sulfate (sulfite) respiration. Our more recent data allowed us to infer that a gene duplication of ancestral *dsr* genes gave rise to *ars* before the archaeal- bacterial divergence. In a related investigation based upon key genes of methanogenesis, *mcr*A, we showed that the populations of Guaymas are phylogenetically and physiologically quite diverse. The sequences include novel lineages within the *Methanosarcinales* that are distinct from all other cultured and cloned *Methanosarcinales*, and from ANME-2 groups. Methanogens and sulfate-reducing bacteria competing for the same carbon substrates coexist in the same sediment horizons, an unusual occurrence in marine sediments. The second investigation seeks to define the distribution and phylogeny of enzymes in the reductive TCA cycle (rTCA). This pathway is used by chemolithoautrophs for carbon fixation. Sievert and Edgcomb have amplified portions of the ATP-citrate lyase gene and flanking regions from several epsilon-protobacteria and members of the *Aquificales*. This is the first report of reductive TCA cycle carbon fixation in epsilon-proteobacteria. Initial phylogenetic analyses support the view that citrate lyase is an early evolved metabolic activity. The next phase will be to analyze PCR amplicons from environmental DNA samples from the deep sea. Seivert is also working towards the complete genome sequence of *Thiomicrospira denitrificans*, a chemolithoautotrophic sulfur-oxidizing epsilon-proteobacterium.

Genome reduction in microbial symbionts.

Phylogenetic analyses of microbial populations from diverse environments provide information about patterns of evolution but few details about underlying mechanisms. An important contribution from genome sequence studies is elucidation of major changes in genome architecture that we can associate with specific

mechanisms. As part of our interest in microbial evolution, Wernegren and Bordenstein are exploring changes in genome organization in endosymbiotic bacteria. They are studying the genome of *Blochmannia pennsylvanicus*, a proteobacterial, intracellular mutualist of carpenter ants. They have completed the 792 kb genome sequence of *B. pennsylvanicus* using facilities in the Bay Paul Center at the MBL. Through bioinformatics techniques they are exploring how severe genome reduction has occurred in this microbe. They have determined that the mutualist has lost many genes that would normally utilize environmental substrates and that the genome is evolving very rapidly. Surprisingly, there is little evidence of gene transfer, inversions or translocations. This is counter to mechanisms that drive major changes in genome structure in free- living microbes. They are also investigating evolution of the genome and associated viruses of *Wolbachia*, a genus of obligate intracellular α–Proteobacteria. One of the major changes in earth's history was ushered in by the rise of oxygen. This may have lead to the evolution of α–Proteobacterial endosymbionts into mitochondria, the site of aerobic energy production in eukaryotic organisms. The *Wolbachia* species parasitize a broad range of arthropods and they are infected with phage that can move between different intracellular bacteria. Wernegreen and Bordenstein demonstrated through microarray analyses that most of the divergent genes between *Wolbachia* strains reside within prophage rather than within other mobile genetic elements, thus offering an explanation for how genes have moved between different *Wolbachia* species.

Project Reports: Marine Biological Laboratory

Genome-Genome Integration: Symbiosis, genetic assimilation, and evolutionary innovation

Project Investigator: Jennifer Wernegreen

Project Progress

This project aims to elucidate genetic changes that catalyze the establishment and diversification of genome-genome interactions. Using insect-associated endosymbionts as model systems, we are examining the molecular and evolutionary forces that shape associations between bacteria and eukaryotic hosts. Our studies target Proteobacterial species that represent both long-term, stable mutualisms and transient parasitic interactions.

This year we completed the 792 kb genome sequence of *Blochmannia pennsylvanicus*, an intracellular mutualist of carpenter ants. This genome was sequenced in house at the MBL. Comparisons with related bacterial species revealed mechanisms driving severe genome reduction in microbes engaged in long-term host associations. For example, the ant mutualist retains numerous biosynthetic pathways due to host-level selection for nutritional functions, but has lost many genes to utilize diverse substrates in the environment. Its small genome also exhibits exceptionally fast rates of amino acid substitutions, yet shows remarkable genome stability with no gene acquisitions, inversions, or translocations for ~20 MY of its host association. This discovery illustrates that an intracellular lifestyle can alter fundamental mechanisms for genetic change in bacteria. Along with our primary genome publication (Degnan et al., 2005), broader comparisons across intracellular bacteria are described in an upcoming review (Wernegreen, submitted) and a collaborative study of mutualist genomes (Schaber et al., 2005). We also completed molecular evolution analyses that demonstrated strong mutational pressure and genetic drift in obligate endosymbionts (Wernegreen and Funk, 2004; Fry and Wernegreen, 2005) and developed new phylogenetic approaches to better resolve bacterial phylogenies and identify the origins of intracellular groups (Herbeck et al., 2005).

Our research progress on *Wolbachia* genome evolution and viruses went farther than expected this year. *Wolbachia* are a genus of obligate intracellular α–Proteobacteria that are closely related to the bacterial ancestor of mitochondria. These bacteria show moderate rates of host-switching and have largely formed parasitic associations with a wide arthropod host range. Our comprehensive review article on mobile DNA in intracellular bacteria (to be featured in a *Nature Reviews* special issue on horizontal gene transfer, Bordenstein and Reznikoff, 2005) highlights the extraordinary phage and transposon colonization of the *Wolbachia* genome relative to other obligate and facultative intracellular species. Bioinformatic and molecular phylogenetic studies this past year determined that a *Wolbachia* temperate phage is the only element known to frequently laterally transfer between obligate, intracellular bacteria (Bordenstein and Wernegreen, 2004) as well as vector transposable elements into the tiny genomes of *Wolbachia* (Reznikoff et al., 2004). Of the 1271 genes annotated in *Wolbachia*, our comparative genomic hybridizations using DNA microarrays (performed in collaboration with TIGR) indicate that the largest fraction of divergent genes between strains tends to be prophage, a finding that is unique among bacterial endosymbionts, yet typical for other free-living bacterial systems in which mobile and repetitive DNA are significant diversifying agents. We also completed molecular evolutionary analyses that specified novel genetic lineages of *Wolbachia* (Bordenstein and Rosengaus, 2005), the molecular phylogeny of this endosymbiont (Casiraghi et al., submitted), and extensive recombination among housekeeping genes (Baldo et al., in preparation).

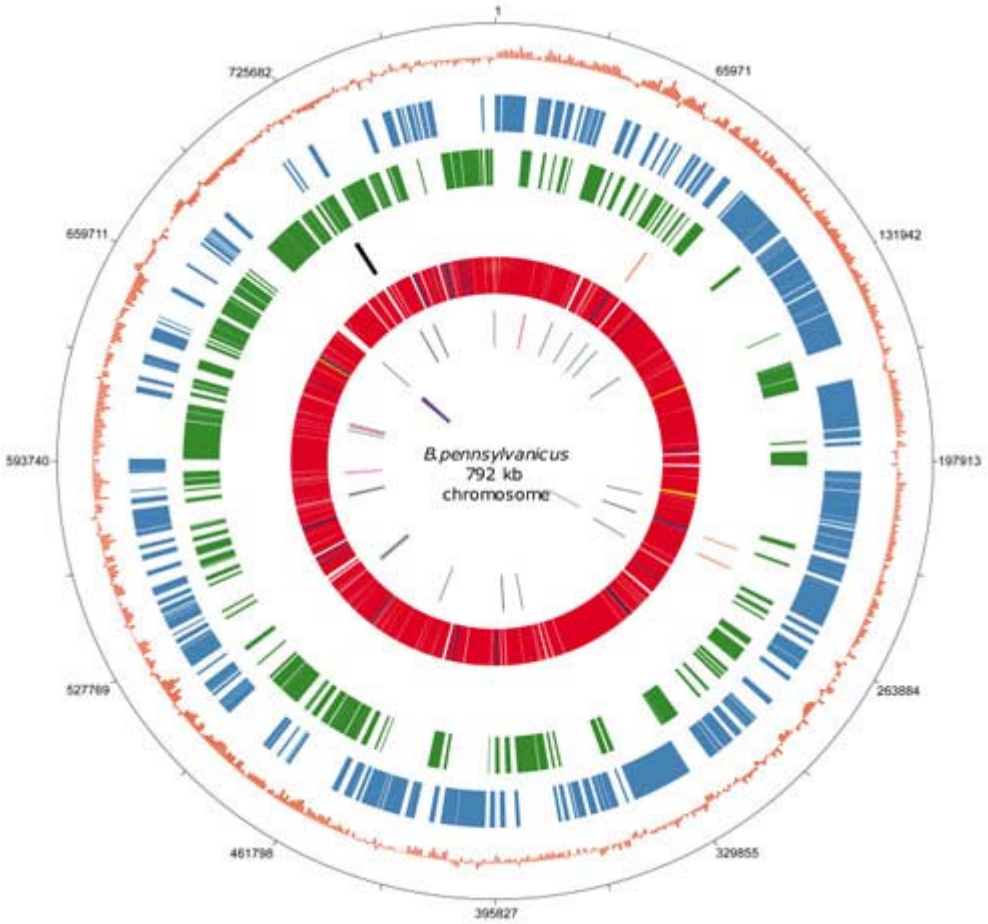

Figure 1. Circular map of the B. pennsylvanicus genome and genome features (From Degnan, Lazarus and Wernegreen, Genome Research, in press). The origin of replication was putatively set upstream of gidA, in accordance with the shift of GC skew. The concentric rings denote the following features: (1) numbered base pair coordinates beginning with base one of the gidA open reading frame (ORF), (2) GC skew as calculated by (G-C)/(G+C) using a 2.5kb sliding window, (3) ORFS present on the leading strand (+), (4) ORFS present on the lagging strand (-), (5) pseudogenes of B. pennsylvanicus that are present in (orange) or absent from (black) the related symbiont B. floridanus, (6) ORFS of B. pennsylvanicus that are shared with (red), pseudogenes in (yellow), or absent in (dark blue) the genome of B. floridanus, (7) transfer RNAs (tRNAs) that are shared with (gray) or absent in (pink) B. floridanus, (8) ribosomal RNAs (rRNAs) 5S, 16S and 23S (purple).

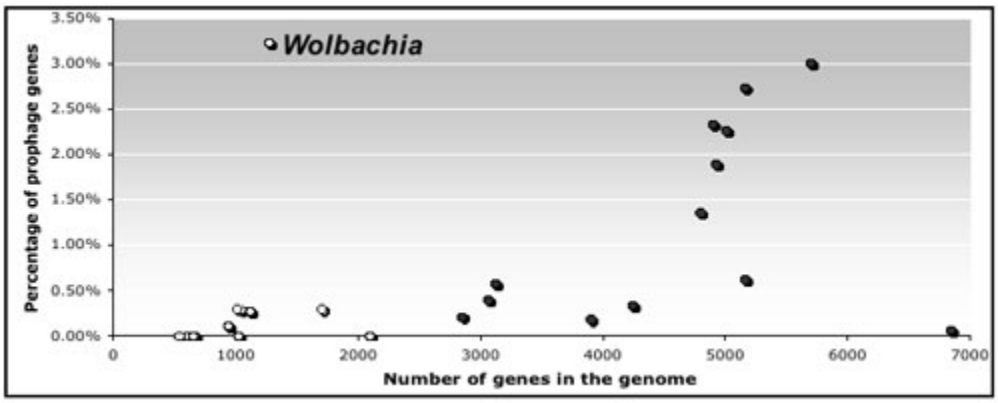

Figure 2. The fraction of prophage genes in intracellular bacteria. Prophage genes are preferentially missing from the small genomes of obligate, intracellular bacteria (open circles). The Wolbachia prophage content is atypical and greater than that of the facultative, intracellular bacteria (dark circles). Data are derived from the TIGR Role Category database for completed genomes.

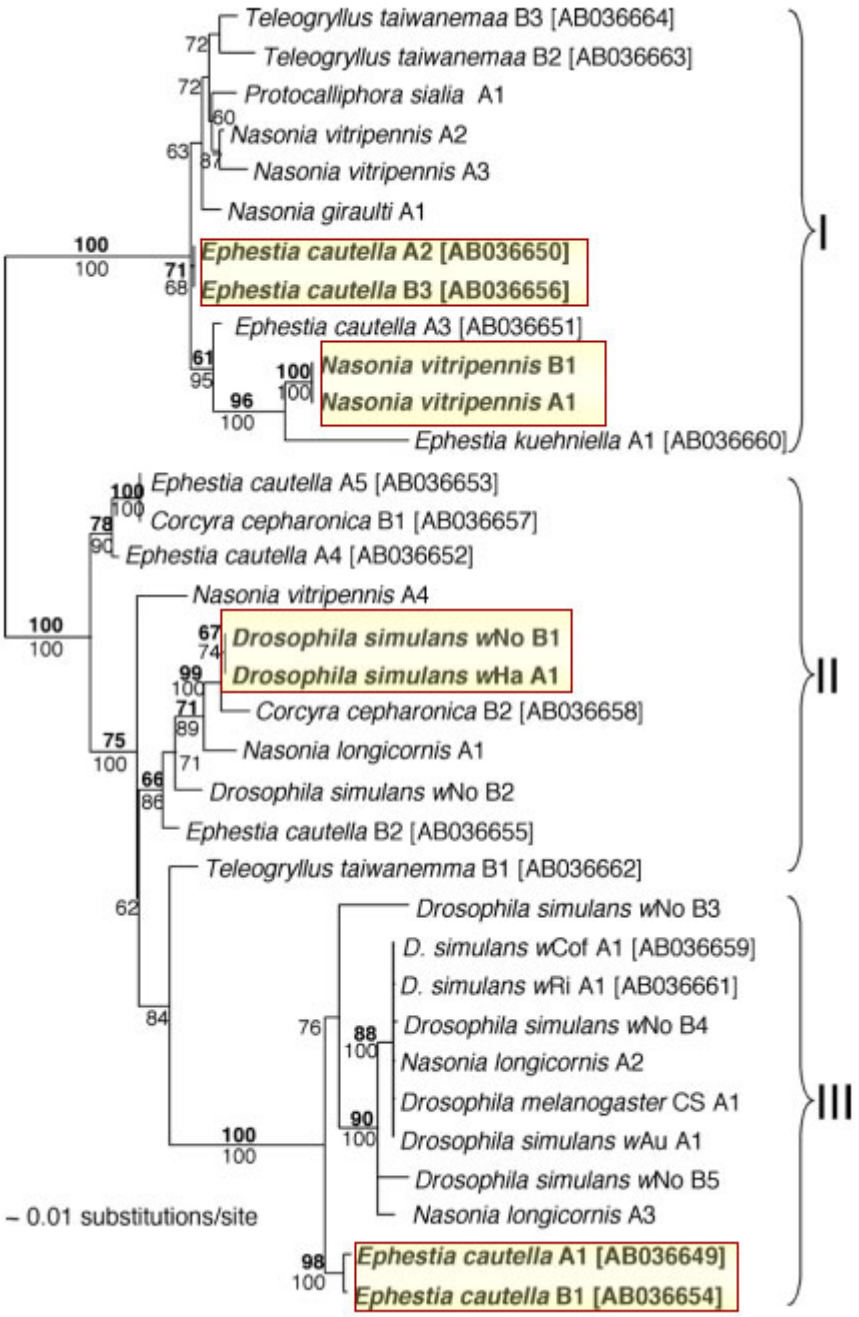

Figure 3. Horizontal transfer of bacteriophage genes between Wolbachia coinfecting the same insect host (from Bordenstein and Wernegreen 2004). Maximum-likelihood (ML) phylogenetic tree of bacteriophage WO-B based upon sequences of the ORF7 region (putative capsid protein). The tree is midpoint rooted. Both ML bootstrap values (bold) and Bayesian posterior probabilities (plain) are shown. Name of the host arthropod species is followed by a letter denoting the Wolbachia supergroup (A or B) and a number designating each unique phage family. P airs of adjacent taxa in bold represent inferred events of lateral phage transfer between A and B Wolbachia that coinfect the same arthropod host.

Roadmap Objectives

- **Objective No. 3.4:** Origins of cellularity and protobiological systems
- **Objective No. 4.2:** Foundations of complex life
- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth

Microbial communities and activities in the deep marine subsurface

Project Investigator: Andreas Teske

Project Progress

1. Deep Subsurface Project: In collaboration with the URI "Subsurface Biosphere" NAI group, the phylogenetic analysis of deep marine subsurface sediments from organic-poor, low activity sites is finished (ODP sites 1225 and1231 in the Equatorial Pacific and Peru Basin). We are continuing with analyses of Peru margin sediments (ODP Sites 1227, 1228, 1229 and 1230), which have a higher organic carbon content and higher microbial activities. All phylogenetic analyses from these sites are based on rRNA. rRNA content is approximately proportional to metabolic activity; thus, we are characterizing the microbial populations that are alive and active, and exclude DNA by dead or inactive cells.

Results so far show very little geochemical evidence of the predominant marine anaerobic remineralization pathways, sulfate reduction and methanogenesis (Lever and Teske 2005, Teske, Lauer and Sørensen 2005). The active archaeal communities in the Peru Margin sites fall into several archaeal lineages that have been repeatedly detected in deep subsurface marine sediments and other subsurface habitats (MCG, Misc. Crenarchaeotal Group; MBG-B, Marine Benthic Group B; SAGMEG-1, South African Goldmine Euryarchaeotal Group 1). Thus, the distinct archaeal subsurface communities that we and others have detected previously based on rDNA sequencing surveys are not only present, they are also active.

Mark Lever has sampled deep sediments and subsurface basalt from IODP Leg 301, a transect of the eastern flanks of the Juna de Fuca Ridge (July/August 2004). These samples will be used for sequencing of functional genes.

2. Guaymas Project: We have finished and published the first combined phylogenetic analysis of dissimilatory and assimilatory sulfite reductases, including novel dissimilatory sequences from Guaymas (Dhillon et al. 2005). As a working model, primitive, monomeric sulfate reductases diverged early into mutually exclusive, deeply rooted branches of dimeric, assimilatory and dissimilatory reductases. This ancient divergence may preceed the archaeal – bacterial divergence, pending more archaeal data.

The initial survey of a key gene of methanogenesis, *mcr*A (the gene for the alpha subunit of coenzyme M methyl reductase) in Guaymas has been completed and is in press (Dhillon et al. 2005). Methanogen populations in Guaymas are phylogenetically and physiologically very diverse (Methanosarcinales, Methanomicrobiales, Methanococcales). The sequences include novel lineages within the Methanosarcinales that are distinct from all other cultured and cloned Methanosarcinales, and from ANME-2 groups. Methanogens and sulfate-reducing bacteria competing for the same carbon substrates coexist in the same sediment horizons, an unusual occurrence in marine sediments. This dataset complements the earlier study of sulfate-reducing key genes in Guaymas (Dhillon et al. 2003).

Mark Lever is working on a *mcr*A sequencing of another Guaymas sediment sample set (with a very steep temperature gradient) that has not been analyzed yet. The initial screening showed deeply branching *mcr*A phylotypes parallel to the extremely thermophilic *Methanopyrus* lineage. Thus, these samples are most promising for the detection of novel *mcr*A phylotypes that fall outside all published Methanogen lineages (Unpublished).

Other: The second publication of Virginia Edgcombs NRC Postdoc in the Teske lab (2000-2002) has been published, on ecophysiology of hydrothermal vent archaea and their survival adaptations to extreme conditions (Lloyd, K.G., Edgcomb, V.P., Molyneaux , S.J., Wirsen, C.O., Atkins, M.S. & Teske, A. (2005) *Applied and Environmental Microbiology* 71: 6383-6387).

Highlights

-
    - Deep subsurface: Analysis of reverse-transcribed archaeal 16S rRNA from a wide range of sites shows that the deep marine subsurface harbors active archaeal communities. All previous

phylogenetic analyses have relied on rDNA, and therefore could not rule out that the sequences derived from the DNA of dead or inactive cells.

- The phylogenetic profile of the reverse-transcribed archaeal rRNA from deep-subsurface sediments resembles previous DNA sequencing results, indicating that most archaeal lineages in subsurface sediments are active (on the rRNA level) and present (on the rDNA level).

- Guaymas Project: Novel lineages of *mcr*A genes have been documented, in particular 1) Intrafamily diversity within the Methanosarcinales, and 2) deeply-branching lineages parallel to the *Methanopyrus* lineage. Comparative analyses of new field sites (cold methane seeps in the Gulf of Mexico) allowed a closer definition of the ecophysiology of specific uncultured *mcr*A gene lineages (ANME-1).

Roadmap Objectives

- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
3	Concept: Deep subsurface life on inhospitable planets	Background Research
3	Concept: Guaymas Project	Background Research

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

1. Deep Subsurface Class 3 Concept: Planets that are characterized by inhospitable surface conditions (UV and cosmic radiation; thin or unsuitable atmosphere; temperature extremes, lack of liquid water, electron acceptor or donor limitations) may still harbor life in their subsurface that is to some extent protected from these stress factors. On Earth, phylogenetically (and presumably physiologically) distinct bacterial and archaeal communities are present and active in the marine sedimentary subsurface. The distinct composition of microbial communities over a wide range of subsurface habitats on Earth suggests that subsurface communities on other planets might show similar distinctive properties, in phylogeny, physiology, or both. These considerations apply to the subsurface of Mars, and to the ocean of Europa.

2. Guaymas Project Class 3 Concept: Electron acceptor limitation is one of the most pervasive geochemical controls on microbial life, and life in general. The methane cycle in Guaymas offers a model system to study the complexity of anaerobic microbial communities under highly reducing conditions (in particular methanogens, sulfate-dependent methane oxidizers, sulfate reducers). Consortia of sulfate-reducing bacteria and methanogenic archaea, together with methanogens, are possibly the only anaerobic prokaryotes that can sustain an inorganic carbon cycle in the absence of all other electron acceptors except sulfate and CO2. Thus, sulfate reducers and methanogens are of great interest as model organisms that can sustain severely electron-acceptor-limited microbial ecosystems. We are searching a wide range of methane-sulfate dominated habitats (Guaymas basin, cold methane seeps, deep subsurface sediments) for novel versions of key genes of anaerobic metabolism (mcrA, dsrAB), to resolve the phylogeny of these ancient, highly conserved genes and gene lineageswhich probably evolved before oxygen respiration.

Field Expeditions

Field Trip Name: IODP Leg 301, Juan de Fuca ridge flanks

Start Date: June 21, 2004

End Date: August 29, 2004

Continent: North America, Pacific Northwest, offshore Oregon

Country: USA

State/Province: Offshore Oregon and Washington

Nearest City/Town: Portland, OR

Latitude: 47°45N to 47°54N

Longitude: 127°10 N to 128°34N

Name of site(cave, mine, e.g.): Boreholes FR-1, SR-1, SR-2, DR-1, DR-2

Keywords: Juan de Fuca, ridge flanks, hydrothermal circulation

Description of Work: --- DNA/RNA extraction, sequencing of key genes (mcrA) and reverse-transcribed 16S rRNA, to infer community structure and activity --- Modeling of key chemical gradients (methane, sulfate), to infer anaerobic process rates in the Leg 301 sediments (sulfate reduction, methanogensis, sulfate-dependent methane oxidation) --- cultivation attempts for methanogens

Members Involved:

Cross Team Collaborations

We are collaborating with the URI Team in a sequencing survey of reverse-transcribed rRNA from all Peru Margin sites that werev sampled on ODFP Leg 201 (Sites 1227, 1228, 1229, 1230). This is the first time that active archaea are detected by sequencing of rRNA; all other published PCR-based sequencing studies of deep-subsurface sediments were performed with genomic DNA. This distinction between rRNA and rDNA is crucial, since rRNA is characteristic for living, active cells, whereas rDNA can also be derived from inactive or dead cells. Thus, this collaborative sequencing project allows for the first time a reliable identification of active archaeal subsurface microbiaota, cultured and uncultured. Individuals involved are A. Teske, K.B. Sorensen, K. Lloyd, and M. Lever (URI team members at UNC Chapel Hill), and M. Sogin and L. Graham at MBL.

So far, Site 1227 rRNA has been sequenced from multiple sediment horizons (Soerensen, Lauer and Teske 2005). Site 1228 is in progress, and is being screened by two summer students (L.Wehrmann und D. Kalhoefer, Oldenburg University, Germany). Site 1229 is being processed by K. Lloyd, and Site 1230 by M. Lever (Lever and Teske 2005). In all cases, archaeal clone libraries are dominated by members of several uncultured phyla (Miscellaneous Crenarchaeotal group, Marine Benthic Group B; SAGMEG-1, and a few others). Thus, active archaeal communities in deep marine sediments consist of representatives of only a few lineages.

Microbial diversity and population structure studies in the Rio Tinto

Project Investigator: Linda Amaral Zettler

Project Progress

Our population studies in the Rio Tinto focus on three stations located in the more extreme headwaters of the river: the Origin (OR), Anabel's Garden (AG) and Berrocal (BE) (Fig. 1). For each station we sampled three different sites with three-fold replication during the wet and dry seasons. We have successfully completed 3 sampling campaigns in October 2002, September 2003 and January of 2004. We have begun applying a new molecular diversity survey method called SARST-V6 (Serial Analysis of Ribosomal Sequence Tags) to the October 2002 samples. With SARST, the PCR products from orthologous hypervariable regions (~100 bp long for the bacterial V6 region) in rRNA genes are ligated together to form large concatemers. From a pilot study of 4545 tags, we have identified 126 bacterial phylotypes. Figure 2 shows a preliminary analysis examining linkages between this diversity and geochemistry in the river. Figure 3 shows a partial list of tags with 100% identity to known bacterial sequences in GenBank. We have also obtained many additional tags with less than 100% similarity to a reported sequence in GenBank for which we are designing primers to extract full-length sequence data. These sequences await further phylogenetic analyses. An analysis of a total of 11,951 tags is underway and this may significantly increase the total number of phylotypes known to date.

Alongside SARST analyses, we are also conducting phylogenetic analyses of the unique phylotypes using small subunit (SSU) rRNA gene clone libraries. Initial surveys of this diversity based on full-length SSU rRNA genes for the three domains of life are summarized in Figures 4-6. We have also begun to further study the newly discovered phylotypes in the Río Tinto by constructing fluorescently-labeled oligonucleotide rRNA probes and conducting fluorescence in situ hybridization (FISH) experiments on environmental samples. Figure 7 shows a CY3-labeled probe specific for the endosymbiont from the Iron Mountain Candidatus captivus acidiprotistae, also present in the Rio Tinto

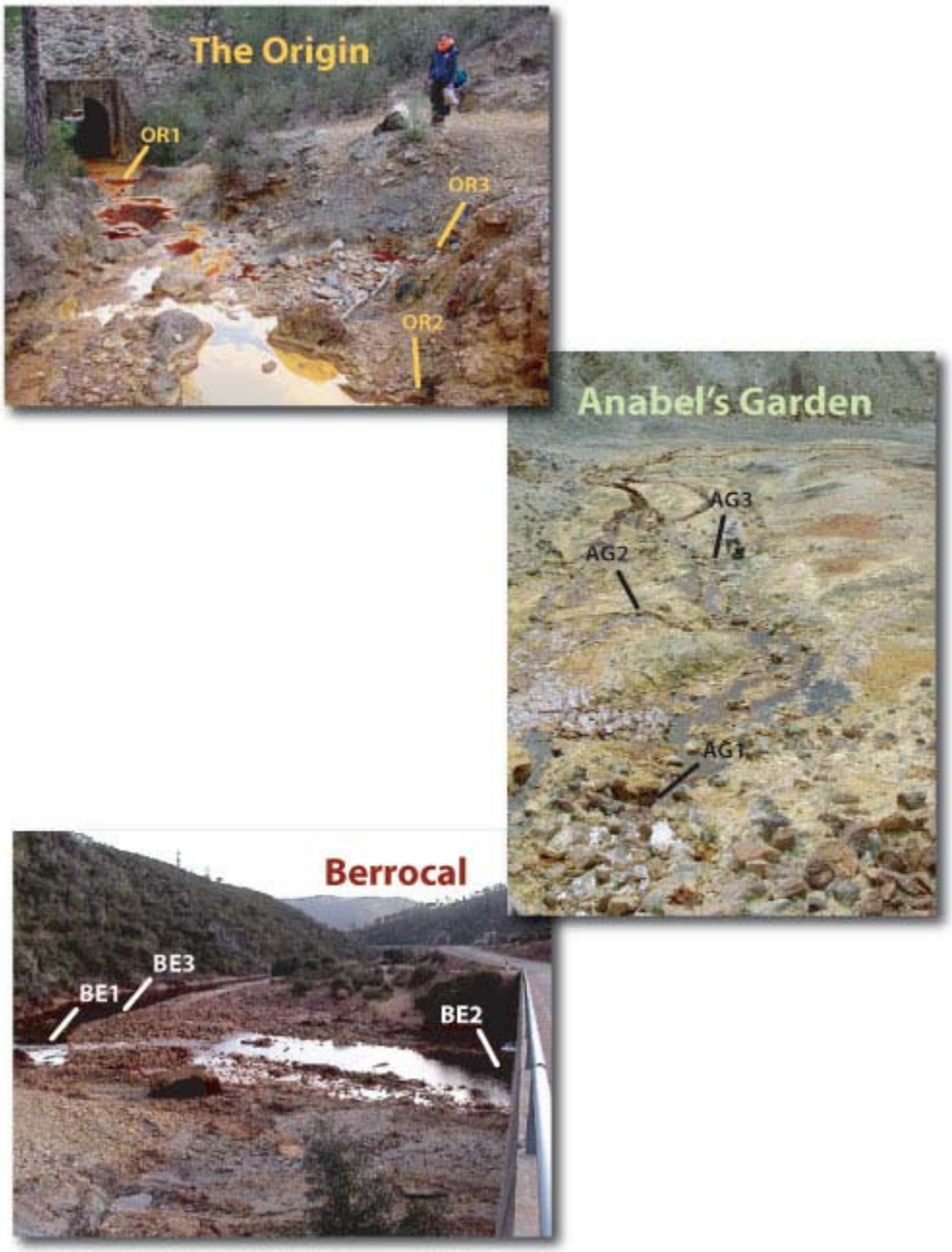

Figure 1. Sampling Stations in the Rio Tinto

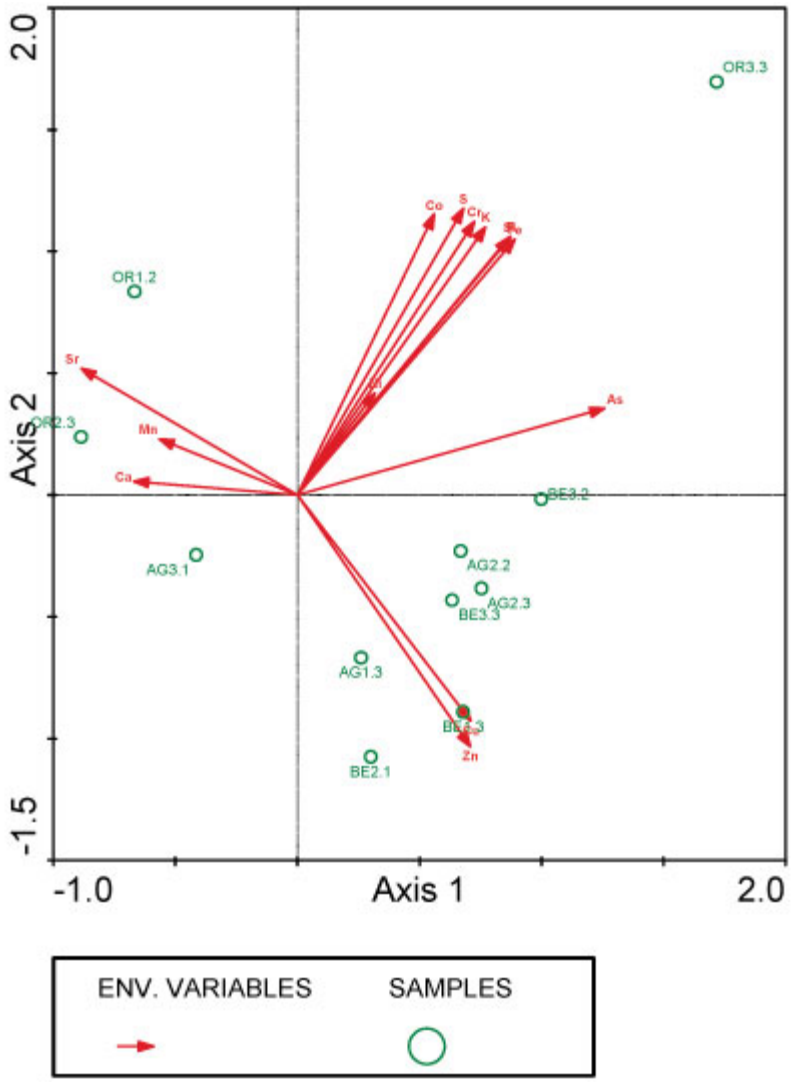

Figure 2. Eleven samples in green from the three sites (OR = origin, AG = Anabel's Garden, BE = Berrocal) are plotted in the ordination space created using a Canonical Correspondence Analysis (CANOCO 5) using 13 geochemical variables (red arrows) that had no missing values and 125 OTUs (not shown). Different areas of the river have distinctly different chemical compositions and OTU distribution. The origin sample OR 3 in the upper right quadrant has the highest Fe, Si, K, Cr, S, and Co, while OR 1.2 and OR 2.3 to the left are characterized by high Sr, Mn, and Ca. Berrocal samples cluster together in the lower right quadrant and share high values of Cu and Zn. Anabel's garden samples are more variable as expected based on gross visual characteristics and distinct biofilms.

GenBank #	100% BLAST HIT ID	Acidic Env?	Not Acidic?
AF251436	*Ferromicrobium acidophilum*	+	
AF523911	Environmental clone RCP1-34	+	
AF523914	Environmental clone RCP1-33	+	
X92700	*Actinomyces* sp. (isolate TM167)	+	
AF047642	Uncultured eubacterium TRA2-10	+	
AY390804	Uncultured bacterium clone 26		+
Y18445	*Acidiphilium cryptum*	+	
AF531477	*Acidocella* sp. IS10	+	
AF356831	*Leptospirillum ferriphilum* strain Warwick	+	
AF543509	Environmental clone BA33	+	
AY387397	*Sphingomonas* sp. HB1		+
AF465608	*Acidithiobacillus ferrooxidans* strain TFY	+	
AF465604	*Acidithiobacillus ferrooxidans* strain ATCC 23270	+	
AF039167	*Rhodanobacter lindaniclasticus*		+
AF523884	Environmental clone RCP2-16	+	
AF356839	*Leptospirillum ferrooxidans* strain Parys	+	
AF356838	*Leptospirillum ferrooxidans* strain Sy	+	
AF543504	Environmental clone BA2	+	
Y18616	*Acidivorax defluvii*	+?	
AY472116	*Pseudomonas fluorescens*		+
AF353297	Uncultured bacterium Tui3-12	+	
AF429122	Uncultured bacterium clone CR99-24-12		+
AY131213	*Alcaligenes* sp. LMG 5906		+
AF540837	Environmental clone DP10u30		+
AF232924	Uncultured bacterium MS11	+	
AY187354	Uncultured bacterium clone csbio160215		+
AJ292574	uncultured eubacterium WD213	+	
AF533509	*Candidatus captivus acidiprotistae* clone ASL6	+	
AF387301	Iron-oxidizing acidophile m-1	+	
AY472115	*Stenotrophomonas maltophilia*		+
AY374112	Rainbow trout intestinal bacterium A75	+	
AY260854	*Acinetobacter* sp. OK1		+
D30769	*Acidiphilium* sp.	+	
AF098671	*Desulfovibrio desulfuricans*	+?	
AF289149	Uncultured *Cytophagales* clone PRD01a001B		+
AB110715	*Acidomonas methanolica*	+	
AF477806	Uncultured beta proteobacterium clone AGCY32		+
AY374113	Rainbow trout intestinal bacterium A97	+	
AY064177	Uncultured beta proteobacterium clone UCT N123		+
AY188313	Uncultured bacterium clone KD4-31		?
AF523888	Uncultured bacterium clone RCP2-96	+	

Figure 3. A partial list of OTUs identified from the Rio Tinto using the SARST technique. Listed are the identities of tags possessing 100% similarity to known GenBank entries across the hypervariable region analyzed.

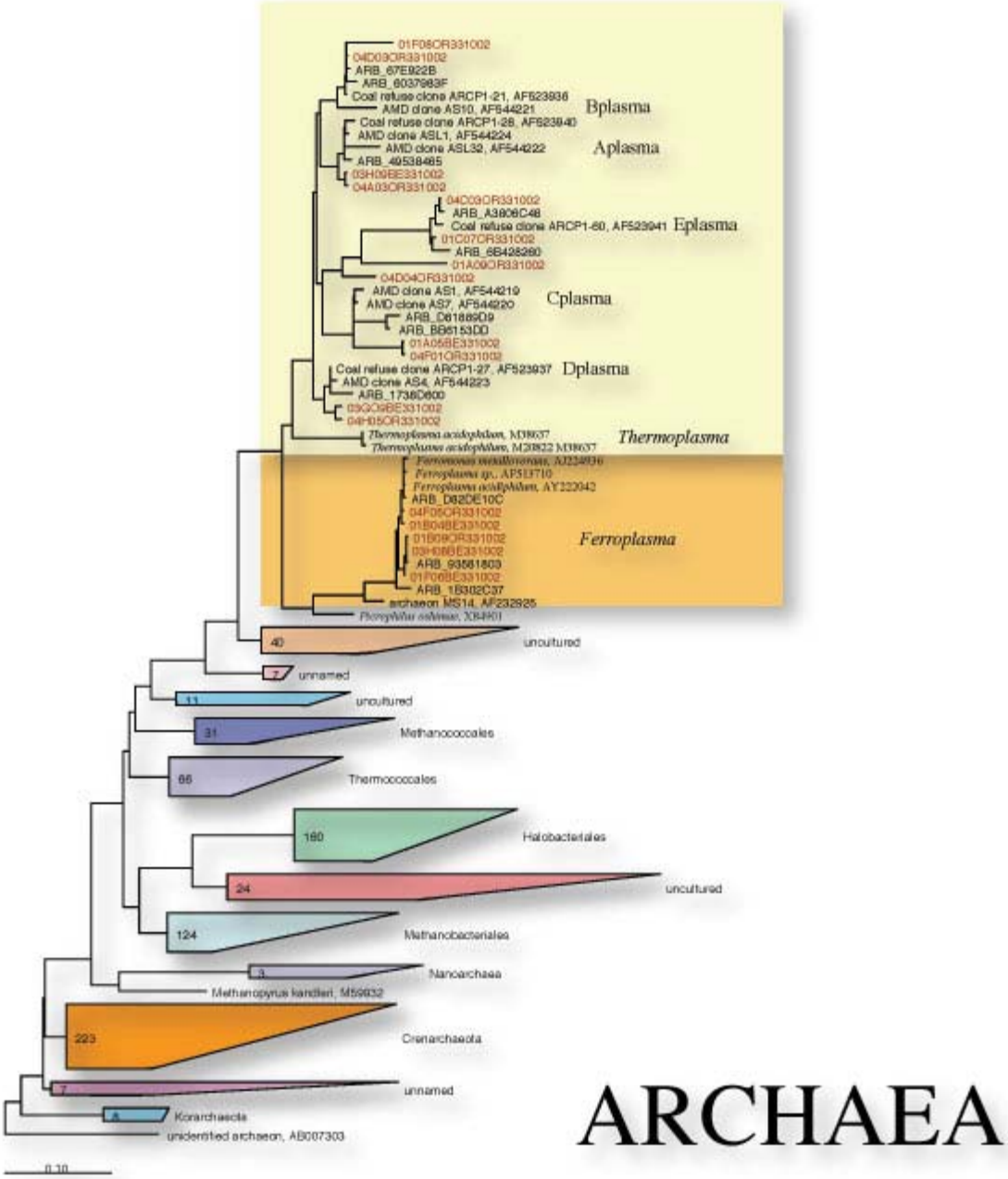

Figure 4. Phylogenetic Tree of Archaea in the Rio Tinto based on SSU rRNA gene analyses

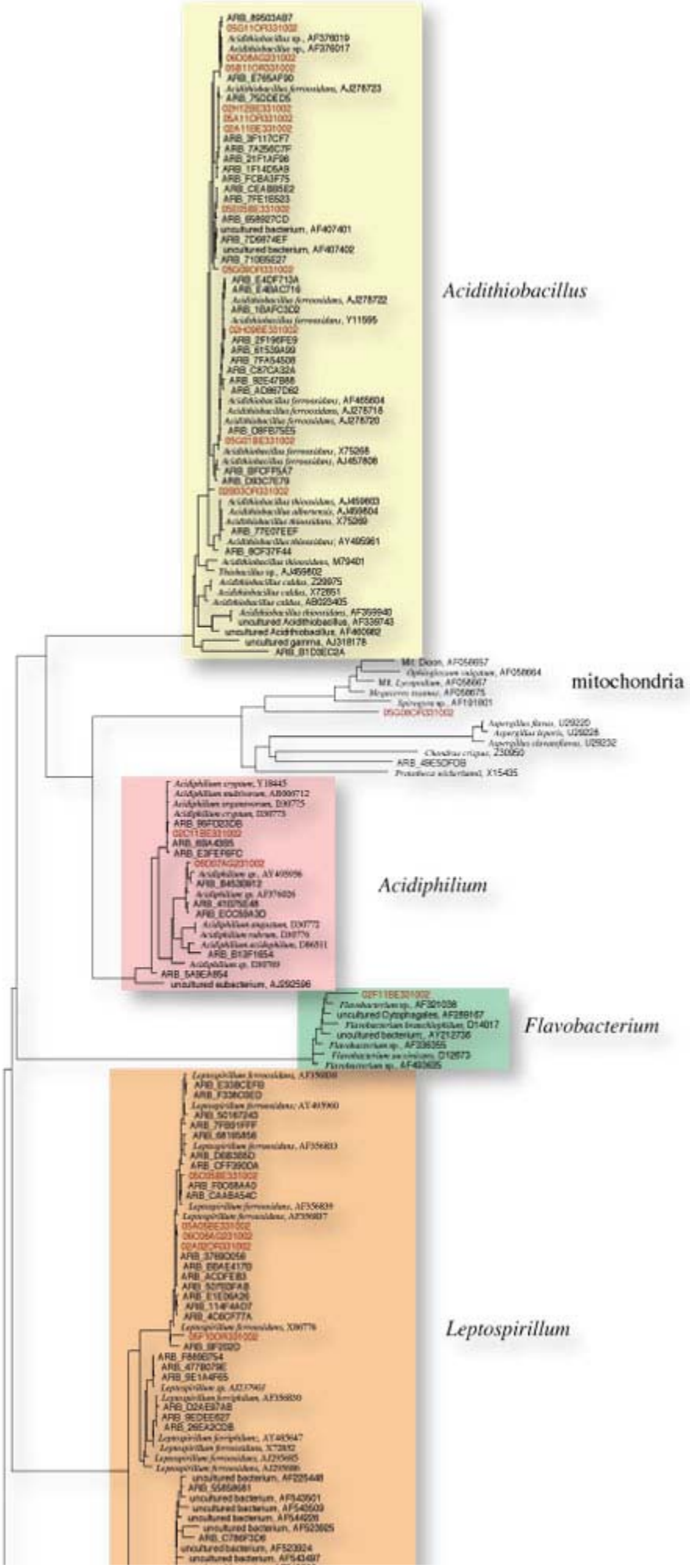
Acidithiobacillus
mitochondria
Acidiphilium
Flavobacterium
Leptospirillum

Figure 5. Phylogenetic Tree of Bacteria in the Rio Tinto based on SSU rRNA gene analyses

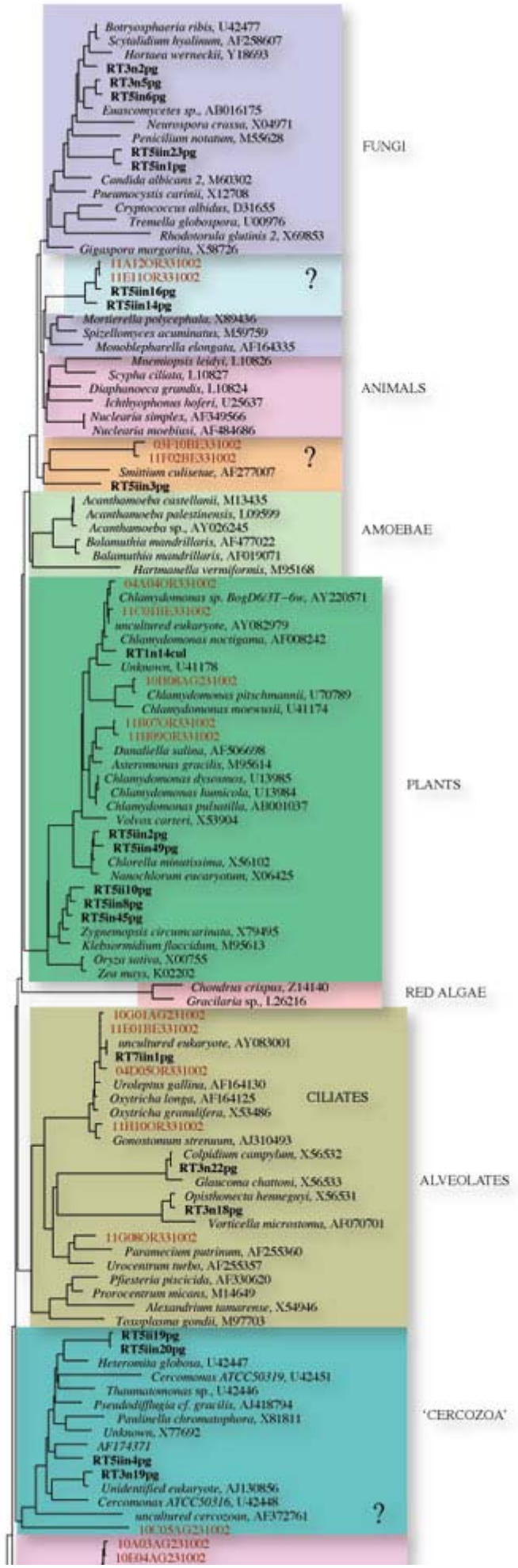
Botryosphaeria ribis, U42477
Scytalidium hyalinum, AF258607
Hortaea werneckii, Y18693
RT3n2pg
RT3n5pg
RT5in6pg
Euascomycetes sp., AB016175
Neurospora crassa, X04971
Penicillium notatum, M55628
RT5iin23pg
RT5in1pg
Candida albicans 2, M60302
Pneumocystis carinii, X12708
Cryptococcus albidus, D31655
Tremella globospora, U00976
Rhodotorula glutinis 2, X69853
Gigaspora margarita, X58726
11A12OR331002
11E11OR331002
?
RT5iin16pg
RT5iin14pg
Mortierella polycephala, X89436
Spizellomyces acuminatus, M59759
Monoblepharella elongata, AF164335
Mnemiopsis leidyi, L10826
Scypha ciliata, L10827
Diaphanoeca grandis, L10824
Ichthyophonus hoferi, U25637
Nuclearia simplex, AF349566
Nuclearia moebiusi, AF484686
03F10BE331002
11F02BE331002
?
Smittium culisetae, AF277007
RT5iin3pg
Acanthamoeba castellanii, M13435
Acanthamoeba palestinensis, L09599
Acanthamoeba sp., AY026245
Balamuthia mandrillaris, AF477022
Balamuthia mandrillaris, AF019071
Hartmanella vermiformis, M95168
04A04OR331002
Chlamydomonas sp. BogD6IT-6w, AY220571
11C01BE331002
uncultured eukaryote, AY082979
Chlamydomonas noctigama, AF008242
RT1n14cul
Unknown, U41178
10H08AG231002
Chlamydomonas pitschmannii, U70789
Chlamydomonas moewusii, U41174
11B07OR331002
11B09OR331002
Dunaliella salina, AF506698
Asteromonas gracilis, M95614
Chlamydomonas dysosmos, U13985
Chlamydomonas humicola, U13984
Chlamydomonas pulsatilla, AB001037
Volvox carteri, X53904
RT5iin2pg
RT5iin49pg
Chlorella minutissima, X56102
Nanochlorum eucaryotum, X06425
RT5ii10pg
RT5iin8pg
RT5in45pg
Zygnemopsis circumcarinata, X79495
Klebsormidium flaccidum, M95613
Oryza sativa, X00755
Zea mays, K02202
Chondrus crispus, Z14140
Gracilaria sp., L26216
10G01AG231002
11E01BE331002
uncultured eukaryote, AY083001
RT7iin1pg
04D05OR331002
Uroleptus gallina, AF164130
Oxytricha longa, AF164125
Oxytricha granulifera, X53486
11H10OR331002
Gonostomum strenuum, AJ310493
Colpidium campylum, X56532
RT3n22pg
Glaucoma chattoni, X56533
Opisthonecta henneguyi, X56531
RT3n18pg
Vorticella microstoma, AF070701
11G08OR331002
Paramecium putrinum, AF255360
Urocentrum turbo, AF255357
Pfiesteria piscicida, AF330620
Prorocentrum micans, M14649
Alexandrium tamarense, X54946
Toxoplasma gondii, M97703
RT5ii19pg
RT5iin20pg
Heteromita globosa, U42447
Cercomonas ATCC50319, U42451
Thaumatomonas sp., U42446
Pseudodifflugia cf. gracilis, AJ418794
Paulinella chromatophora, X81811
Unknown, X77692
AF174371
RT5iin4pg
RT3n19pg
Unidentified eukaryote, AJ130856
Cercomonas ATCC50316, U42448
uncultured cercozoan, AF372761
?
10C05AG231002
10A03AG231002
10E04AG231002
FUNGI
ANIMALS
AMOEBAE
PLANTS
RED ALGAE
CILIATES
ALVEOLATES
'CERCOZOA'

Figure 6. Phylogenetic Tree of Eukaryotes in the Rio Tinto based on SSU rRNA gene analyses

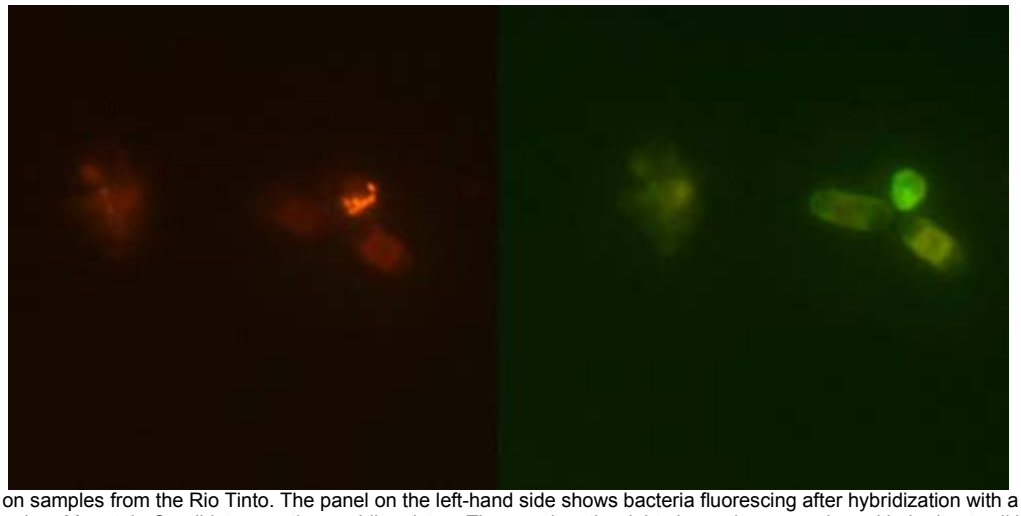

Figure 7. FISH experiments on samples from the Rio Tinto. The panel on the left-hand side shows bacteria fluorescing after hybridization with a CY3-labeled probe specific for the endosymbiont from the Iron Mountain Candidatus captivus acidiprotistae. The panel on the right shows the same view with the host cell hybridizing with a cocktail of eukaryotic-specific probes labeled with FITC.

Roadmap Objectives

- **Objective No. 3.3:** Origins of energy transduction
- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.2:** Co-evolution of microbial communities

Field Expeditions

Field Trip Name: Rio Tinto Sampling	
Start Date: January 12, 2005	**End Date:** January 16, 2005
Continent: Europe	**Country:** Spain
State/Province: Huelva	**Nearest City/Town:** Nerva/Rio Tinto
Latitude: N 37°43.316'	**Longitude:** W 06° 33.067'
Name of site(cave, mine, e.g.): Origin, Anabel's Garden, Berrocal	**Keywords:** acidic, high metal, microbial diversity, Mars Analogue
Description of Work: To assist John Mustard in initiating field work in the Rio Tinto and also begin FISH experiments on environmental samples.	
Members Involved:	

Cross Team Collaborations

Angeles Aguilera (Centro de Astrobiologia; CAB) spent 2 months at the Marine Biological Laboratory, one month enrolled in the Genomics Course at the MBL and one month collaborating with Linda Amaral Zettler (MBL NAI team) on eukaryotic diversity in the Rio Tinto. A manuscript entitled: "EUKARYOTIC COMMUNITY IN THE TINTO RIVER (SW SPAIN), AN EXTREME ACIDIC ENVIRONMENT" is in preparation.

Julian Simon at the Autonomous University of Madrid is a graduate student of Ricardo Amils (CAB) who has been screening fungal cultures for evidence of iron oxidation activity in the Rio Tinto fugal culture collection maintained by Amils. To date, they have screened <20 fungal cultures and have not detected any evidence of iron oxidation. However, they have detected putative iron reduction that may be associated with detoxification. Culture screening will continue and prospective clones will be shipped to the MBL for further molecular study. This work is part of a collaboration between Amaral Zettler (MBL), Katrina Edwards (WHOI) and Ricardo Amils (CAB).

Recognition of Theoretical Environments on Mars

Project Investigators: James Head, John Mustard

Project Progress

The diverse iron and sulfate mineralogy, and its associated complex biology, at Rio Tinto is an analog for possible environments on Mars. We are interested in developing an understanding of this site from a remotely sensed perspective and thus increase the capacity for exploration of Mars using existing and pending orbital and lander instruments. Our first goal is to develop extensive, quantitative remote sensing databases for the interpretation of Mars observations. This is accomplished through in situ observations, sampling, and laboratory measurements. The first phase of this work (in situ observations and sampling) was accomplished through a field trip to Rio Tinto in January of 2005 when we made in situ reflectance measurements across the range of habitats and ages of deposits, and collected diverse materials for laboratory analysis (Figure 1).

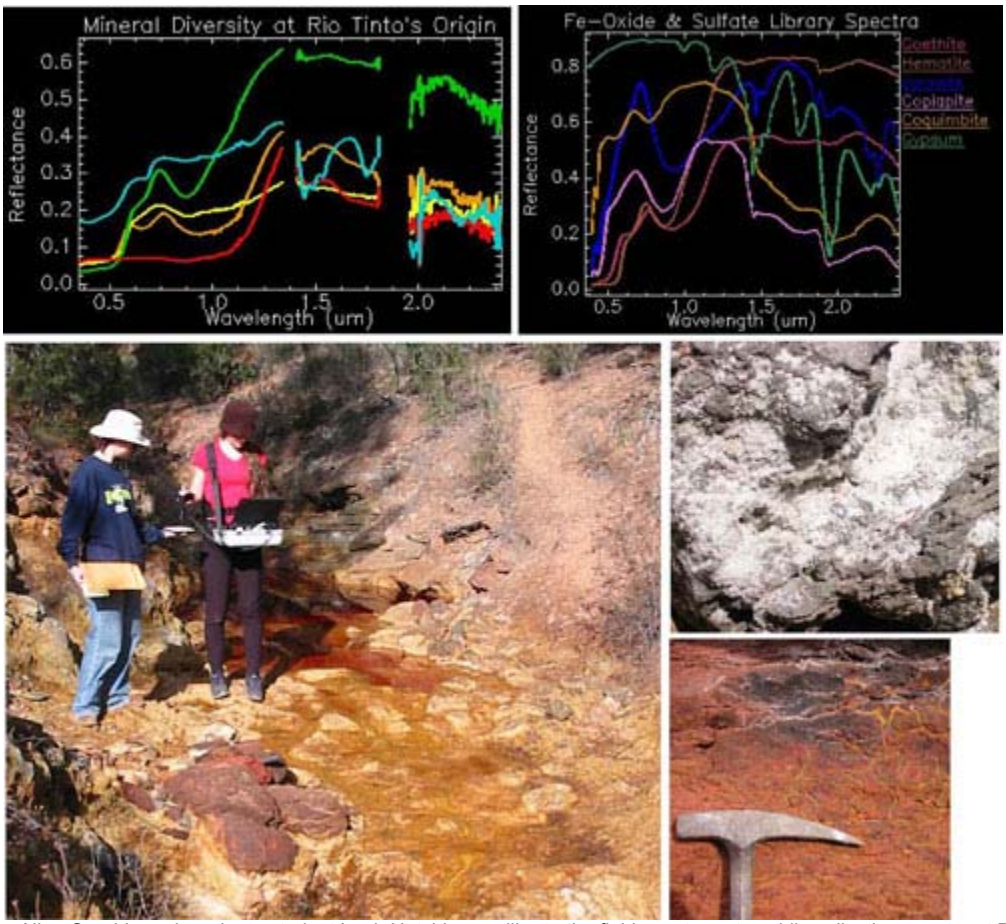

Figure 1. Lower left: Post-doc Aline Gendrin and graduate student Leah Hutchison calibrate the field spectrometer while collecting spectra at Rio Tinto's Origin. Upper left: Spectral diversity measured at Rio Tinto's oldest river terrace, including mixtures of hematite, goethite, jarosite and gypsum. Above right: Lab-derived spectral library of various Fe-oxides and sulfates. Upper Right: Szmolnokite, a Fe2+ sulfate, on pyrite/quartz at Angeles' Garden. Scale is ~15cm across. Lower right: Close up of a hematite boulder with possible biogenic texture. Rock hammer for scale

The field data have been reduced and shown to capture the expected diversity of minerals as determined from previous field investigations. The returned samples have been characterized and prioritized for laboratory measurements and detailed analyses of these samples are proceeding. We have requested airborne hyperspectal data to complete the scaling analyses needed to assess the detectability of Rio Tinto-type environments from orbital platforms. The scaling analyses will proceed from detailed in situ and laboratory observations (cm2 areas) to field-based spatial averaging (m2 areas) to airborne (10s of m2) observations. These analyses will develop a quantitative link between the mineralogy of the Rio Tinto site and remotely sensed measures. Concurrently, we have been investigating remotely acquired data for Mars and have identified a number of sulfate-rich environments that are promising to investigate further. These Mars observations are being used to establish exploration guidelines and inputs to future Mars missions to refine the search for habitats on Mars.

Roadmap Objectives

- **Objective No. 2.1:** Mars exploration
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
1	Mars Express	Co-Investigator
1	Mars Express	Co-Investigator
1	Mars Reconnaissance Orbiter	Other

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Mission 1 - Co-I of the OMEGA Imaging spectrometer experiment (Mustard and Gendrin). Our group is deeply involved in the planning support, data analysis, and development of analysis techniques for the extraction of mineralogic information from these data. This work is also a critical component of preparations for Mars Reconnaissance Orbiter. Data from this MBL-NAI project are being used in the interpretation of OMEGA data of Mars.

Mission 2 - Co-I of the HRSC imaging experiment (Head). The HRSC data are analyzed in our laboratory and are being integrated with the existing Mars data, including OMEGA compositional information. Also critical for preparations for Mars Reconnaissance Orbiter. Data from this MBL-NAI project are being used in the interpretation of OMEGA data of Mars.

Mission 3 - Deputy PI of the CRISM imaging spectrometer experiment (Mustard) and involved in all aspects of planning and data reduction. Data from this MBL-NAI project are being used in the preparations for the analysis of data of Mars to be returned by CRISM.

Field Expeditions

Field Trip Name: Spectroscopy of Rio TInto
Start Date: January 10, 2005 **End Date:** January 17, 2005
Continent: Europe **Country:** Spain
State/Province: Huelva **Nearest City/Town:** Rio Tinto
Latitude: 37.6214 N **Longitude:** 6.5128 W
Name of site(cave, mine, e.g.): Rio Tinto **Keywords:** ferric oxides, sulfates, spectroscopy, remote sensing
Description of Work: In situ measurement of reflectance spectroscopy of environments of the Rio Tinto from the youngest, active deposits to the oldest preserved. Sampling of key sites for laboratory investigation and characterization of the site mineralogy.
Members Involved:

Searching for Ancestral Biosignatures

Project Investigators: Rebecca Gast, Norman Wainwright

Project Progress

Our major objective and one of the objectives of the Astrobiology roadmap is "Biosignatures to be sought in Solar System materials search for signs of life in the Solar System and beyond". We are developing techniques which can be used for direct *in situ* measurements on future missions.

In addition to our goal of linking lipopolysaccharide (LPS) to an antigen and subsequent detection by Limulus Amebocyte Lysate (LAL), we extended our technique to amplify the detection of biosignatures using an enzyme labeled monoclonal antibody to a model antigen. This is compatible with our existing prototype instrument design to collect kinetic spectrophotometric data from competitive labeled antibody assays.

We have demonstrated feasibility of immobilizing our test antigen (insulin) to the plastic surface and binding of the enzyme labeled monoclonal to the immobilized antigen, shown in Figure 1A. Our portable reader will quantify that signal which does not bind as proportional to the amount of antigen in the sample (Figure 1B).

Through collaboration with Andrew Steele, Carnegie Institution of Washington (CIW) Astrobiology Center, we have incorporated protein microarrays (Figure 1C) to our assay format. This will significantly impact our work by enabling simultaneous detection of up to 50 different antigens per test. Currently our portable reader will accommodate 4 tests, or 200 potential biosignature targets. Part of that collaboration was a study of the immunological detection of biosignatures extracted from JSC Mars-1 simulant regolith (paper submitted to Astrobiology). These observations demonstrate the practicality of microarray immunoassay for *in situ* detection of biological molecules in environmental samples, including martian regolith.

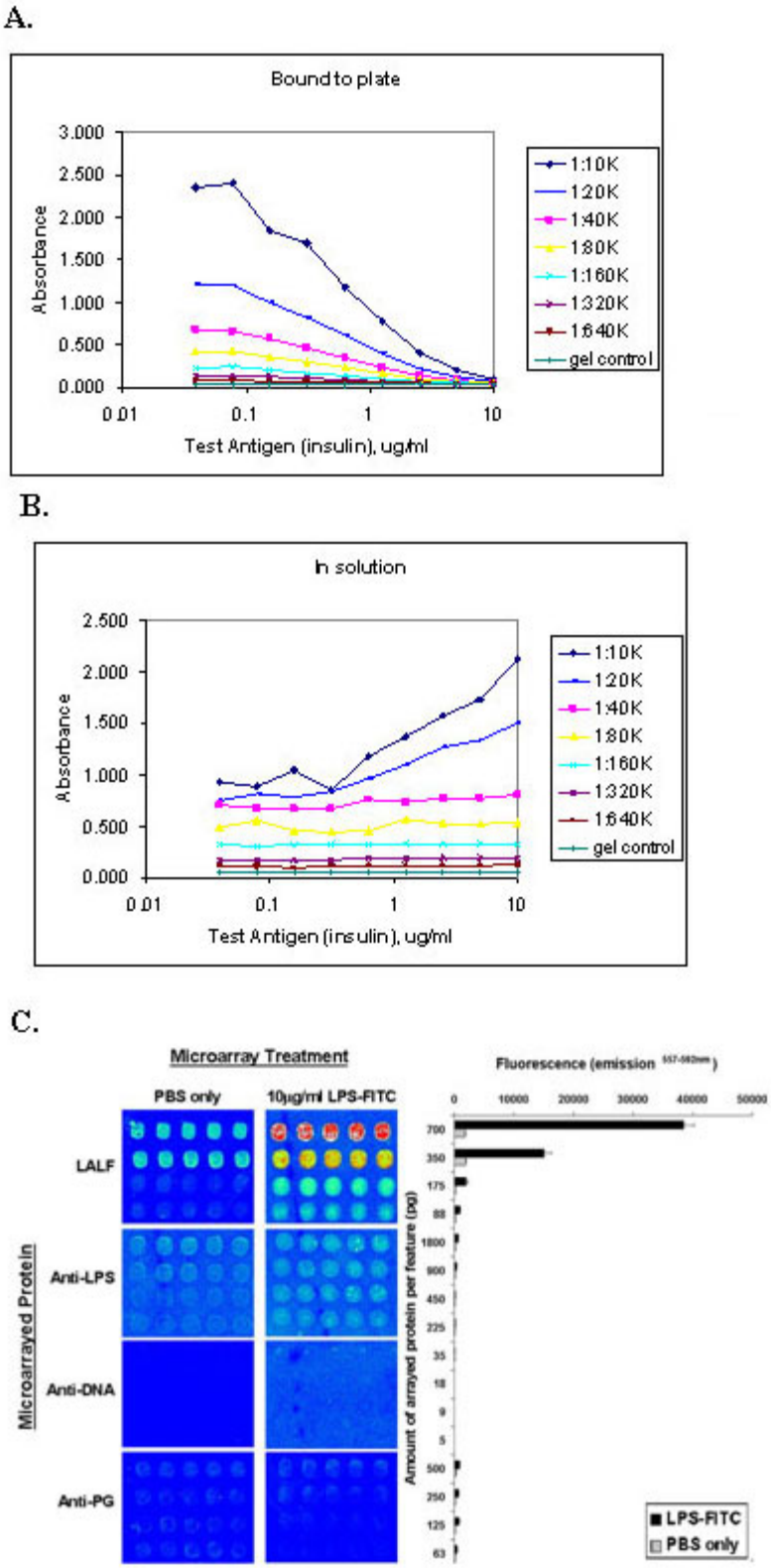

Figure 1. HRP Enzyme-linked detection of bound, (A) and non-bound, (B) test antigen (insulin) demonstrates a proportional development of HRP substrate by optical absorption. Microarray detection of fluorescein-labeled E. coli LPS by Limulus Anti-LPS Factor (LALF), (C) is demonstrated.

Highlights

-
  - Feasibility of linking enzyme-labeled monoclonal to a specific antigen for amplified detection was demonstrated.
  - Through collaboration with Andrew Steele at the Carnegie Institution of Washington, we demonstrated linking our project protein microarrays to our prototype instrument.

Roadmap Objectives

- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
1	Shuttle 12 A-1	Science Team Member

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Our portable LAL reader is manifested to fly on Shuttle mission 12A-1 (April, 2006) as LOCAD-PTS to the International Space Station. LOCAD-PTS (Lab on a Chip Portable Test System) is a joint effort with Marshall Space Flight Center will be tested on station to monitor microbial bioburden on surfaces for environmental health. It has particular relevance for future long duration missions for environmental monitoring and crew health.

Cross Team Collaborations

Through collaboration with Andrew Steele, Carnegie Institution of Washington (CIW) Astrobiology Center, we have incorporated protein microarrays (Figure 1C) to our assay format. This will significantly impact our work by enabling simultaneous detection of up to 50 different antigens per test. Currently our portable reader will accommodate 4 tests, or 200 potential biosignature targets. Part of that collaboration was a study of the immunological detection of biosignatures extracted from JSC Mars-1 simulant regolith (paper submitted to Astrobiology). These observations demonstrate the practicality of microarray immunoassay for in situ detection of biological molecules in environmental samples, including martian regolith.

The evolution and diversity of ancient CO2-fixation pathways in anaerobic and extremophilic microorganisms: Clues to the early evolution of life on Earth

Project Investigator: Stefan Sievert

Project Progress

This project report reports on the accomplishments of the project "The evolution and diversity of ancient CO_2-fixation pathways in anaerobic and extremophilic microorganisms: Clues to the early evolution of life on Earth" as part of NNA04CC04A "From Early Biospheric Metabolisms to the Evolution of Complex Systems". (Dr. Stefan Sievert – Co-PI, WHOI)

We have amplified and sequenced the ATP citrate lyase gene, a key enzyme of the reductive TCA cycle (rTCA) used by certain chemolithoautotrophic microorganisms for autotrophic carbon fixation, from a variety of epsilon-proteobacteria (seven in total) as well as members of the Aquificales (six in total). By using additional, newly designed primers we have in many cases sequenced a gene fragment that includes the gene encoding for the small subunit and the large subunit of ATP citrate lyase as well as the region between the genes. This longer sequence will significantly improve our phylogenetic analyses aimed at reconstructing the evolutionary history of this gene and potentially the whole pathway. The data obtained so far support the view of the rTCA as an ancient metabolic pathway from which other pathways could have evolved and the usefulness of the ATP citrate lyses gene as a functional gene marker. Additionally, we have tested for the activities of key enzymes of the different carbon fixation pathways in seven chemolithoautotrophic organisms, and could further confirm that epsilon-proteobacteria and members of the Aquificales generally use the reductive TCA cycle for autotrophic carbon fixation. This has important ecological implications as members of these groups are important components of microbial communities in hydrothermal systems (both terrestrial and marine). We have also started analyzing environmental samples obtained from deep-sea hydrothermal vents and the Rio Tinto for the presence and diversity of organisms utilizing the rTCA using the ATP citrate lyase gene as a functional gene marker. In addition, the Co-PI successfully nominated *Thiomicrospira denitrificans*, a chemolithoautotrophic sulfur-oxidizing epsilon-proeteobacterium that uses the reductive TCA cycle for carbon fixation, for whole genome sequencing at JGI through DOE. In the meantime, the genome is finished and we are currently involved in annotation. Having the genome available will prove invaluable for further evolutionary and physiological studies, ranging from comparative genomics to gene expression studies.

Meanwhile, our work demonstrating the operation of the reductive TCA cycle for autotrophic carbon fixation for the first time in epsilon proteobacteria has now been published in the Journal of Bacteriology (Vol. 187: 3020-3027). We are currently in the process of preparing two manuscripts for submission based on the work performed over the last year.

Roadmap Objectives

- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.3:** Biochemical adaptation to extreme environments

The Distribution of Early Life into Geographically Distinct Subseafloor Microbial Habitats: A Metagenomic Strategy

NAI-NRC Postdoctoral Fellow : Julie Huber

Project Progress

The primary goal of this research is to use a metagenomic approach to identify the core genomic content of the thermophilic anaerobic subseafloor microbial community in the context of its complex chemical and hydrogeological environment. Microbes unique to the subseafloor in oceanic crust could provide insight into metabolic processes, strategies for growth, and survival of life forms in the subsurface of solar bodies with a water history. The first step, and the greatest challenge, is to construct large insert DNA libraries from low temperature diffuse hydrothermal vent fluids. Much of the first 6 months of my tenure have been spent on methods development, including high molecular weight DNA extraction, fosmid cloning, and high throughput clone screening. Because we only have a few very valuable vent fluid samples (collected on a research cruise to Axial Seamount in the NE Pacific in 2004), many of these techniques are being tested and carried out on cultured vent isolates and low priority environmental samples, including old low-volume filtered vent fluids and filtered pond water from here in Woods Hole. We have developed a successful DNA extraction method that yields high molecular weight DNA, as well as created 3 fosmid libraries; one from an autotrophic thermophile isolated from a diffuse vent at Axial, another from a 32 °C diffuse vent at Axial (Bag City), and one from Eel Pond in Woods Hole. Currently, we are still working on increasing the cloning efficiency so the libraries will be more representative of the natural microbial community. We also continue to develop methods for screening our large insert libraries, including functional screens, PCR, and random end sequencing so that once a library of satisfactory quality is obtained, we can investigate the genetic content and the functional and metabolic potential of the anaerobic thermophilic subseafloor microbial community at deep-sea hydrothermal vents.

Roadmap Objectives

- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 5.3:** Biochemical adaptation to extreme environments

Field Expeditions

Field Trip Name: NeMO 2004	
Start Date: September 18, 2004	**End Date:** October 1, 2004
Continent: Open ocean	**Country:** International Waters
State/Province: OR	**Nearest City/Town:** Newport
Latitude: 45 N	**Longitude:** 130 W
Name of site(cave, mine, e.g.): Axial Seamount	**Keywords:**
Description of Work: Collection of diffuse vent fluid samples from hydrothermal vents at Axial for chemical and microbiological analysis. In particular, we collected high volume filtered vent fluid samples for metagenomic work.	
Members Involved:	

Cross Team Collaborations

During 2004, while Julie Huber was still a graduate student, John Baross, a member of the Carnegie NAI Team, funded collection of multiple diffuse vent samples to be used for her post-doctoral metagenomic work.

Horizontal gene transfer in the evolution of early branching eukaryotes

NAI-NRC Postdoctoral Fellow : Jinling Huang

Project Progress

Preliminary analyses of lateral gene transfer for a eukaryotic genome have been finished. One paper has been accepted by Molecular Biology and Evolution (advance access available online). The second paper is being written.

Roadmap Objectives

- **Objective No. 3.2:** Origins and evolution of functional biomolecules
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.2:** Foundations of complex life

Cross Team Collaborations

I have participated in the activities of the EvoGenomics focus group.

Iron Oxidation - Shaping the Past and Present Environments

Project Investigator: Katrina Edwards

Project Progress

1. The biology of Iron Oxidation
   - A genetic system has been developed for our model neutraphilic Fe-oxidizing bacterium, *Marinobacter aquaeolei* ;
   - A fosmid library has been constructed for *M. aquaeolei* and screened for Fe-oxidizing clones. Pigmented clones contain *HemA* .
   - The genome of *M. aquaeolei* has been sequenced and draft annotation completed. The genome is being closed and manually annotated.
   - Biochemical studies have confirmed that Heme production increases under Fe-oxidizing conditions. A genbank screening of the genome revealed a putative operon which includes Di-heme cytochrome C peroxidase and four neighboring proteins with predicted functions in electron transfer; gene arrangement is distinct compared to other available genomes. A manuscript is in preparation reporting these results. We suspect that this operon plays an important role in iron oxidation and are now conducting studies to confirm this hypothesis.
2. Iron Isotopic Studies
   - The Fe isotopic composition of sulfides in black shales has been measured for samples ranging in age from Precambrian to Late Cretaceous, with specific focus on Late Archean to early Paleoproterozoic time.
   - Highly variable and negative Fe isotopes before 2.3 Ga were measured and reported in Science earlier this year.
   - Our interpretation of these results is that the oceans were globally Fe-rich, their Fe isotope composition and Fe content were variable in response to the episodic establishment of an Fe-rich pool supplied by hydrothermal activity and deposition of Fe-oxides, either in BIFs or dispersed throughout sediments on continental shelves and in the deep sea. After the rise of atmospheric oxygen by ca. 2.3 Ga, Paleoproterozoic oceans became stratified and characterized by an increase of sulfide precipitation relative to Fe-oxide precipitation. The effect of the increased role of sulfide precipitation on the change of Fe isotope record by 2.3 Ga is presently uncertain since reliable estimates of isotope fractionation during pyrite, or its precursor formation in the water column are lacking.

Roadmap Objectives

- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems

Cross Team Collaborations

David Emerson Thomas McCollom Jill Banfield

EPO Reports: Marine Biological Laboratory

micro*scope (http://www.mbl.edu/microscope) - a web-based tool for microbial diversity research, education and outreach

micro*scope (http://www.mbl.edu/microscope) was developed to improve information about microbes for both educational and research objectives. The approach was to use some innovative web-based services, since referred to as "Taxonomic Indexing" as new means of organizing local and distributed data within a layered knowledge environment. The informatics dimension is being explored with our partner uBio (http://www.ubio.org). A new alliance has developed with the NSDL funded 'Microbial Life', http://microbial.life.mbl.edu. We provide a near foundation layer of factual information for curriculum-compliant educational exercises.

micro*scope developed a dynamic index based on a complete list of all bacterial and protist genera organized into a hierarchical classification. We have extended the indexing service to have coverage of virtually all life as CU*STAR. Micro*scope currently provides descriptions and pictures of all categories of microorganisms and contains approximately 9000 freely downloadable high-resolution images organized in numerous collections, along with descriptions of 5000 protists. Habitats that have been surveyed include marine, saltwater marshes, fresh water ponds, and other environments including Yellowstone National Park, Rio Tinto (Spain), Ross Sea (Antarctica), Alkaline habitats, and Toolik Lake in Arctic Alaska. Laboratory culture collections (e.g. American Type Culture Collection the Culture Center for Marine Phytoplankton) have also been surveyed.

During the present year we have completely re-organized the underlying software in preparation for its availability as a generic biological content management system. We have converted the system into a distributed workgroup system to allow collaborators world-wide to add content. We have added a new domain referred to as micro*lite in which we will develop resources for students and teachers in the K-12 category.

Our next objectives are to increase the interoperability with molecular environments, and to develop network services that will make taxon-specific ties between taxa in molecular analyses and complementary content within micro*scope. The micro*scope project is directed by David Patterson with assistance from Sarah Roland, Phillip Neal, Adrian Ardelean and Mindy Richelen.

MBL course: Living in the Microbial World

Living in the Microbial World is a one-week intensive hands-on workshop for middle and high school teachers, grades 6-12. Our objective is to prepare middle and high school teachers to teach students and other teachers about the importance of the microbial world by incorporating hands-on microbiology activities into existing curricula. During the workshop, resident and visiting scientists from within the Woods Hole community present teachers with background information and current research developments on topics related to the importance of diversity of microbes in natural environments and microbial processes in the biosphere. In addition to presentations, teachers spend most of the time in a teaching laboratory, engaging in easy and inexpensive hands-on activities that exemplify basic principles of microbiology. During the workshop, teachers hear lectures from research scientists highlighting the role of microbes in maintaining the biosphere, the origin of ecosystems, extremophiles, protist diversity and fungal biology, and symbiosis. Teachers took field trips to the MBL's Marine Resources Center and the Great Sippiwissett Marsh in Falmouth to see microbial mats. Days were structured to include one lecture per day, and the balance of the time was spent doing hands-on activities in the lab. Evening sessions highlighting available Internet and video resources and a tour of the Bay Paul Center DNA sequencing facility also took place. Activities included: an investigation of fungal biology using an inquiry approach; culturing of basidiomycetes using sawdust culture techniques; making simple agar media; soil sample dilutions; mesuring oxygen profiles in microbial mats, making Winogradsky columns; construction of plankton nets, Uhlig extractors, and coverslip traps for collecting microorganisms; observation of termite hindgut microbes; and demonstration of the effects of naturally produced antibiotics on microbial growth. Three lab options involving culture of bacteria and slime molds were offered simultaneously: culture and isolation of luminescent bacteria, culture and isolation of lactic acid bacteria, and investigation of slime mold behavior. Culture and isolation of antibiotic-resistant bacteria from alfalfa sprouts was also demonstrated. Astrobiology teaching materials were

highlighted in a one-hour demonstration of the website micro*scope and in an exploration of other Astrobiology URLs. Teachers received copies of the Educators Resource Guide, the "Life on Earth and Elsewhere?" poster and the Carnegie Institute "Voyages of Discovery" poster. Course material can be viewed online though the Microbial Life Educational Resources website. Michele Bahr assisted course directors Lorraine Olendzenski and Barbara Dorrittie. Virginia Edgcomb and David Patterson were among the speakers. This workshop is offered yearly, and this year included teachers from throughout the U.S. and Singapore.

Planetary Protection: Policies and Practices

Michele Bahr presented an introductory lecture on microbiology and organized a laboratory portion for the course "Planetary Protection: Policies and Practices". The course is designed to familiarize current and future planetary protection practitioners with NASA and COSPAR Planetary Protection policies, and with the practices and procedures necessary to implement Planetary Protection procedures during the conceptualization, design, fabrication, assembly, launch, operation and recovery of solar system exploration missions. The course combines presentations with a laboratory component emphasizing general microbiology and current planetary protection protocol. Participants extracted DNA, cultured samples from a variety of environments, viewed and counted bacterial colonies, and used a new system (Limulus Ameobocyte Lysate, LAL) being developed for detection of bacterial Presentation topics by other faculty included communicating policy to the public, current and upcoming interplanetary missions, policy and guidelines for hardware designers, and lessons learned in implementing planetary protection. The course was held at the Long Marine Lab, UC-Santa Cruz.

MBL course: Advances in Genome Technology and Bioinformatics

Genome sequencing, genome analysis, and high throughput gene expression systems have provided major breakthroughs and insights for Astrobiologists and researchers in all fields of biology. PI Mitchell Sogin was the co-director of a comprehensive, four-week course that integrated bioinformatics with the latest laboratory techniques. The course combined a series of lectures with laboratory exercises both at the computer and in a high technology, high throughput facility. The major instructional modules were Genome Sequencing, Bioinformatics and Functional Genomics. Symposia offered included: Advances in genome assembly; Genomes and development; Genome science and environmental biology; Genome evolution; and Impact of genome science on Drug design. The breadth of topics in genome science and the advanced training based upon advanced laboratory technology distinguish this course from all other offerings. In addition to attending the symposia, students had daily hands-on experience with genome sequencing and analysis.

MBL course: Discover the Microbes Within! Teacher Enhancement Workshop on Symbiosis.

MBL Astrobiology and Frontiers in Integrative Biological Research (FIBR) hosted a workshop for high school teachers, entitled "Discover the Microbes Within! Teacher Enhancement Workshop on Symbiosis." This three-day, intensive workshop drew high school teachers from both inner city and rural school districts. Faculty from across the U.S., including members of the MBL's NAI team, led teachers as they conducted hands-on laboratory exercises on microbes, symbiosis, insect biology, bioinformatics, and evolution.

The reproductive parasite Wolbachia was selected as a model to illustrate themes of symbiosis, because this bacterium is prevalent in insects and allowed educational protocols in which students can obtain their own insect samples for analysis. Lesson plans emphasize activities that can be used easily and inexpensively in the classroom to teach basic biological principles. These lessons covered insect identification using a web-based taxonomic key, the bacteria that live within insects, DNA extraction, molecular biologytechniques and evolutionary analysis skills based on an NCBI tutorial developed by Seth Bordenstein. Participants were allowed time to examine new curriculum materials and share teaching experiences. There was also focus on

spending time in the laboratory engaging in hands-on activities and touring MBL facilities. Workshop presentations and educational tools are freely available for teachers to download at http://research.amnh.org/FIBR/workshops.html

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UNC course: Extreme microorganisms: pushing the limits of life on Earth and beyond

Co-I Andreas Teske taught an undergraduate non-majors seminar to freshman entitled "Extreme microorganisms: pushing the limits of life on Earth and beyond? at the University of North Carolina at Chapel Hill. The course introduced students with no prior exposure to microbiology to a wide range of Astrobiology-related topics including physiology and diversity of extremophilic archaea, molecular phylogeny based on ribosomal RNA with reading of seminal papers by Carl Woese, hydrothermal vents enhanced with original samples of vent invertebrates, and viewing of original video tapes from ALVIN dives, and the early biosphere evolution, based on Andrew Knoll's book "Life on a Young Planet: The first three billion years of evolution on Earth".

MBL course: Microbial Diversity

Team members Mitchell Sogin, David Patterson, Jennifer Wernegreen and Andreas Teske presented lectures on their research in the summer Microbial Diversity Course at the MBL. The course is designed primarily for scientists with a substantial background in microbiology who want to isolate, cultivate, and initiate research programs with a diverse range of microbes. The emphasis of the course is on the variety of metabolic pathways and the range of environmental habitats occupied by microbes, similar to the questions posed by NAI. Wernegreen spoke on "Bacterial endosymbionts of insects: lifestyle diversity and insights from genomics", Patterson spoke on "Protistan Diversity; and Teske spoke on "Beggiatoa, Thioploca and Thiomargarita - large, morphologically conspicuous sulfur bacteria". Mitchell Sogin presented a special seminar as part of the popular Friday Evening Lecture series open to the public. He spoke on "Unresolved mysteries about parasites and our oldest ancestors."

Falmouth High School Science Fair

Team members Michele Bahr, Stefan Sievert and Julie Huber interacted with students and evaluated elementary and high school science projects at the Falmouth school district science fair.

Brown course: Global Environmental Change

Co-I John Mustard led this freshman seminar course which examined the relationship between human habitation and planetary processes. Mustard sought to frame some of the compelling environmental questions of our day and examine them from a systems-process point of view. Students examined the evidence that supports or refutes various perspectives on the problems, but also delve deeper into the scientific principles that govern the fundamental processes at work. Their first goal was to determine what we know, how we know it, and the quality of the data informing this position. Their second goal was to determine what we don t know, what we need to know, and strategies to increase our knowledge to solve current and future problems. Students read classic and contemporary reading in advance of each seminar period and prepared lists of questions or concepts intended to provoke discussion among their peers.

Brown course: Global Environmental Remote Sensing

Our understanding of planetary science includes recognizing a set of interconnected global systems here on

Earth, the hydrosphere, geosphere, cryosphere, and biosphere. Team member John Mustard led a seminar examining the nature of these global systems, their inter-relationships, and the scope, origin, and resolution of global environmental problems. Our ability to understand these systems and their connections will require expert use of remote sensing, the only tool that allows global analysis of the Earth on a regular basis. This course provided a detailed understanding of remote sensing techniques and an assessment of the types of global environmental processes that can be analyzed quantitatively using global remote sensing systems. The principles of remote sensing were examined in detail, with emphasis on optical, thermal, and microwave remote sensing. Students examined commonly used remote sensing systems and developed techniques for quantifying key environmental variables from these systems through the use of laboratory assignment, homework problems, and independent research projects.

Astrobiology in-service training for Falmouth High School science teachers

micro*scope education specialist Sarah Roland and NAI team member Michele Bahr conducted an afternoon in-service training session on Astrobiology for Falmouth High School science teachers. Twenty teachers listened to a lecture on microbial life which emphasized biodiversity and life in extreme environments, participated in the "Habitable Planets" activity from the Educators Resource Guide and viewed a demonstration of the micro*scope and Microbial Life Educational Resources websites. ERGs, bookmarks, and "Life on Earth and Elswhere?" posters were distributed.

Seen and Unseen: Discovering the Microbes of Yellowstone

Team member David Patterson is a co-author of this book about the microbial ecology of Yellowstone National Park. The thermal hot springs of Yellowstone are an extreme environment in which complex microbial communities have evolved. The book combines landscape photography of springs, pools, streams and wildlife with photomicrography of their diverse microbial inhabitants. The aim of the book is to use habitats as a starting point for introducing the general public to species found and relationships within microbial communities. Published by Falcon Press, 1 July 2005.

The Search for Life Beyond Our Planet at the N.Y. Hall of Science

Linda Amaral Zettler provided scientific expertise, images, and culture material for an exhibit entitled "The Search for Life Beyond Our Planet" at the New York Hall of Science, Queens, NY. The interactive exhibit included a section on the extreme environment of the acidic Rio Tinto in Spain, and featured living eukaryotes that could be viewed through a microscope. "The Search for Life Beyond Our Planet" opened in November, 2004.

Switch on the micro*scope!

"Switch on the micro*scope!" by Sarah Roland, Michele Bahr, Lorraine Olendzenski and David Patterson was published in the The Science Teacher, the journal of the National Science Teachers Association. The article provides background information and detailed instructions for preparing an easily constructed method for concentrating protests from soils and sediments. It emphasizes eukaryotic biodiversity and refers teachers to the micro*scope website.

Plymouth School District Ocean Studies curriculum

The Plymouth MA school district has initiated an innovative seventh grade Ocean Studies curriculum based

on science standards. micro*scope education specialist Sarah Roland and team member Michele Bahr are among the ocean scientists planning student activities. They will emphasize the diversity and importance of microbial life in the ocean. All seventh grade students in the district will spend a field day onboard the "floating classroom" sponsored by Capt. John boats. The students will sample with plankton tows, "protest catchers", and sand and sediment collections. Subsequent classroom activities will include construction of Winogradsky columns and microscope observations. Students will access the micro*scope website and be encouraged to develop their own class micro*scope web page.

Astrobiology kiosk at the WHOI Exhibit Center

The Woods Hole Oceanographic Institution is the home institution of the deep-sea submersible vessel Alvin and WHOI scientists have been leaders in exploring the extreme environment of hydrothermal vents. It is particularly appropriate the WHOI Exhibit Center is the current host for the "Voyages of Discovery" kiosk on vent environments that was developed by the Carnegie Institution NAI team. Woods Hole is a summer tourist destination and the Exhibit Center draw visitors from around the world. In conjunction with the display, team member Katrina Edwards presented a talk on "Astrobiology and Iron" as part of a public lecture series. Her talk describes how our understanding of life on Earth is expanding and guiding our search for life that may exist in the extreme environments on other planets. Scientists have found life where it was never thought possible- in hostile, iron-rich environments here on our planet. Attendees will learn more about the link between iron, the extreme environments in the deep sea, and the possibility of life elsewhere in the universe. The "Voyage of Discovery" poster was also distributed.

Woods Hole Science & Technology Education Partnership

As the MBL liaison for the Woods Hole Science & Technology Education Partnership ('WHSTEP'), Wernegreen and her lab are very much involved in forging links between linking local grade school programs and research activities in Woods Hole. These activities include bringing Woods Hole scientists into the classroom to help students develop independent science projects, and to serve as counselors for science fair competitions. Several members of the NAI team have joined the WHSTEP Registry of Science Outreach Volunteers (ROV). This internet-based directory allows local teachers to find scientists who are willing to assist with specific educational programs.

Astrobiology resources at the National Science Teachers Association annual meeting

MBL team member Michele Bahr joined Pamela Harman and Tim Slater for a session on Astrobiology Resources at the National Science Teachers Association annual meeting in Dallas, TX. Approximately 150 middle and high school teachers attended. Bahr spoke on the ecological impact and biodiversity of microbes, emphasizing their presence in extreme environments. She described and distributed the "Life on Earth and Esewhere?" and IMax film "Aliens of the Deep" (hydrothermal vent) Educators Resource Guides and demonstrated the new Microbial Life Educational Resources (MLER) (http://microbial.life.mbl.edu) and micro*scope (http://www.mbl.edu.microscope) websites. micro*scope education specialist Sarah Roland and Michele Bahr presented a session on Digital Resources for Astrobiology. Twenty middle and high school teachers heard a talk "Why study microbes?" which emphasized extremophiles and received the Educational Resources Guide. Roland demonstrated the micro*scope website (http://www.mbl.edu.microscope) with instructions for constructing individual micro*scope sites. She also demonstrated the Microbial Life Educational Resources website (http://microbial.life.mbl.edu), which was premiered at this meeting.

Exploring the Universe teachers workshop

Concurrent with the National Science Teachers Association convention, a free workshop for local teachers

was held at the University of Texas-Dallas. Twenty middle and high school teachers attended "Exploring the Universe", hearing talks and experimenting with classroom activities related to Astrobiology. Michele Bahr joined NAI E/PO leads Edna DeVore, Pamela Harman and Tim Slater, along with other educators, and presented a talk on microbiological diversity with an emphasis on extreme environments.

Astrobiology in the Classroom at the American Society of Microbiology annual meeting

Michele Bahr presented a poster on Astrobiology in the Classrom at the American Society of Microbiology annual meeting in Atlanta, GA. The poster Life on Earth and Elsewhere? was described in detail with classroom activities highlighted. 100+ posters were distributed to researchers with teaching responsibilities, primarily at an undergraduate level. The Educators Resource Guide was also distributed, along with brochures about the new Microbial Life Educational Resources and the micro*scope websites.

Could Life Exist on Mars? Answers May Lie in the Otherworldly Environment of a River in Spain article

A general article about Rio Tinto research, "Could Life Exist on Mars? Answers May Lie in the Otherworldly Environment of a River in Spain" was published in "Inside Brown". The article describes how understanding the Rio Tinto's extremophiles and the fingerprints they leave on the geologic record could provide important clues about how and where life might survive on the Red Planet. It was distributed during Brown Graduation Weekend, reaching all the participants at graduation, and can be viewed online at: http://www.brown.edu/Administration/InsideBrown/2005/050605h.html

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WHOI Geomicrobiology Group

The WHOI Geomicrobiology Group works toward deciphering the co-evolution of earth and life. CoI Katrina Edwards' research focuses on the role of microorganisms in mediating the rates and mechanisms rock, mineral, and organic matter transformations. Edwards advises graduate student Sheri Simmonson on community structure, biogeochemistry, phylogeny and genomics of marine magnetotactic bacteria and their role in Fe and S cycling, and Peter Canovas and Cara Santelli on microbial Fe and sulfide mineral oxidation at seafloor hydrothermal vents. Postdoctoral researcher Olivier Rouxel presented his work at the NAI meeting in Boulder, and again as part of the NAI director's seminar series, in a talk entitled "Iron Isotope Constraints on the Archean and Paleoproterozoic Ocean Redox State." NAI postdoctoral investigator Ashita Dhillon also works with the Edwards group. The Edwards group research is described in depth at the website http://www.whoi.edu/science/MCG/edwards.

The Deeps of Time in the Depths of the Ocean article

Oceanus is both an online magazine published continually and a print magazine published three times a year by Woods Hole Oceanographic Institution. Oceanus explores the oceans in depth, featuring stories and images on ocean-related research, discoveries, expeditions, education, technology, and policy. Co-Is Andreas Teske and Katrina Edwards wrote "The Deeps of Time in the Depths of the Ocean" for Oceanus. They described how the discoveries of unusual marine microbes are radically changing our views about the evolution of life. The article can be viewed online at http://oceanusmag.whoi.edu/v43n2/teske_edwards.html.

Climate Change On Mars Sigma Xi talk

Co-I John Mustard spoke about "Climate Change On Mars" at the Sigma Xi Annual Dinner at Rhode Island College.

Brown Planetary Geology students

John Mustard has been mentoring post-doctoral research associate Aline Gendrin and graduate student Leah Hutchison, who have been doing research at the Rio Tinto site. Gendrin presented her findings at the annual NAI meeting held in Boulder, CO in a talk entitled "Mineral deposits on Mars revealed with the OMEGA visible-infrared imaging spectrometer and their implications for astrobiology."

Astrobiology in the GED classroom

Team member Michele Bahr is also a GED instructor for Cape Cod Community College. The "Life on Earth and Elsewhere" poster is part of her classroom display, and the students viewed and discussed the PBS Origins series segments on the early history of Earth, the origins of life and evolution.

Insect endosymbionts as targets and agents of evolutionary change: Recent insights and opportunities

Society for the Study of Evolution (SSE) symposium, Insect endosymbionts as targets and agents of evolutionary change: Recent insights and opportunities. SSE/SSB/ASN annual meeting, Fairbanks Alaska. This symposium, proposed and co-organized by Jennifer Wernegreen and Seth Bordenstein, was selected by the SSE Council through a competitive application process. Our objective was to illustrate the utility of insect endosymbionts as models to study species interactions, with an emphasis on the integration of evolutionary, ecological, and genomic approaches. Wernegreen, Bordenstein, and six other speakers presented new research findings in symbiotic systems ranging from obligate mutualists to reproductive parasites.

In Search of Microbial Eukaryotic Diversity

Linda Amaral Zettler was an invited speaker at the Memorial University Biology Seminar Series in St. John's, Newfoundland, Canada. Amaral Zettler's talk was entitled "In Search of....Microbial Eukaryotic Diversity" and focused on her findings from the extremely acidic Rio Tinto Astrobiology research site.

Institute for Science Instruction

The Institute for Science Instruction (ISIS) is an intense, two-year, interdisciplinary program aimed at advanced-degree science teachers interested in bringing new discoveries, technologies, and ideas into the classroom. ISIS teachers visited Woods Hole, and co-I Linda Amaral Zettler was invited to speak to them on her Astrobiology-related research. She presented "In Search of...Microbial Diversity at Life's Extremes." As an outcome, one teacher volunteered to work in the Bay Paul Center for 2 weeks (August 1-14) to obtain a research experience that can be used to help develop secondary school teaching materials.

North East Microscopy Society meeting

Linda Amaral Zettler was an invited speaker at the North East Microscopy Society meeting. The title of

Amaral Zettler's talk was "In Search of...Microbial Diversity at Life's Extremes."

Canadian Institute for Advanced Research Microbial Diversity Workshop

The Canadian Institute for Advanced Research (CIAR) held a Microbial Diversity Workshop in Vancouver, British Columbia targeted at establishing new Canadian research programs. Linda Amaral Zettler was a participant and presented a talk entitled "Microbial Diversity: A Three-Domain Approach."

NRC Committee on the Origin and Evolution of Life

The National Research Council Space Studies Board Committee on the Origin and Evolution of Life met at the J. Erik Jonsson Center in Woods Hole, MA. Linda Amaral Zettler was an invited speaker and gave a talk entitled: "Acidophiles in the Rio Tinto."

Sea Education Association Diversity Workshop

The Sea Education Association of Woods Hole, MA held a Diversity Workshop targeted at encouraging involvement of underrepresented groups in Marine Science. Linda Amaral Zettler participated in the workshop, with the outcome of being invited to speak at Morehouse College, Atlanta, Georgia, and possibly other MSIs in the area, in January 2006.

Discover Biology textbook images

Linda Amaral Zettler contributed two images of the Rio Tinto Astrobiology research site to the textbook "Discover Biology" to be published by W. W. Norton in 2006.

Austrian Broadcasting Corporation Astrobiology interview

Linda Amaral Zettler discussed her research in an interview with Austrian Radio Reporter Dr. Madeleine Amberger from the Austrian Broadcasting Corporation/ Radio and Television.

Centro de Astrobiologia student mentoring

Angeles Aguilera (Centro de Astrobiologia; CAB) spent two months at the Marine Biological Laboratory, one month enrolled in the Advances in Genome Technology and Bioinformatics Course at the MBL and one month collaborating with Linda Amaral Zettler (MBL NAI team) on eukaryotic diversity in the Rio Tinto. A manuscript entitled "Eukaryotic community in the Tinto River (SW Spain), an extreme acidic environment" is in preparation.

UNC Geomicrobiology Group

Andreas Teske is mentoring two graduate students, Karen Lloyd and Mark Lever, who focus on molecular analysis (16S rRNA and fucntional genes) of deep subsurface microbial communities in Peru Margin sediments (ODP sites 1229 and 1230), and on methane seep sediments in Guaymas and the Gulf of Mexico.

Lloyd and Lever presented results at the NAI annual meeting in Boulder, CO. Teske is mentoring senior undergraduate student Kate Harris, who is doing her honors thesis project on 16S rRNA and Rubisco gene sequencing of microbial communities in formation fluids of Mid-Ocean Ridge basalt (ODP bore hole 896A on the Costa Rica Rise). Teske is also mentoring two postdoctoral researchers, Ketil B. Soerensen and Antje Lauer until December 2004. Soerensen and Lauer worked on archaeal communities of organic-poor subsurface sediments of central oceanic basins (ODP sites 1225 and 1231). Soerensen developed the rRNA isolation protocol now used in the Teske lab to sequence ribosomal RNA (not rDNA) of active archaeal populations of all Peru Margin and Peru trench sites (ODP Sites 11227, 1228, 1229, 1230).

Wolbachia student research project

Volunteer summer researcher Pia Hugus from the University of Connecticut is working on the molecular phylogenetics of the endosymbiont Wolbachia to determine if obligate intracellular parasitism or mutualism arose first during the radation of this symbiotic bacteria. She is doing this work in synergy with Drs. Jennifer Wernegren and Seth Bordenstein. Pia is learning molecular biology techniques such as endosymbiont isolations and polymerase chain reaction.

Brown Planetary Science Seminar

Co-Is James Head and John Mustard conducted a Planetary Science Seminar for six students. The course focused on discussion of current problems in planetary geology.

Brown course: Problems in Antarctic Dry Valley Geoscience

James Head taught a Planetary Geological Science course to six students on "Problems in Antarctic Dry Valley Geoscience". The course is based on Head and other's experience as an Astrobiology researcher in this extreme environment.

Astrobiology Winter School

James Head taught at the Astrobiology Winter School sponsored by the University of Hawaii NAI team in Hilo, HI. Topics covered included Antarctic Dry Valleys (Head andThorsteinsson), Follow the Water on Mars, and Mars Ice: Intermediate and Distant Past.

Mars II summer session

James Head taught at the Mars II summer session held in Les Houches, France. Topics covered included Water on Mars and a critique, interpretation and discussion of Geology of Mars.

Lunar Science, the Next Decade conferencer

James Head participated in the summer session on Lunar Science, the Next Decade held in Bad Honnef, Germany. He presented "Lunar Science: An Overview."

Geological Evidence for Climate Change on Mars

James Head presented a talk on the "Geological Evidence for Climate Change on Mars" at the University of Mass., Amherst.

Mars: Geological Evidence for Climate Change and Ice Ages

James Head presented a talk on "Mars: Geological Evidence for Climate Change and Ice Ages" at North Dakota State Univ., Fargo, ND.

Planetary Geology and Geophysics Intern

James Head mentored Amanda Nahm, a Planetary Geology and Geophysics Intern. Nahm is a senior at Univ. of Colorado, Boulder, CO.

Falmouth Academy Science

Team member Virginia Edgcomb taught 7th grade Life Science and 8th grade Physical Science at Falmouth Academy 2004-2005 (60 students). Edgcomb introduced a unit on Astrobiology touching on origin of life theories, microbiology of extreme environments, and planetary exploration. She also mentored the students through science fair projects. Michele Bahr and Julie Huber interacted with students while evaluating projects related to microbiology at the Falmouth Academy Science Fair.

WHOI Career Development Symposium

Virginia Edgcomb was a panel member for a Career Development Symposium hosted by WHOI. The symposium addressed career paths, fields of research, professional and personal development. Approximately 80 undergraduate and graduate students attended.

NASA Planetary Biology Internship Program

The NASA Planetary Biology Internship Program (PBI) provides opportunities to explore scientific questions of global scale about planet Earth. Each year the PBI program sponsors nine or ten interns who undertake research at NASA Research Centers or NASA-sponsored laboratories and academic institutions. As the MBL representative to the MA Space Grant consortium, Michele Bahr evaluated thirty applications and made recommendations for student participation in NASA internships throughout the U.S.

Alien Earths exhibit

Team member Michele Bahr participated in a professional development workshop for Astrobiology E/PO leads based on the museum exhibit "Alien Earths". "Alien Earths" was developed by the Space Science Institute and premiered at the Lawrence Hall of Science, University of CA, Berkeley. The exhibit displays interactive activities exploring interstellar and planetary formation, the history of the search for other interstellar planets, characteristics of life, and the quest to find life in other solar systems. Participants toured the exhibit and then developed presentations highlighting various aspects of the displays. Presentations were discussed with museum directors from throughout the Bay Area.

Ancient carbon fixation pathway research

Stefan Sievert is mentoring Michael Hugler, a WHOI postdoctoral scholar who is working on the reductive TCA cycle. This project has the goal to better understand the evolutionary history of one of the most ancient carbon fixation pathways and to lay the foundation for an assessment of its environmental significance. Many consider the reductive TCA cycle to be the most ancient autotrophic carbon fixation pathway. This cycle occurs in phylogenetically-diverse prokaryotes whose growth conditions fit well with our view of the primitive Earth.

The shallow subsurface at hydrothermal vents: A prime habitat for novel sulfide-oxidixers?

Stefan Sievert lectured on "The shallow subsurface at hydrothermal vents: A prime habitat for novel sulfide-oxidixers" at the Department for Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA. This lecture was also presented at the Marine Biological Laboratory, University of Copenhagen, Helsingor, Denmark

Microbiology and Biogeochemistry of Autotrophic Microbes in the Subsurface at Hydrothermal Vents: Filamentous-Sulfur Producing Bacteria

Stefan Sievert spoke on "Microbiology and Biogeochemistry of Autotrophic Microbes in the Subsurface at Hydrothermal Vents: Filamentous-Sulfur Producing Bacteria" at the Earth Sciences Department, Swiss Federal Institute of Technology in Zurich (ETHZ), Switzerland.

Origin of Life Gordon Research Conference

Virginia Edgcomb gave a talk at the Gordon Research Conference on Origin of Life, Ventura CA, entitled "Deep Marine Environments: Microbial Ecology and Discovery: Dens of Antiquity"

Museum of Science Educator's Night

Team member Michele Bahr and micro*scope education specialist Sarah Roland attended the Boston Museum of Science Educator's Night. They toured the facility and spoke with MA teachers about the Astrobiology program and micro*scope website.

Publications: Marine Biological Laboratory

There are **39** publication entries for the Marine Biological Laboratory

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Amend, J.P. & Teske, A. (2005). Expanding frontiers in deep subsurface microbiology. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 219:131-155.

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Degnan, P.H., Lazarus, A.B. & Wernegreen, J.J. (In Press, 2005). Genome sequence of Blochmannia pennsylvanicus indicates parallel evolutionary trends among bacterial mutualists of insects. *Genome Research*.

Dhillon, A., Goswami, S., Riley, M., Teske, A. & Sogin, M. (2005). Domain evolution and functional diversification of sulfite reductases. *Astrobiology*, 5(1):18-29 [Online].

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Edwards, K.J., Rogers, D.R. & Webb, E.A. (2005). Microbial weathering of seafloor hydrothermal sulfides [Abstract, Oral Presentation]. *Goldschmidt Meeting*. Moscow, Russia.

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Executive Summary: Michigan State University

Executive Summary: Michigan State University
Principal Investigator: Michael Thomashow
Reporting Period: 2005 (7/04-6/05)

Project Reports: Michigan State University

Transcriptomes of Permafrost Bacteria

Project Investigator: Michael Thomashow

Project Progress

Bacteria in the Siberian permafrost environment must contend with low temperatures (-10°C) and low water activity (a_w=0.85-0.9). To gain knowledge of microbial adaptation to low temperature and low water activity, the genome of a Siberian permafrost isolate, *Psychrobacter arcticus* 273-4, was sequenced and gene expression monitored using microarrays consisting of 70-mer oligonucleotides representing the large majority of predicted genes for this bacterium. Only a few genes known to be low temperature and salt responsive in certain mesophiles and psychrotrophs were differentially expressed in *P. arcticus*, although many were constitutively expressed. Experiments reveal that shifting *P. arcticus* from 22°C to 4°C resulted a 2-fold increase in transcripts for certain transport-associated and metabolic genes. Genes for increased synthesis and uptake of compatible solutes were up-regulated in the presence of high salinity (5% NaCl) which may help balance the cell's internal osmolarity. Several genes with unknown functions were also up-regulated in response to low temperature and high salinity, which may indicate their importance in stress survival. Growth in 5% NaCl-amended 1/2 TSB lead to induction of capsule synthesis genes. A capsule was visible around cells grown at both 22°C and 4°C that could allow *P. arcticus* to adhere to soil particles within the permafrost. In addition, total respiratory activity increased in the presence of high salt (5% NaCl), perhaps due to increased expression of genes encoding a Na^+-dependent dehydrogenase and a decarboxylase, suggesting that *P. arcticus* has adapted for energy generation in the low temperature and low water activity of the permafrost environment.

Roadmap Objectives

- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Proteomes of Permafrost Bacteria

Project Investigator: Michael Thomashow

Project Progress

Global protein profiling and comparative proteomic analysis of two bacterial strains that were isolated from Siberian permafrost, *Psychrobacter* 273-4 and *Exiguobacterium* 255-15, have been performed using two-dimensional HPLC and mass spectrometry. The results with *Psychrobacter* 273-4 indicate that more than 50 proteins were differentially regulated in response to a temperature shift from 22°C to 4°C. Of the cold-induced proteins, 14 had roles in translation indicating a need for major modifications of the translational apparatus at low temperature. In addition, there were increases in the levels of certain chaperons including HSP60 and HSP10 and a putative cold shock protein related to *Escherichia coli* CspA. Changes in the levels of more than 50 proteins were also observed to occur in response to high salinity (5% NaCl), most of which were in common with those affected by low temperature. Significantly, the transcript levels for many of the differentially expressed proteins did not change in response to low temperature or salinity indicating that these genes are regulated by posttranscriptional control mechanisms. Similar experiments with *Exiguobacterium* 255-15 have resulted in the detection of some 800 proteins, of which, about 60 were differentially expressed (by a factor of at least 5-fold) in response to a temperature downshift from 25°C to 4°C. Efforts are now in progress to determine the identities of these proteins. The long term goal is to determine whether the differentially expressed proteins of *Psychrobacter* 273-4 and *Exiguobacterium* 255-15 have critical roles in adaptation to low temperature and low water activity, conditions that are fundamental to the Siberian permafrost environment.

Roadmap Objectives

- **Objective No. 5.3:** Biochemical adaptation to extreme environments

Indigenous Bacteria of Arctic and Antarctic Permafrost

Project Investigator: Michael Thomashow

Project Progress

The permafrost environment is extremely nutrient-limited due in large part to its frozen state. Thus, it would be predicted that permafrost bacteria should be able to synthesize most of their cellular constituents, vitamins and cofactors from a limited array of available substrates. Indeed, a metabolic pathway reconstruction for *Psychrobacter* sp. 273-4 performed by Natalia Ivanova (Lawrence Berkeley National Labs), based on our genome sequencing of this organism, indicated that this bacterium has a gene complement that would enable it to synthesize all of the amino acids, most vitamins and cofactors from a limited set of carbon sources including glycine, proline, serine and TCA cycle intermediates. The analysis also indicated that *Psychrobacter* sp. 273-4 would not be capable of growth on sugars due to a lack of genes encoding glycolytic enzymes, but that it should be able to utilize acetate and fatty acids as energy and carbon sources. Overall, the results suggested that *Psychrobacter* sp. 273-4 should be able to grow on a minimal sea salts based medium that included acetate as the carbon and energy source and ammonium chloride as the sole nitrogen source. This hypothesis was confirmed experimentally establishing the presence of the predicted metabolic pathways and providing a valuable medium that can be used to conduct a wide range of physiological and genetic studies on this bacterium.

In addition to isolating *Psychrobacter* sp. 273-4 from the Siberian permafrost, we have isolated *Psychrobacter* sp. K5. Both isolates were thoroughly characterized phenotypically and genetically and shown to be distinct species within the genus *Psychrobacter*. These species represent the first fully described novel species of *Psychrobacter* isolated from permafrost. Significantly, species K5, which was isolated from a salt lens within the permafrost, was tolerant to higher salt concentrations than species 273-4, which was isolated from permafrost sediments. In addition, reflective of the anaerobic nature of some permafrost environments, the membrane lipids of species K5 were dominated by lipids that do not require the presence of O_2 for their formation.

We previously described the isolation of three *Exiguobacterium* strains from different layers of the Siberian permafrost with ages ranging from 20 thousand to 3 million years old. These results suggested that members of this bacterial genus might be widely distributed and abundant in the Siberian permafrost environment. To test this, 29 Siberian permafrost soil samples with ages between 5 thousand and 3 millions years were collected and analyzed through quantitative real time PCR (Q-RT-PCR) using specific *Exiguobacterium* primer sets for the genes *gyr* B (gyrase B), *rpo*B (RNA polymerase beta subunit) and a hypothetical gene found in *Exiguobacterium* isolates from the Siberian permafrost. The results were consistent with *Exiguobacterium* species being widely distributed in the Siberian permafrost and accounting for up to 1% of the microbial community at certain locations.

Roadmap Objectives

- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth

Bacterial Adaptation to Low Temperatures

Project Investigators: Albert Bennett, Richard Lenski

Project Progress

This project uses experimental evolution to adapt lineages of the bacterium *Escherichia coli* to low temperature and examines the genetic basis and functional consequences of that adaptation. We previously developed a primary set of six clonal lineages and a secondary set of an additional 24 lineages adapted to 20°C. We are now in the process of developing twelve new lineages adapted to 14°C. After 800 generations, these 14°C lines have increased fitness over 15%, indicating a significant improvement in their ability to grow and compete at cold temperatures. Fitness improvement has been greatest in lines derived from the least cold adapted progenitors, indicating that the degree of prior cold adaptation is not necessarily a good predictor of future ability to adapt to cold conditions.

We have also evolved a set of 14 experimental populations of *E. coli* for 1000 generations under freeze-thaw-growth cycles. All have improved fitness in this regime owing to improved freeze-thaw survival and a shorter lag prior to the start of growth. To investigate the genetic changes responsible for this adaptation, six candidate genes were sequenced in clones from the evolved populations. However, no mutations were found relative to their progenitors. Next, we looked for genetic changes involving insertion sequence (IS) elements in several of the evolved populations, and a number of IS-associated changes were detected. Of particular interest, it was found that in six populations, an IS*150* element inserted into the intergenic region of the *uspA-uspB* operon, which encodes Universal Stress Proteins A and B,. Also, in several populations, IS*150* and IS*186* elements were found to have inserted into *cls*, which encodes cardiolipin synthase. Goals now include determining the physiological significance of these mutations, and to test whether they are beneficial in freeze-thaw-growth conditions in isogenic strains.

As part of this project, we have purchased a set of PCR primers required to amplify every gene in *E. coli* and are using these to create our own custom-made genomic arrays. These will consist of a solid support onto which all 4,200 *E. coli* genes will be arrayed in a regular grid, allowing us to make genome-wide "queries" of gene expression and gene content of all of our cold-adapted lineages. In addition, these arrays will be made available to the research community.

Roadmap Objectives

- **Objective No. 4.2:** Foundations of complex life
- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth

How low can they grow? Bacterial physiology at subzero temperatures

NAI-NRC Postdoctoral Fellow : Corien Bakermans

Project Progress

A fundamental goal of this project is to identify genes that enable bacteria to successfully inhabit the permafrost environment. One approach that we are taking is to create mutations in the genome of "*Psychrobacter arcticum* 273-4" and determine whether the genes (and proteins) affected are required for growth and/or survival under conditions common to the permafrost environment (e.g., low temperature, high salinity, low water activity, etc.). We have recently developed a genetic system for "*P. arcticum* 273-4" to create sight-specific mutations. Using this system, two deletion mutants were created in "*P. arcticum* 273-4." One of these mutants (Δ571) was in a transport protein that is predicted to have a glutamate-binding domain. Deletion of this gene was found to significantly increase the growth rate of "*P. arcticum* 273-4" only under low temperatures (4°C) and low salinity (0.5%) conditions (not at 22°C or 5% salinity) in both marine broth and minimal media with glutamate. Glutamate is believed to act as a cryoprotectant in "*P. arcticum* 273-4" at low temperatures, but not as a compatible solute for high salinity conditions. The enhanced growth rate of mutant Δ571 at low temperatures may reflect the removal of a negative competitor for glutamate. The second mutant (Δctc) could not be fully resolved (the wildtype copy of the gene was not removed from the genome). We believe this indicates that the gene is essential to the function of the organism. This is the first mutation in the general stress protein Ctc, which is found in a diverse array of bacteria, to display any kind of phenotype.

Two of the Siberian permafrost isolates were thoroughly characterized phenotypically and genetically and shown to be distinct species within the genus *Psychrobacter* ("*Psychrobacter arcticum* 273-4" and "*Psychrobacter cryohalolentis* K5"). These species represent the first fully described novel species of *Psychrobacter* isolated from permafrost. Significantly, species K5, which was isolated from a salt lens within the permafrost, was tolerant to higher salt concentrations than species 273-4, which was isolated from permafrost sediments. In addition, reflective of the anaerobic nature of some permafrost environments, the membrane lipids of species K5 were dominated by lipids that do not require the presence of O_2 for their formation.

In addition, a draft genome sequence of "*Psychrobacter cryohalolentis* K5" was generated in collaboration with JGI and proteomic studies of growth at subzero temperatures are ongoing.

Roadmap Objectives

- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.3:** Biochemical adaptation to extreme environments

Cross Team Collaborations

A collaboration has been established with Lisa Pratt and Tullis Onstott of the Indiana-Princeton-Tennessee Astrobiology Institute for the study of the geochemistry and microbiology of a permafrost system in the Canadian Shield. Cold, deep-subsurface environments are important analogs to the Martian subsurface. Our goal is to isolate, identify, and characterize microbes that are capable of inhabiting cold, deep-subsurface environments on Earth. Initial deep-subsurface water samples were taken during a reconnaissance trip in May 2004 and are undergoing microbiological analysis. Analysis revealed that the microbial communities were adapted to the low-temperature conditions as evidenced by the high number of culturable microbes that were able to grow at low temperatures. The identity of the isolates revealed that many were related to organisms that have been isolated from low-temperature and/or low-nutrient environments. The high number and diversity of culturable organisms present supports the idea that large diverse communities persist in deep subsurface waters. Future trips will sample rocks and water within the permafrost zone for microbiological analysis. Analyses will identify and characterize the low-temperature adaptations of Canadian permafrost isolates for comparison to Siberian permafrost isolates. These comparisons will enable us to determine what adaptations are specific to low temperatures rather than to the specific environment.

EPO Reports: Michigan State University

There are no EPO Records for this reporting period. (2005 (7/04-6/05))

Publications: Michigan State University

There are **11** publication entries for the Michigan State University

Ayala-del-Rio, H.L., Baez, Y.M., Seplveda, L.C. & Tiedje, J.M. (2004). Development of a PCR-based system for the detection and enumeration of Psychrobacter sp. in environmental samples [Abstract]. *Tenth International Symposium on Microbial Ecology.*. Cancun, Mexico.

Gilichinsky, D., Rivkina, E., Bakermans, C., Shcherbakova, V., Petrovskaya, L., Ozerskaya, S., Ivanushkina, N., Kochkina, G., Laurinavichuis, K., Pecheritsina, S., Fattakhova, R. & Tiedje, J. (2005). Biodiversity of cryopegs in permafrost. *FEMS Microbiology Ecology*, 53(1):117-128.

Pörtner, H.O., Bennett, A.F., Bozinovic, F., Clarke, A., Lardies, M.A., Lucassen, M., Pelster, B., Schiemer, F. & Stillman, J.H. (In Press, 2005). Trade-offs in thermal adaptation: The need for a molecular to ecological integration. *Physiological and Biochemical Zoology*.

Ponder, M.A., Gilmour, S.J., Bergholz, P.W., Mindock, C.A., Hollingsworth, R., Thomashow, M.F. & Tiedje, J.M. (2005). Characterization of potential stress responses in ancient Siberian permafrost psychroactive bacteria. *FEMS Microbial Ecology*, 53:103-115.

Qiu, Y., Kathariou, S., Thomashow, M., Tiedje, J. & Lubman, D.M. (2005). Proteomic analysis of Permafrost bacterium - Exiguobacterium 255-15 at different growth temperatures and media [Abstract]. *53rd ASMS Conference on Mass Spectrometry*. San Antonio, TX.

Rodrigues, D.F., Goris, J., Thomashow, M.F. & Tiedje, J.M. (2005). Phylogeny of three Exiguobacterium isolates from Arctic permafrost [Abstract]. *NAI 2005: Biennial Meeting*, 5:264. Boulder, CO.

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Seplveda-Torres, L.C., Ayala-del-Rio, H.L., Maldonado, M., Alvarez, S.H., Gonzalez, M., Martinez, J., Caraballo, K., Tiedje, J.M. & Thomashow, M. (2005). Physiological and phylogenetic comparisons between Psychrobacter strains isolated from Siberian and Puerto Rican samples [Abstract]. *NAI 2005: Biennial Meeting*, 5:265. Boulder, CO.

Sepulveda-Torres, L.D.C., Ayala-del-Rio, H.L., Alvarez, S.H., Maldonado, M., Baez, Y., Gonzalez, M. & Tiedje, J.M. (2004). Characterization of Psychrobacter strains isolated from Puerto Rican environmental samples [Abstract]. *Tenth International Symposium on Microbial Ecology*. Cancun, Mexico.

Zheng, S., Lubman, D.M. & Bennett, A.F. (2005). A new modification of MALDI matrix and its application on identification of proteins from Escherichia Coli [Abstract].. *53rd ASMS Conference on Mass Spectrometry*:Abstract TP 150. San Antonio, TX.

Zheng, S., Ponder, M.A., Thomashow, M., Tiedje, J. & Lubman, D.M. (2005). How psychrobacter survives in a permafrost environment: A proteomic perspective [Abstract]. *NAI 2005: Biennial Meeting*, 5:274. Boulder, CO.

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

Executive Summary: Pennsylvania State University

Executive Summary: Pennsylvania State University
Principal Investigator: Hiroshi Ohmoto
Reporting Period: 2005 (7/04-6/05)

EXECUTIVE SUMMARY

The Evolution of a Habitable Planet

The Penn State Astrobiology Research Center (PSARC) was created in 1998 as part of the NASA Astrobiology Institute (NAI). With a new hire of Jenn Macalady (Assistant Professor of Astrobiology) as part of PSU's commitment to NAI, PSARC currently is comprised of 19 (Co)-PIs and their research teams from The Pennsylvania State University (Mike Arthur, Sue Brantley, Lisa Brown, Jean Brenchley, Will Castleman, Greg Ferry, Kate Freeman, Blair Hedges, Chris House, Jim Kasting, Lee Kump, Jenn Macalady, Hiroshi Ohmoto, Mark Patzkowsky, Steinn Sigurdsson, and Alex Wolszczan), The University of Pittsburgh (Rosemary Capo and Brian Stewart), and SUNY Stony Brook (Martin Schoonen). During the period of July 1, 2004 – June 30, 2005, PSARC has supported all or part of the research/education/PO activities carried out by 80 persons (19 (Co-)PIs, 10 research associates and postdoctoral fellows, 35 graduate students, 8 undergraduate students, 4 technicians, and 4 staff in administration/IT/EPO). In addition, 30 Associate Members for Research (who are mostly professors at other institutions) closely collaborate with the 19 (Co)-PIs. Three other Associate Members work closely with the EPO team. More than 100 peer-reviewed papers were published by PSARC members during the period 7/1/04 – 6/30/05.

Research

PSARC's research has focused on critical issues concerning *planetary habitability:* (1) the evolutionary history of the biosphere, hydrosphere, and atmosphere on Earth and other planets, specifically the times, causes, and consequences of the emergences of major organisms (e.g., cyanobacteria, methanogens, sulfate reducers, fermenters, sulfide oxidizers, and eukaryotes); (2) the effects of photochemical reactions on the early biosphere; and (3) detection of biosignatures on other planets. Our approaches to these critical issues, and some important achievements during the last year, are briefly summarized below:

I. Investigations of the Geochemical Record of the Earth's Early Biosphere. Ohmoto directed the Archean Biosphere Drilling Project (ABDP), which conducted drilling of two new deep holes during summer 2004 in the Pilbara district, Western Australia to recover modern-weathering-free rock sequences 3.5-2.7 Ga in age. Mineralogical and geochemical investigations of the five drill cores from the 2003 ABDP drilling yielded evidence that microbes flourished in the oceans and land, and that the atmosphere-ocean system was O_2- and CO_2-rich, but CH_4-poor, during this period. Determination of an accurate age of a Precambrian paleosol has been difficult, but Capo-Stewart's group was successful in determining the ages of one of the oldest paleosols at Steep Rock, Canada (3.0 Ga) and of the oldest lateritic (ferric-iron enriched) soils at Hokkalampi, Finland (2.35 Ga) by applying the Nd-Sm and Rb-Sr methods.

II. Investigations of Photochemical Reactions of Sulfur and Iron in the Early Earth. To understand the mechanism(s) for the creation of MIF of S isotopes and to aid in the reconstruction of the Precambrian S cycle using the isotope record in rocks, Castleman's group has been conducting series of laboratory experiments on photochemical reactions of SO_2 by utilizing a reflectron time-of-flight mass spectrometer (RETOF-MS) and a femtosecond laser system coupled with the pump-probe technique. They found an inverse kinetic isotope effect during the photolysis of $^{32}SO_2$ and $^{34}SO_2$. From laboratory experiments at 35-150 °C, Schoonen's group has initiated molecular modeling to evaluate the energetics and kinetics of Fe(II) mediated reduction of dinitrogen and the photochemical reduction of dinitrogen with Fe(II) as the electron donor. In order to estimate the production rate of methane in early Archean Earth, Kasting's group has conducted coupled ecosystem/atmosphere modeling, which incorporates organisms that utilize H_2, H_2S, and Fe^{2+} as reductants.

III. Investigations of Genomic Record of the Earth's Early Biosphere. Hedge's group developed a method

for phylogenetic analysis of complete genome sequences, for use with either prokaryotes or eukaryotes. They have also completed an analysis of complete prokaryote genomes and better constrains on the origin of organisms producing metabolic products that influenced the history of the biosphere. House has made significant progress in redefining the Tree of Life by developing a method for building Prokaryotic trees based entirely on Gene Order.

IV. Laboratory Microbial Simulations: Astrobiological Signatures. In order to relate the biogeochemical signatures in Precambrian rocks to specific organisms and environments, to understand the response of consortia of organisms to their environment, and to provide the references of biogenic gases in remote sensing of possible life-sustaining planets, our group (House, Arthur, Kump, Freeman, Ferry, Ohmoto and their students) has set up a series of microbial microcosms. Special foci are placed on the chemical and isotopic signatures of inorganic substrates, biogenic gases, and microbial lipids, and on the responses of anaerobes to oxygen and aerobes to methane and sulfide. From separate experiments, House's group has made significant progress in understanding: (i) the effects of metal limitation (Fe, Mo) on cyanobacteria growth and N_2 fixation; (ii) trace metal acquisition by hydrothermal microorganisms; (iii) barite ($BaSO_4$) dissolution by sulfate-reducing bacteria; and (iv) the effects of different vitamins on C isotope fractionation during methanogenesis. Ferry' group has made significant advancement in understanding the structure, function (especially in reduction of oxygen to water), and properties of iron-sulfur flavoproteins (ISF) which constitutes a widespread family of redox-active proteins in anaerobic prokaryotes.

V. Investigations of Modern Analogues of Precambrian Microbial Ecosystems. Kump, Arthur, House, Freeman and their students have initiated a comprehensive geochemical - microbial investigation of Fayetteville Green Lake, New York, a meromictic lake, as a modern analogue of the Proterozoic marine biosphere. Arthur's group has been investigating N isotope systematics in anerobic environments and at oxic/anoxic interface using the Black Sea and Fayetteville-Green Lake as Proterozoic analogues. Kump and Arthur published a paper proposing that episodic release of hydrogen sulfide (H_2S) from the ocean caused the end-Permian mass extinction. The discovery by Brenchley's group of ultra-small microorganisms (< 0.2 micron size) in a 120,000-year-old Greenland-Glacier ice sample has been followed by a series of investigations (phylogenetic and morphological analyses; growth and culturability) to increase understanding their roles in the biosphere on Earth and other planets.

VI. Investigations on Planetary Habitability and Life Detection. Sigurdsson's group has completed: (1) HST imaging search and data analyses; (ii) followup observations using *Gemini*, *CFHT* and *NO*; (iii) *Spitzer* observations and data analyses. Wolszczan's group has continued a search for planets around K-giants with the Hobby-Ebbery Telescope (HET). They have discovered two (or more) stars that may have giant planets around them, one with a ~8 Jupiter mass. Kasting's group, working in conjunction with Vikki Meadows' NAI group at Caltech/JPL, have made progress in understanding potential biomarkers on planets around F, G, K, and M stars.

Fieldwork: Geologic field work was conducted in: (a) the Pilbara district, Western Australia by Ohmoto's group to conduct deep drilling under the Archean Biosphere Drilling Project (5 weeks, July-August, 2004; 3 weeks, June-July, 2005); (b) Arctic Russia by Kump for research on the Archean-Proterozoic transition (July, 2004); and (c) Fayetteville Green Lake, New York by Kump, Arthur, Freeman, House and their students to investigate the microbial ecology and to collect water and microbial samples for laboratory simulators (July, 2004 – June, 2005).

Education and Public Outreach

Public Outreach: An annual Astrobiology workshop for high school teachers (~10 attendees) was held under the direction of Darren Williams (PSU, Erie) and Jim Kasting during the week of July 25-July 29, 2005. Space Day at PSU, an annual one-day event to showcase the exciting space-related research carried out at PSU, was held on April 2, 2005. PSARC faculty and graduate students exhibited posters describing their Astrobiology research and worked with the general public on hands-on experiments to increase the public's awareness of Astrobiology. In May, 2005, we created an Astrobiology Exhibit, with displays of illustrations, cores, and outcrop samples from the ABDP, in a newly renovated Museum of the College of Earth and Mineral Sciences. This exhibit has already attracted a large number of visitors.

Undergraduate Education: The Astrobiology Minor Program, established in Fall 2000, as inter-college undergraduate program, has attracted about ten students from the Departments of Geosciences, Astronomy, Microbiology, Biology, and Mathematics. It has been administered by Chris House. An undergraduate summer training program in astrobiology was established at Penn State, with the help of a 3-year NSF REU-Site award (Blair Hedges, PI). Last summer it supported 8 students (sophomores and juniors) from colleges and universities other than PSU to participate in research training under the PSARC PIs for a 10 week period.

Graduate Education: A Dual-Title Ph.D. Degree Program in Astrobiology was inaugurated in August 2004 with a 10-day Astrobiology field trip to southern Canada for ~11 graduate students in this program. Currently, about 10 graduate students are in this program. The dual-title program is under the direction of Lee Kump.

Project Reports: Pennsylvania State University

Geochemical Processes and Biosignatures (House)

Project Investigator: Christopher House

Project Progress

For geochemical processes and biosignatures, Aubrey Zerkle made great progress in understanding trace metal limitation during nitrogen-fixation by cyanobacteria. This work has disproven the hypothesis by Anbar and Knoll (2002) that the Proterozoic ocean was limited by Mo, as well as discovered a novel negative _15N isotope signature for increased Fe-availability in the rock record. Also, Vyllinniskii Cameron made important efforts in understanding trace metal content and acquisition by hydrothermal microorganisms. The work has shown that these species probably do not release metal-binding ligands.

Undergraduate Chris Urban has shown that Barite is actively dissolved by sulfate-reducing bacteria, which may be an important sink for methane in deep sea sediments. Undergraduate student Jenny Vrentas has found that different vitamins act as controls on isotopic fractionation during methanogenesis. We are also moving forward with studies of microbial microcosms as models for the oceans through time, and efforts are currently geared towards understanding the transition from anoxygenic photosynthetic communities to oxygenic photosynthetic communities on early Earth.

In our efforts to link geochemistry with phylogenetics, Jen Biddle has made insights in the microbiology of deeply buried marine sediments in areas of anaerobic methane oxidation using FISH-SIMS and culturing techniques. Jim Moran has made further progress with efforts to develop a method for the capture and isotopic analysis of rRNA. Aubrey Zerkle has investigated the coevolution of microbial metal use and carbon isotope signatures with changing environmental conditions through time.

I have also made some progress redefining the Tree of Life by developing a method for building Prokaryotic trees based entirely on Gene Order. Additionally, we have created consensus phylogenetic trees based on the combined gene content of groups of individual prokaryotes.

Roadmap Objectives

- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems

Field Expeditions

Field Trip Name: Eel River Basin Methane Vent
Start Date: July 27, 2005 **End Date:** August 7, 2005
Continent: NORTH AMERICA **Country:** USA
State/Province: California **Nearest City/Town:** Monterey
Latitude: **Longitude:**
Name of site(cave, mine, e.g.): Eel River Basin in Pacific Ocean **Keywords:** Eel River Basin, methane vent
Description of Work: Collection of marine biological and sediment samples from submarine methane vent
Members Involved:

Evolution of atmospheric O2, climate, and biosphere - Ohmoto

Project Investigator: Hiroshi Ohmoto

Project Progress

Evolution of the Atmosphere, Oceans, and Biosphere on Early Earth: Geological, Geochemical, and Biological Approaches

Hiroshi Ohmoto, Yumiko Watanabe, Tsubasa Otake, David C. Bevacqua, Dennis Walizer, and Alice Klarke

Highlights of the Achievements in Year 7

1. The presence of mass-independent fractionation of sulfur isotopes (MIF-S) in some sedimentary rocks older than ~2.45 billion years (Gyr), and absence of MIF-S in sediments younger than ~2.32 Gyr, have been used to suggest a dramatic rise of atmospheric pO_2 from $<10^{-5}$ PAL (present atmospheric level) to $>10^{-5}$ PAL around 2.35 Gyr. However, during the course of geochemical investigations of deep drill core samples from the Archean Biosphere Drilling Project (ABDP), we have discovered the absence of MIF-S through a 63 m section of 2.76 Gyr lake sediments and through a 170 m section of ~2.92 Gyr marine shales in the Pilbara Craton, Western Australia. Based on these and other data, we suggest the following three possibilities to connect the evolutionary history of atmospheric O_2 to MIF-S: (I) The atmospheric pO_2 level greatly fluctuated during the Archaean era: from anoxic (before ~3.0 Gyr), to oxic (between ~3.0 and ~2.75 Gyr), to anoxic (between ~2.75 and ~2.45 Gyr), and to oxic (after 2.45 Gyr); (II) The atmosphere remained oxic since ~3.8 Gyr, and the MIF-S signatures represent periods when volcanic eruptions ejected large volumes of SO_2 to the stratosphere; or (III) The atmospheric pO_2 history was not linked to the geologic record of MIF-S. (I) and (II) are possible scenarios if the only mechanisms to create MIF-S in geologic samples are photochemical reactions of volcanic SO_2 by UV light in the absence of an ozone shield; (III) is possible if other mechanisms existed to create MIF-S in geologic samples. Future research should be directed to evaluate these possibilities (manuscript submitted to *Nature* by Ohmoto et al., June, 2005).

2. We have discovered abundant hematite (ferric oxide) crystals in a deep drill core (ABDP #1) of Archaean greenstones from the Pilbara Craton, Western Australia. The greenstones, which erupted mostly as basaltic lavas and tuffs on the seafloor ~3.46 Gyr ago, have emerged near the land surface several times since ~3.43 Gyr ago. We obtained a rhenium-osmium (Re-Os) isotopic age of 2.762 ± 0.016 Gyr for pyrite (iron sulfide) veinlets that clearly cross-cut (i.e., are younger than) the haematized greenstones. These data, together with mineralogical and geochemical data, suggest that reactions with O_2-rich ground-water formed the hematites before ~2.76 Gyr ago. Therefore, an oxygenated atmosphere most likely developed more than 400 million years before the currently accepted ~2.35 Gyr date (manuscript to be submitted to *Nature* by Kato et al., August, 2005).

3. We have discovered that the abundant micro crystals of hematite in the Marble Bar Chert in the ABDP #1 core most likely formed by the mixing of Fe^{2+}-rich submarine hydrothermal fluids with O_2-rich deep ocean water 3.46 Gyr: evidence for the early development of an oxygenated atmosphere (pO_2 > 40% PAL) (Ohmoto, et al., abstract for the Ann. Mtgs. of the American Geophysical Union, 2005).

4. An alteration zone with strong enrichment of Al and depletion of Fe is developed underneath the oldest unconformity (3.4 Gyr land surface) over a very large area (>100, 000 km^2) in the North Pole area of the Pilbara Craton, Western Australia. This alteration zone has previously been interpreted by some Australian geologists as the products of submarine hydrothermal alteration. During the field work in July, 2005, Watanabe and Ohmoto discovered a strong possibility that this alteration zone represents an extensive lateritic soil (characterized by hematite-rich zone that is sandwiched by Fe-depleted soil zones). Since the development of a lateritic soil requires organic acids and an O_2-rich atmosphere, our discovery strongly suggests that the terrestrial biosphere and an oxygenated atmosphere had developed by 3.4 Gyr.

Figure 1. Ohmoto Group in Pilbara, Australia

Figure 2. Pilbara Landscape, Western Australia

Figure 3. 2.76Ga Stromatolite in Pilbara, Australia

Roadmap Objectives

- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems

Field Expeditions

Field Trip Name: Eastern Pilbara, Australia
Start Date: June 29, 2005 **End Date:** July 8, 2005
Continent: AUSTRALIA **Country:** Australia
State/Province: Western Australia **Nearest City/Town:** Port Hedland
Latitude: 21 - 22° S **Longitude:** 119-120° E
Name of site(cave, mine, e.g.): Drilling sites (ABDP#1, #3, #4, #5, and #10), and outcrops of Archean sedimentary rocks and paleosols in Pilbara Craton.
Keywords: stromatolite, jasper, paleosol, Pilbara
Description of Work: To increase understanding of the geological setting and hematized mechanisms of the targeted sedimentary units of ABDP (Archean Biosphere Drilling Project), Ohmoto and Watanabe visited several localities of the drilling sites and outcrops of Archean sedimentary rocks. The most exciting discovery was the oldest probable paleolaterite developed underneath the 3.43 Ga Strelley Chert. (Add figure 1, figure 2, figure 3.)
Members Involved:

Field Trip Name: Hamersley & Pilbara, Australia
Start Date: 7/15/2004 **End Date:** 8/9/2004
Continent: Australia **Country:** Australia
State/Province: Western Australia **Nearest City/Town:** Port Hedland
Latitude: 21-25° S **Longitude:** 114-120°E
Name of site(cave, mine, e.g.):

Drilling sites (ABDP#1, #2, #3, #5, #4 & #10), outcrops of Archean BIFs and sedimentary rocks in the Hamersley-Pilbara area, an

Keywords: BIF, stromatolite, Pilbara, Hamersley

Description of Work: To increase understanding of the formation mechanisms of BIFs (Banded Iron Formations), Ohmoto and Otake visited several localities of BIFs in the Hamersley Basin. We visited #8 ABDP drilling site and several localities of the 2003 drilling sites in the Pilbara Craton. They also visited the GSWA core storage in Perth.

Members Involved:

Evolution of a Habitable Planet (Arthur)

Project Investigator: Michael Arthur

Project Progress

Research for the Michael A. Arthur Group

Graduate Students: *Anthony Riccardi* (co-advised with L. R. Kump), *Jamey Fulton* (co-advised with K. Freeman) and *Chris Junium*; Associates and Collaborators: *Matt Hurtgen* and *Galen Halverson* (Harvard Univ.), *Lee R. Kump, Alexander Pavlov* (U. Colorado), *Erik Cordes* (PSU/Harvard, Biosciences)

Our focus has been the chemistry of and biogeochemical cycling in the Proterozoic Ocean (Namibia, S. Australia, Great Basin U.S.) and in modern euxinic basin analogs (Black Sea, Fayetteville-Green Lake).

At present it is not known what sustains organic-carbon burial for long-lasting black shale depositional events. In many cases black shales are characterized by orgC/Ptot and orgC/Ntot ratios much higher than Redfield stoichiometry. This suggests preferential release of phosphate and nitrogen from particles in the water column or during early diagenesis as a result of anaerobic degradation of organic matter and reduction of metal oxide particles. Recent research suggests that a substantial proportion of what has typically been considered “organic P” is sorbed to metal oxide coatings on cell walls and, therefore, is easily liberated in dysaerobic to anaerobic conditions. Such rapid recycling of P, in particular, could be a strong positive feedback to productivity in surface waters of anoxic basins. However, availability of N is limited because of N consumption during denitrification or annamox reactions in the shallow chemocline of anoxic basins. Thus, without further addition of N, productivity is limited. However, N isotope and limited biomarker data from some black shales seems to indicate that N fixation becomes a dominant mode of organic matter production because of the enhanced P availability and N limitation. However, we are also examining N cycling within euxinic basins (Black Sea and Fayetteville-Green Lake) and the possibility of direct utilization of ammonia as an explanation for ^{15}N-depleted signatures in organic matter. Fulton and Junium are preparing manuscripts now on nitrogen cycling in the Holocene Black Sea and nitrogen isotopic signatures of Oceanic Anoxic Events, respectively. Junium is pursuing the sedimentology and geochemistry of the Proterozoic Chuar group in this regard. With Kate Freeman we have begun to develop methods for direct analysis of geoporphyrin compounds as a tool to examine possible organism-specific signals as well as to avoid possible diagenetic overprints in ancient sediments.

We have also been examining sulfur cycling in modern and ancient euxinic basins. With Matt Hurtgen and other collaborators (Hurtgen et al., 2004; 2005) we have examined the possibility that the largely euxinic Neoproterozoic ocean was relatively sulfate depleted and that “Snowball Earth” events may have been triggered by sulfate depletion. In addition, we (Kump, Pavlov, and Arthur, 2005) have proposed that CUE (chemocline upward excursion) events may release toxic amounts of sulfide causing extinctions, for example associated with the Permo-Triassic Boundary (PTB). Tony Riccardi is studying PTB sequences in China and Turkey to test this hypothesis.

As an interesting aside we have studied sulfur cycling by tubeworms associated with Gulf of Mexico “cold seeps” and have hypothesized that a sulfide-oxidation - sulfate-recycling loop to the “roots” of tubeworm aggregations coupled with hydrocarbons supplied at seeps fuels continuous bacterial sulfate reduction in sediments and allows rapid and prolonged growth of tubeworm colonies (Cordes et al., 2005).

Roadmap Objectives

- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems

Cross Team Collaborations

University of Colorado, Alexander Pavlov: published paper (Kump, Pavlov, Arthur) on the possible effects of sulfide poisoning created by "chemocline upward excursions" in journal Geology, 2005, as an explanation of Permian/Triassic boundary extinctions. Harvard University, Matthew Hurtgen and Galen Halverson: published paper on sulfur cycling and disporportionation in the Proterozoic based on sulfur isotope data from Australia, Namibia and the U.S., in journal Geology, 2005.

Prebiotic Synthesis: Experimental Studies (Schoonen)

Project Investigator: Martin Schoonen

Project Progress

Using reaction path modeling we have been able to place important constraints on the formation of secondary minerals often viewed as having catalytic potential. The results of the work indicate that the composition of the secondary mineral assemblage is predominantly controlled by the degree mass transfer with the atmosphere is allowed. Weathering reactions proceeding with unimpeded transfer between the hydrosphere and atmosphere leads to a mineral assemblage dominated by simple binary minerals. By contrast, when weathering reactions proceed without exchange with the atmosphere, complex secondary minerals, such as zeolites are formed. In addition, these restricted environments become very reducing and alkaline—conditions favorable for the stabilization of metal alloys. These results indicate that systems with restricted exchange with the atmosphere (e.g., cracks in the ocean floor) may have more catalytic potential than systems open to the atmosphere.

In this year we have started to use a molecular modeling package (Gaussian 03) to evaluate the energetics and kinetics of Fe(II) mediated reduction of dinitrogen and the photochemical reduction of dintrogen with Fe (II) as the electron donor. The results of these calculations, in collaboration with Dr. James Kubicki at Penn State, have guided the design of experiments that are now underway. Integration of theoretical and experimental studies is an important step in more efficiently studying the vast array of reactions that are of interest to researchers in the field of prebiotic chemistry.

Roadmap Objectives

- **Objective No. 3.1:** Sources of prebiotic materials and catalysts

Isotope effects in atmospheric sulfur chemistry (Castleman)

Project Investigator: Albert Castleman

Project Progress

Studies are underway to elucidate the influence of oxidation reactions, and subsequent photolysis on the evolving isotope composition of sulfur compounds that pertain to questions of the origin of the earth's early atmosphere. We continued our development of a detector system for our femtosecond-laser-based time-of-flight mass spectrometer system that will overcome conventional difficulties encountered in making such measurements. The objective is to enable the study of individual isotopes without the need for "spiking" ones of small abundance, which is fraught with difficulties due to acquiring accurate and uniform mixtures. We have constructed a more sensitive detection system to better analyze minor isotopes embedded along with others of proximate mass having much greater abundance. This system is undergoing extensive testing and evaluation, with the objective of learning about effects in the ensuing chemistry of sulfur compounds that give rise to mass independent ratios.

Recent experiments conducted in our laboratory have shown that heavier isotopes of sulfur can undergo different temporal dynamics in a dissociative process than the light isotopes. Dissociative processes of SO_2, photo-excited through intermediate states with conical intersections have been found to display unexpected behavior on isotope mass. Photo-ionization studies of SO_2 and SO_2 clusters also have been performed to assess what effects ionic state dissociation has on the relative ratios of the various sulfur isotopes. Covariance mapping is being employed to identify the dissociative paths and sequential order of the reaction pathways being observed. These experiments give us reactant/product information that allows for comparison of individual species in the mass spectra to all other species present. Dynamics experiments are also performed as a complement to the photo-ionization investigations. These experiments allow us to track reactants and products on a femtosecond time scale, thus addressing the temporal behavior of the reactions in comparison to the respective isotopes.

Roadmap Objectives

- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 4.1:** Earth's early biosphere

Evolution of a habitable planet (Capo)

Project Investigator: Rosemary Capo

Project Progress

Our work currently involves two main areas:

(1) Understanding the evolution of ancient soil profiles (paleosols) and their record of Earth's early atmosphere and climate:

We have examined core and outcrop samples from two Paleoproterozoic weathering profiles developed on granodiorite in the Hokkalampi area of Finland. Analyses by Ph.D. student Sherry Stafford suggests that pedogenic REE fractionation, including development of Ce anomalies, took place about 2.35 Ga ago, coincident with the "Great Oxidation Event." The Rb-Sr system records metamorphism around 1.8 Ga ago. Geochemistry and morphology of the Nuutilanvaara profile suggests formation under unsaturated, oxidized conditions; Fe and LREE depletions from the Paukkajanvaara profile suggest formation in a saturated zone. Soil textures in the Archean South Roberts Pit profile, Steep Rock region, Canada include intertexic and agglomeroplasmic fabric and cutans; rip up clasts and soft sediment deformation features are present near the unconformity. Geochemistry and Rb-Sr systematics for the profile suggest K-metasomatism occurred during greenschist metamorphism at 2.7 Ga. However, the Sm-Nd systematics yield a relatively precise age of 3.0 Ga, and document the preservation of Archean pedogenic REE fractionation.

(2) Investigations of sedimentary pyrite oxidation.

Current studies center on massive and framboidal sedimentary iron sulfides and siderite within Paleozoic coal seams and associated shale units. M.S. student Amy Wolfe developed methods for separating finely disseminated pyrite from coal and organic-rich underclay. A portion of this investigation involves NSF-supported experimental determination of Fe isotope fractionation associated with pyrite oxidation, in collaboration with Dr. David Dzombak of Carnegie Mellon University. Because preparation methods can significantly affect dissolution rates, part of this effort involved development of methods for reproducibly obtaining a restricted grain size distribution for dissolution experiments. Related work includes sequential extraction experiments to assess trace metal provenance on goethite derived from pyrite oxidation (Kairies et al., in press).

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems

Evolution of a Habitable Planet (Stewart)

Project Investigator: Brian Stewart

Project Progress

Paleosols. The Sm-Nd system has proven to be a useful chronological tool for pedogenesis in some Precambrian weathering profiles where the ages of weathering are poorly constrained, and the system can provide insight into the robustness of the REE system in the face of post-pedogenic metamorphism and alteration. Dissertation work of Sherry Stafford shows that the Sm-Nd system can record (or see through) pedogenesis in some cases, while the Rb-Sr system is sensitive to subsequent metamorphic events. However, recent results from the ultramafic Kalkkloof paleosol, S. Africa (Masters project of Katherine Walden) demonstrate that the REE can be highly mobile well after pedogenesis. This could be a general characteristic of mafic and ultramafic paleosols.

Archean Biosphere Drilling Project (ABDP): Work was initiated on Fe-bearing cherts and basalt flows from the 3.46 Ga Marble Bar greenstone belt. Results from the first samples of chert yield positive initial epsilon-Nd values, consistent with derivation of the REE from submarine hydrothermal sources. However, this is somewhat at odds with the LREE-enrichment exhibited by these samples, which suggests possible REE fractionation when the chert was precipitated. Additional work will focus on the basalt flows and microbands within the chert units.

Modern Soil Analogs: The Atacama Desert of northern Chile is one of the driest, least vegetated regions on Earth outside of Antarctica, thus making it a useful analog for both Mars and the early Earth. We are collaborating with R. Amundson and his colleagues at UC Berkeley to examine the provenance of nitrate, sulfate and carbonate that have accumulated in the Atacama soils over millions of years. Initial Sr isotope work suggests a largely lithogenic sulfate source, but with greater marine influence toward the surface. Current work is focusing on sources of Ca in both sulfate and carbonate minerals in multiple profiles.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems

Examinations of the Microbial Diversity found in Ice Cores

Project Investigator: Jean Brenchley

Project Progress

Our research focuses on psychrophilic (cold-loving) microorganisms and their cold-active enzymes. This includes the analysis of psychrophiles from cold environments including the subseafloor, Antarctica, lakes, and cold soils. One project designed for PSARC investigates microorganisms deposited over 100,000 years ago in the basal portion of a Greenland glacier (GISP2) ice core. Research with this ice core serves as a model for severe conditions, such as cold temperatures, nutrient and oxygen limitations, desiccation, pressure, etc. that could exist extraterrestrially. Our current PSARC goals include: Determining microbial diversity in the ice core, 2) Examining the ultra-small cells and their viability and 3) Testing factors that affect the survival and culturability of the ice core microbes.

Our investigation demonstrated the presence of an abundant viable (10^7 cells/ml) microbial population trapped in the ice core and the existence of many ultra-small cells. Dr. Miteva examined ultra-small cells in cultures inoculated with samples repeatedly filtered to exclude larger cells and demonstrated that many pass through filters with pore sizes as small as 0.2, and even 0.1, microns. Growth studies demonstrated that some isolates retain their small cell size throughout their growth cycles in different media suggesting that they are intrinsically small. Phylogenetic comparisons of the 16S rRNA gene sequences showed a wide diversity of bacterial isolates including some that may represent new genera and species. Our results show that numerous viable ultra-small cells are present in the ice core sample and that filtration and long-term incubations significantly increase the number and diversity of colonies. The ultra-small cells compose a large fraction of the uncultivated microorganisms in many environments, and thus, our results are relevant to other studies where samples were filtered and only the cells trapped on filters examined or where short incubations were used to recover colonies.

Roadmap Objectives

- **Objective No. 2.1:** Mars exploration
- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth

Genomic Record of the Earth's Early Biosphere

Project Investigator: S. Blair Hedges

Project Progress

Our research involves molecular clocks and phylogenetics to better understand the relationship between planetary history and the evolution of life. We made progress in theoretical and empirical studies during the past year. In the former area we developed a method for phylogenetic analysis of complete genome sequences, for use with either prokaryotes or eukaryotes (Blair, Shah, & Hedges, 2005; BMC Bioinformatics 4:53). The method makes use of a conservative criterion (single copy genes) for determining gene orthology, which is a major issue in the field (evolutionary genomics). The procedure is fully automated, which greatly increases the speed at which complete genomes can be analyzed, while still making use of a large number (>1000 in some cases) of genes. In another paper, we presented an analysis of complete prokaryote genomes and better constraints on the origin of organisms producing metabolic products that influenced the history of the biosphere (Battistuzzi & Hedges, 2004; BMC Evol. Biol. 4:44). We found that some divergences occurred before 4 billion years ago, indicating an early origin of life on Earth. We also found an early origin of methanogenesis and phototrophy, but a “late” origin (<3Ga) of oxygenic photosynthesis. In another study (Blair & Hedges, 2005; Mol. Biol. Evol. 22:387-390) we critiqued two recent molecular clock studies by other laboratories bearing on the Cambrian Explosion of animal phyla and concluded that methodological problems in their analyses resulted in biased time estimates. A fourth paper reporting divergence times and phylogeny of deuterostomes (Blair & Hedges, 2005; Mol. Biol. Evol.) has been accepted and is in press.

Roadmap Objectives

- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.2:** Foundations of complex life

Lee Kump

Project Investigator: Lee Kump

Project Progress

This year we published a paper in Geology which proposed that episodic release of hydrogen sulfide (H_2S) from the ocean caused the end-Permian mass extinction. Moreover, we suggested that the underlying environmental driver, euxinic deep waters (enriched in H_2S), may have been the norm during a billion years of Earth history (from 1.8 Ga to 0.8 Ga), and that H_2S eruptions may have delayed colonization of the land surface.

Our work at Fayetteville Green Lake, NY continues, in collaboration with Kate Freeman (PSU), Chris House (PSU) and Michael Arthur (PSU). This is a meromictic lake with a sulfidic monimolimnion and a chemocline at ~20m water depth that supports a S-based phototrophic community dominated by purple sulfur bacteria (Figure 1), benthic carbonate buildups produced by cyanobacteria (Figure 2), and sulfidic seeps colonized by chemoautotrophic sulfur-oxidizing bacteria (Figure 3). We are studying this lake as an analog Proterozoic ocean ecosystem. Coring sediments across the chemocline has revealed a signature that may prove to be diagnostic of the intersection of a chemocline with bottom sediments. If so, we will have a tool to explore shifts in chemoclines in ancient rocks, including the shift to the air-sea interface we propose for the Permian event.

We are also collaborating with Greg Retallack (U. Oregon) and Shuhei Ono (Carnegie Institute) on a study of unusual S enrichments in Proterozoic and Late Permian paleosols. Such enrichments would be expected if H_2S did indeed erupt into the atmosphere during times when the deep sea was euxinic.

Another publication addressed the nature of hydrothermal fluid emissions during the Precambrain. This work, in collaboration with Bill Seyfried (U. MN) explored the consequences of low seawater sulfate concentrations and possibly shallower ridge depths for midocean ridge fluid compositions (Kump and Seyfried, 2005). In short, vent fluids were likely Fe and H_2-rich and S poor during the Precambrian. We discuss implications for Precambrian banded-iron deposition and vent community metabolism.

Kump also traveled to Arctic Russia to conduct field research on the Archean-Proterozoic transition, in collaboration with Victor Melezhik and others. This collaboration has already led to a manuscript submitted to GSA Today and funding for a International Continental Drilling Program workshop to develop a drilling proposal.

Kump and master's student Ellen Herman have a paper in press in Geobiology that describes a numerical model of a microbial mat and its sensitivity to changing overlying water conditions. In particular, we investigate how the biogeochemistry of a mat responds to changes in the sulfate and oxygen concentration of the overlying water (relevant to the behavior of microbial mats during the Precambrian.

Figure 1. Collaborator Dale Holen (PSU) displays water samples collected within the chemocline at Fayetteville Green Lake, NY. The pink coloration reflects the abundance of purple phototrophic sulfur bacteria.

Figure 2. Thrombolitic carbonate buildup produced by cyanobacteria at Fayetteville Green Lake, NY. Encrusted log is approximately 30cm in diameter.

Figure 3. Groundwater seep, presumably sulfidic, discharging into oxidized upper lake (mixolimnion) and supporting the growth of chemoautotrophic sulfur oxidizing bacteria (the white "veil"). Photograph is approximately 10cm wide.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.3:** Effects of extraterrestrial events upon the biosphere
- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems

Field Expeditions

Field Trip Name: Fayetteville Green Lake as a Proterozoic Ocean Analogue

Start Date: Ongoing

End Date: ongoing

Continent: North America

Country: USA

State/Province: NY

Nearest City/Town: Fayetteville

Latitude: 43°03.055'

Longitude: 75°57.946'

Name of site(cave, mine, e.g.): Fayetteville Green Lake (Green Lakes State Park)

Keywords: meromictic; hydrogen sulfide; sulfur bacteria; photoautotrophs; stromatolites; cyanobacteria; chemocline; whiting

Description of Work: Ongoing investigation of the chemical, physical, and biological interactions within this microbially dominated aquatic ecosystem. This stratified lake supports a diverse anaerobic ecosystem in its chemocline. The oxic surface waters promote biocalcification in the water column and the formation of "stromatolites" on the lake margins.

Members Involved:

Cross Team Collaborations

We have been pursuing an informal and incipient collaboration with the University of Washington team led by Peter Ward, focused on the interpretation of extreme variations in the carbon isotopic composition of the ocean during biotic turnover events.

Modeling early atmospheric composition and climate

Project Investigator: James Kasting

Project Progress

Pushker Kharecha, James Kasting, and Janet Siefert have written a paper, currently submitted to *Geobiology*, that describes a coupled model of the anaerobic, early Archean biosphere, prior to the origin of oxygenic photosynthesis. The model includes organisms that metabolize using H_2, H_2S, and Fe^{++} as reductants. A primary goal was to estimate the production rate of methane. We find that for reasonable assumptions about hydrogen outgassing rates and the hydrogen escape rate to space, CH_4 production should have been within a factor of 3 of the modern value, ~500 Tg CH_4/yr. In the low-O_2 Archean atmosphere, this would have been enough to produce CH_4 concentrations of 1000 ppmv, or higher if the escape rate was slower than assumed. Such CH_4 concentrations could have made a major contribution to Earth's greenhouse effect, helping to keep the climate warm despite reduced solar luminosity at that time. Prior to the origin of anoxygenic photosynthesis, primary production by H_2-using methanogens could have produced extremely high CH_4 concentrations, several percent or more. Greenhouse warming might then have produced a hot early Earth, ~70°C, perhaps explaining the observed predominance of hyperthermophiles near the base of the rRNA tree.

More recently, a graduate student, Irene Schneider, and an undergraduate, Patrick Kasting, have derived a new set of near-IR absorption coefficients for CH_4. This should allow us to improve our estimates of the greenhouse effect of CH_4-rich atmospheres.

Also, climate modeler David Pollard and I have a paper in press in JGR concerning Snowball Earth. In it, we argue that "thin-ice" solutions like the ones proposed by Chris McKay in GRL (2000) are plausible, even likely, in the tropics. This may explain how photosynthetic algae and other light-dependent organisms survived the Neoproterozoic glaciations.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 4.1:** Earth's early biosphere

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
0	TPF-C	Science Team Member

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

I?m co-chair of the TPF-C Science and Technology Definition Team. Our work on CH4-rich early atmospheres may eventually be applicable to interpreting spectroscopic results from TPF-C.

Cross Team Collaborations

All of our work is carried out in collaboration with Vikki Meadows? NAI team at Caltech/JPL. I am a member

of that team as well. In separate efforts with that group (not described here), we have modeled Earth-like planets around F, G, K, and now M stars, and calculated what they might look like spectroscopically to TPF-C or TPF-I.

Feng Tian, from the Colorado NAI group, will be joining our group within the coming year. He will be working on hydrodynamic escape of hydrogen from planetary atmospheres and on other aspects of planetary habitability.

Searching for planets around evolved stars

Project Investigator: Alexander Wolszczan

Project Progress

During the period covered in this report, we have continued a search for planets around K-giants with the Hobby-Eberly Telescope (HET). Collaborators in this research are Drs. M. Konacki (Caltech) and A. Niedzielski (Toru_ Centre for Astronomy, Poland). Detection and studies of planets around post-main sequence stars provide information on planet formation and survival around massive stars and represent an important extension of the ongoing planet searches around Sun-like stars. They also probe the dynamical evolution of old planetary systems driven by changes in their parent stars as they leave the main sequence.

So far, we have collected multiple epoch observations for 41 stars out of the ~400 targets on our observing list. Further scrutiny has revealed at least two stars that may have giant planets around them. In fact, one of these stars is almost certain to have a ~8 Jupiter mass companion in a 2 A.U., ~500 day orbit. If confirmed by further observations, this will be the first planet detected by our survey. Furthermore, in our continuing quest to improve the precision of radial velocity measurements with the HET, we have achieved a ~5 m/s precision and are on our way to improve it even more. The survey itself and its first results have been reported at two international conferences in Berlin, Germany, and Syros, Greece.

Roadmap Objectives

- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
1	SIM	Co-Investigator

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Part of stars selected for our survey come from the SIM/EpicS reference star candidate list.

The Evolution of a Habitable Planet (Sigurdsson)

Project Investigator: Steinn Sigurdsson

Project Progress

HST imaging search completed, all data analysed. Followup observations using Gemini, CFHT and NOT completed. HST followup on one candidate approved for next cycle. Spitzer observations completed, data being analysed. First two papers on data analysis and candidate detections and upper limits in press with Astrophysical Journal and Astronomical Journal respectively.

Modeling of migrating planets and Kozai pumping of orbital eccentricity in progress. Paper on orbital eccentricity perturbations in preparation. Results presented at multiple meetings and conferences.

John Debes received PhD, thesis on planet imaging search. Moving to Carnegie Institute for postdoc (NAI site). Avi Mandell going to GSFC (NAI site) for co-op research for his PhD thesis.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
0	HST	
0	SST	

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Guest Observer

Cross Team Collaborations

Initiated a collaboration with Dr M. Mumma at LEP, GSFC. Student A. Mandell will do co-operative research at GSFC starting 2005, to work on observational techniques for detecting extra-solar planets.

Oxygen Adaptation in the Anaerobic Methanogenic Archaeon Methanosarcina acetivorans

NAI-NRC Postdoctoral Fellow : Daniel Lessner

Project Progress

Many prokaryotes classified as strict anaerobes, such as methanogens, have been shown to tolerate exposure to oxygen and reactive oxygen species. We have chosen *Methanosarcina acetivorans* as a model organism to elucidate the oxidative stress response in methanogenic Archaea. The complete genome of *M. acetivorans* has recently been sequenced and a survey of the genome revealed many potential oxidative stress related genes. Of interest is the MA4664-MA3743 gene cluster that encodes homologs of well-characterized oxidative stress proteins, including superoxide reductase (MA3737) and rubredoxin:oxygen oxidoreductase (MA3743). The remaining eight genes are predicted to encode proteins with unknown functions. MA3736 contains a CXXC motif similar to the active site of alkylperoxide reductase (AhpD) from *Mycobacterium tuberculosis*. AhpD functions primarily as a disulfide reductase, catalyzing the reduction of the oxidized alkylperoxide reductase, AhpC, which is the site of peroxide reduction. To begin to understand the function of MA3736 the recombinant protein was purified to homogeneity from *Eschericia coli*. MA3736 showed no detectable peroxide reductase activity, but clearly demonstrated *in vitro* disulfide reductase activity. Unlike AhpD, MA3736 contains two additional cysteine residues. Site-directed mutagenesis was used to generate variants of MA3736 and demonstrated the CXXC cysteines are responsible for disulfide reductase activity similar to AhpD. Additional analysis of MA3736 and variants revealed the presence of a putative metal cofactor. Iron-sulfur reconstitution and spectroscopic techniques yielded results consistent with the presence of an iron-sulfur center. These results suggest MA3736 may function as a novel disulfide reductase consistent with a role in the oxidative stress response of *M. acetivorans.*

I have also been involved in the characterization of the pathway for acetate conversion to methane in the marine isolate *M. acetivorans*. These results revealed profound differences in electron transport and energy conservation strategies during growth with acetate between marine and freshwater *Methanosarcina* species. An understanding of the basic physiology of *M. acetivorans* provides a foundation to better understand the effect of and response to environmental stressors such as oxygen.

Roadmap Objectives

- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems

EPO Reports: Pennsylvania State University

Evolution of a Planetary System: Exploring Our Origins (Educator Workshop)

Seventeen teachers participated in this five-day, 2-graduate credit Astrobiology workshop designed to expose middle and high school science teachers to the latest research related to the age and origin of the Universe, the Earth and life, and to engage teachers in activities that they could take back to their classroom. Participants in the workshop learned how the evolution of our universe, galaxies, and planetary systems are related, and they tracked their journey through history by creating a wall-sized timeline of the universe. Additional activities included a field trip to investigate how layered terrain provides information about Earth's history and the creation a model comet. Teachers viewed Mars in 3-D with the new Penn State GeoWall technology, part of the College of Earth and Mineral Sciences museum. Pamela Harman of the SETI Institute, facilitated activities taken from the SETI Institute's Voyages Through Time curriculum.

The lead instructor for the course was Darren Williams, associate professor of physics and astronomy, Penn State Erie. Scientists led discussions on how the Universe came to be, how planets form around stars, and how biospheres suitable for life are formed and maintained on some planets. Additional topics included cosmology, comparative planetology, Earth history, evolution of life, and extrasolar planets. Educators received posters, lithographs, CDs, and other resources for their classroom. Activities from NASA and the NASA Astrobiology Institute were featured. Pamela Harman of the SETI Institute, facilitated activities taken from the SETI Institute?s Voyages Through Time curriculum

The Penn State Astrobiology Research Center, the NASA Astrobiology Institute, and the Pennsylvania Space Grant Consortium provided funding for the workshop. Housing, meals and partial travel support were provided. Fifteen teachers were awarded tuition subsidies. The workshop was approved by the Pennsylvania Department of Education for Act 48 Professional Development credit.

The workshop evaluation included a summative professional development questionnaire developed by the Horizon Research, Inc. and a focus group discussion. The evaluation techniques were intended to measure the effectiveness of workshop design for increasing teacher content knowledge and improving student learning in the middle and secondary classroom.

Teachers building a model to detect planets around a star.

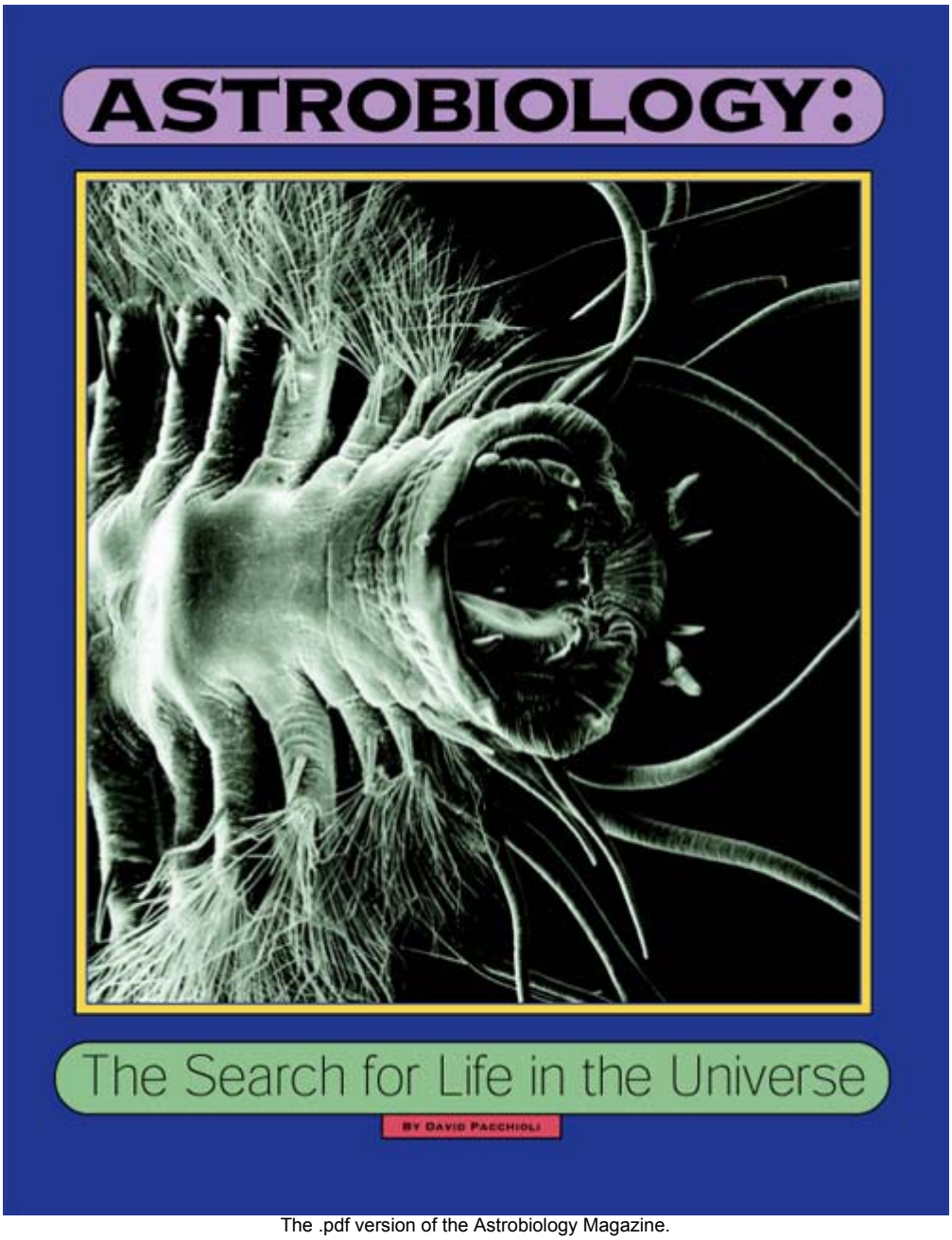
More teachers buidling a model to detect planets around a star.

Melba Martin, 6-12 grade teacher from Navajo Reservation in Arizono, finding and identifying fossils from the Ordovician Period during field trip.

James Bonelli, Penn State graduate student, describing fossil identification techniques to Margaret Vigneullle, teacher from Washington, D.C.

Astrobiology: The Search for Life in the Universe (Magazine)

This color publication provides an overview of the field of Astrobiology written at the high school level. The piece was originally published by Research Penn State magazine in their January 2001 issue and is based on a lecture series that was held at Penn State University in January 2000. The lecture series and the magazine supplement features NASA Astrobiology Institute scientists from Penn State University, The University of Colorado, and Harvard University as well as researchers from the SETI Institute and Rice University. The Penn State Astrobiology Research Center and Pfizer, Inc provided funding for the publication. The Pennsylvania Space Grant Consortium is distributing the publication to interested educators, students, researchers and others across the country and internationally. The final copies of the publication were distributed this year: 90 to the University of Tennessee and 60 to educators in Pennsylvania. PDF and web versions are still available: http://www.psu.edu/spacegrant/astrobiology/



The .pdf version of the Astrobiology Magazine.

Astrobiology public lectures, short courses, and websites- Penn State Astrobiology Research Center

The Penn State Astrobiology Research Center (PSARC) team gave a number of lectures for the general public and civic groups. Some of this year's presentations were as follows: Dr. Jim Kasting: "Climate and Life on the Early Earth" (University of Western Ontario public seminar, Fall 2004); Dr. Jean Brenchley presented "Astrobiology: The small, cold, and hungry ultra-small microbes from a 120,000 year old Greenland glacier ice sample" at the Fellowships in Mathematics and Science program for school teachers held at NASA Goddard Space Fight Center on August 2-4, 2005 ; and Julie Maresca 1) helped organize BioDays, an outreach event focusing on life science and microbes, on April 2, 2005 at Penn State and 2) gave a talk about her research at the University of Delaware.The Penn State Astrobiology Research Center hosts a website located at http://psarc.geosc.psu.edu/

Astrobiology Undergraduate Minor

Undergraduate students at Penn State can participate in the Astrobiology Undergraduate Minor, which is

designed to educate students in the varied scientific disciplines that contribute to our general understanding of life, the origin of life, the past history of life on Earth, possible futures for life on Earth, and the possible existence of life on other planetary environments. The principal goal of the minor is to develop students literacy in astrobiology so that they can critically evaluate claims related to this field. Dr. Jenn Macalady, PSARC co-investigator, manages the program.

Over 1500 students per year are enrolled in the following Astrobiology-related courses: Earth 002 (Gaia-Earth System), Geosc 021(Earth & Life), Astro 140 (Life in Universe), Astro 475W (Stars & Galaxies), Geosc 204 (Geo-Biology), Biol 427(Evolution), Geosc /Biol 474 (Astrobiology), Micrb 201 (Intro Microbiology), Astro 291 (Solar System), Geosc 416 (Intro to Isotopes), Geosc 419 (Organic Geochemistry of Natural Waters and Sediments), BmB 401/402 (General Biochemistry), Biol 405 (Molecular Evolution).

PSARC also supports an undergraduate student research program for students who are enrolled in the Astrobiology Minor, have taken undergraduate Astrobiology classes, or have expressed particular interest in Astrobiology. Students from this program also often participate in the yearly Penn State Undergraduate Research Poster Session.

Dual Title Ph.D. Program in Astrobiology

Graduate students at Penn State are able to obtain a dual-titled Ph.D. in their primary field of endeavor and Astrobiology. The program enables students from several graduate programs to gain the perspectives, techniques, and methodologies of Astrobiology, while maintaining a close association with primary program areas of application. The program is chaired by Lee Kump (co-investigator) and administered by the Department of Geosciences. Five other Penn State Astrobiology Research Center (PSARC) co-investigators serve on its program faculty. Students take three core courses (Planetary Habitability, Astrobiology Field Experience and Astrobiology Seminar), a fourth course outside of their primary area of relevance to astrobiology, and must incorporate astrobiology into their candidacy and comprehensive examinations and their dissertation research. PSARC faculty teach all of the Astrobiology courses, and help fund the field experience and seminar classes. There are currently 9 graduate students pursuing the dual-title Ph.D. in Astrobiology.

Space Day 2005 at Penn State

PSARC research was featured again this year in the annual Space Day at Penn State public outreach event. During Space Day at Penn State, scientists, engineers, and students from across the university share presentations and hands on activities with over 1500 adults and children as they explore Earth, air, and space research at Penn State. Jen Biddle and Alice Klarke led a team of PSARC scientists and students that facilitated exhibits on extreme life, Early Earth, the history of the universe, geologic time and ancient rocks, and collaborated with students from the science education program at Penn State to develop engaging activities for visitors. Dr. James Kasting, PSARC Co-PI, gave a public lecture entitled "Water and Climate on Early Mars: An Update from the Mars Exploration Rover Mission". Dr. Ann Schmiedekamp, NASA Solar System Ambassador, gave a talk entitled "Ringside Seat at Saturn: A NASA Cassini-Huygens Mission Update" and led a K-4 grade workshop entitled "Calling all young artists! Make a model of Saturn."

The Pennsylvania Space Grant Consortium sponsors space Day at Penn State. The website is http://www.psu.edu/spacegrant/spaceday/

PSARC exhibit at Space Day at Penn State

PSARC exhibit at Space Day at Penn State

The Astrobiology Summer Program (ASP)

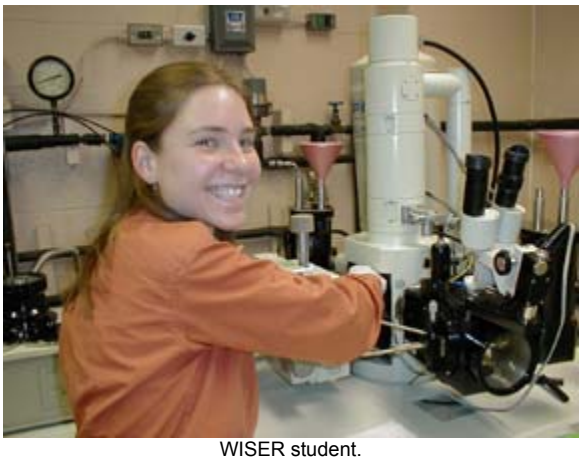
The Astrobiology Summer Program is an undergraduate summer training program in astrobiology that was established at Penn State with the help of a 3-year National Science Foundation REU-Site award (S. Blair Hedges, PI). In summer 2005, ten students from colleges and universities across the U.S. participated in research training under the guidance of PSARC faculty mentors, field trips, weekly seminars, laboratory tours, stargazing, discussion groups, and a research symposium. Women and minorities were encouraged to apply. The program has a director (Dr. Blair Hedges) and a coordinator (Dr. Carla Hass). Six PSARC faculty hosted students during the 2005 summer. The students presented the results of their work as an oral presentation during a symposium during the last week in the program.

Penn State's Astrobiology Summer Program (ASP) was hosted by the NAI team at NASA Goddard Space Flight Center on June 28th for a mini-symposium, lunch, and tour of research facilities. Marla Moore of the Goddard NAI team organized the event. There, the five undergraduate participants in Goddard's Summer Undergraduate Internship in Astrobiology (SUIA) program met the ten ASP students, and three undergraduates from the University of Puerto Rico in another Penn State program, "Life on the Rocks" (LOR). NAI participants included Marla Moore, Drake Deming, Danny Glavin, and Paul Cooper of the Goddard team and Michael Arthur and Blair Hedges of the Penn State team. Also present to help coordinate were Carla Hass and Fabia Battistuzzi from Penn State.

Funding for Penn State Astrobiology Summer Program is from the National Science Foundation (Research Experiences for Undergraduates Sites). The Astrobiology Summer Program webiste is http://evo.bio.psu.edu/asp/

Women in Science and Engineering Research (WISER) program

Faculty members from the Penn State Astrobiology Research Center (PSARC) participate in this two-semester research internship program, which is sponsored by the Pennsylvania Space Grant Consortium. The program is designed to retain women students in the science and engineering fields by providing first-year students invaluable experience and mentoring at the critical early stages of their undergraduate career. Students begin their research in the spring semester and continue during either the subsequent summer or fall semester. Since the program began in 1994, over 430 women students have been hosted by over 80 faculty members from all of the science and engineering colleges at Penn State. In 2004-2005, Dr. Blair Hedges, PSARC co-investigator, hosted a student. The WISER website is http://www.psu.edu/spacegrant/wiser/



WISER student.

WISER student.

Girls Utilizing Technology and Science (GUTS)

The Girls Utilizing Technology and Science (GUTS) is a five-day program offered by the Diversity Enhancement Programs of the College of Earth and Mineral Sciences (EMS) at Penn State. It is a program designed to increase interest in science, sharpen problem-solving skills and build self-esteem, in girls from all socio-economic and cultural backgrounds. In 2005, 20 girls participated, and topics included Astrobiology, Meteorology, Geosciences, Energy and Geo Environmental Engineering, and Materials Science and Engineering. An all-women team of elementary and middle school teachers led activities with assistance from faculty and graduate and undergraduate students in the College of Earth and Mineral Sciences. Laura Liermann, Research Associate, Penn State Astrobiology Research Center, dedicated two half days making a positive impact on the lives of young girls by helping them observe and understand how to grow bacteria in a session called "The Biology of Rocks". She created a simple experiment that allowed the girls to use multiple materials commonly used by scientists. The GUTS website is http://www.ems.psu.edu/admin/GUTS/

Reizelie Barreto, Director for Nittany Science Camp for Girls (NSCG) and Girls Utilizing Technology and Science Camp (GUTS) would like to formally express appreciation to the camp sponsors: the Center for Nanoscale Science, the Pennsylvania NASA Space Grant Consortium, the faculty, staff and students of the College of Earth and Mineral Sciences, and community members that in one way or another made these camps a success. Thank you for your time, energy, and efforts to provide middle and high school girls with enriched opportunities to engage in science. Your collaboration certainly had a positive impact in the lives of future generations of female scientists, and we hope you continue, and encourage other colleagues and friends, to support these programs in the future.

Below is a brief highlight of some of the volunteers who led camp activities:

Angel Bennett, Meteorology Undergrad

Angel participated in NSCG and is shown here explaining her field of study—meteorology. She was a great role model, showing how successful students can be while still in school.

Tanya Furman, Associate Director of AESEDA

Tanya dedicated two mornings helping at both camps. She taught the girls how to make toothpaste and that most things we consume start from dirt and other elements from the ground.

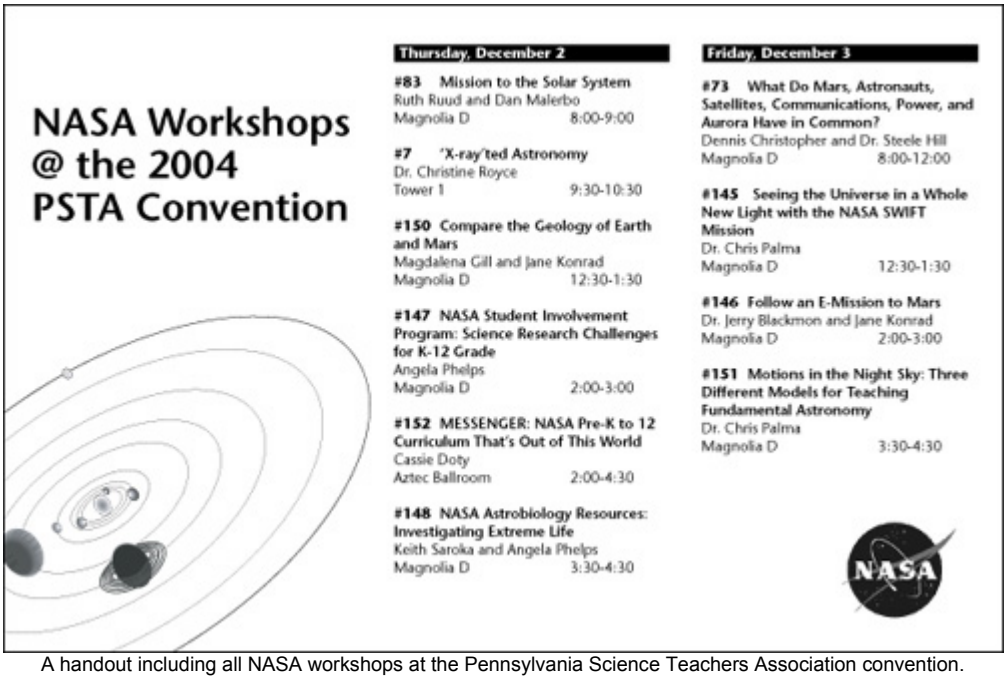
Doug Smith, EMS Glassblower

Doug provided a great example of how art can combine with science and how this union has impacted our society in a positive direction. He showed great patience in allowing 20 anxious girls to blow glass!

Penn State summary of the GUTS program.

Astrobiology Workshop and Exhibit at the Pennsylvania Science Teachers Association Conference

The Pennsylvania Space Grant Consortium organized an exhibit booth and a series of hour-long NASA-related workshops at the 2004 Pennsylvania Science Teachers Association meeting. The astrobiology workshop was entitled "NASA Astrobiology Resources: Investigating Extreme Life" and was aimed at middle-school teachers; 15 teachers attended. Activities from the Astrobiology Educator Resource guide and the Meet the Microbes guide were featured. Angela Phelps, PA Space Grant Consortium & Penn State Astrobiology Research Center and Keith Saroka, 6-8 Grade Teacher, Tinnicum School, Essington, PA co-taught the workshop.



NASA Workshops @ the 2004 PSTA Convention

Thursday, December 2

#83 Mission to the Solar System
Ruth Ruud and Dan Malerbo
Magnolia D 8:00-9:00

#7 'X-ray'ted Astronomy
Dr. Christine Royce
Tower 1 9:30-10:30

#150 Compare the Geology of Earth and Mars
Magdalena Gill and Jane Konrad
Magnolia D 12:30-1:30

#147 NASA Student Involvement Program: Science Research Challenges for K-12 Grade
Angela Phelps
Magnolia D 2:00-3:00

#152 MESSENGER: NASA Pre-K to 12 Curriculum That's Out of This World
Cassie Doty
Aztec Ballroom 2:00-4:30

#148 NASA Astrobiology Resources: Investigating Extreme Life
Keith Saroka and Angela Phelps
Magnolia D 3:30-4:30

Friday, December 3

#73 What Do Mars, Astronauts, Satellites, Communications, Power, and Aurora Have in Common?
Dennis Christopher and Dr. Steele Hill
Magnolia D 8:00-12:00

#145 Seeing the Universe in a Whole New Light with the NASA SWIFT Mission
Dr. Chris Palma
Magnolia D 12:30-1:30

#146 Follow an E-Mission to Mars
Dr. Jerry Blackmon and Jane Konrad
Magnolia D 2:00-3:00

#151 Motions in the Night Sky: Three Different Models for Teaching Fundamental Astronomy
Dr. Chris Palma
Magnolia D 3:30-4:30

A handout including all NASA workshops at the Pennsylvania Science Teachers Association convention.

"Ask an Astrobiologist" Videoconference

On July 1, the Penn State Astrobiology Research Center team consisting of Dr. Chris House, Dr. Jean Brenchley, Irene Schneider, and Lev Horodyskyj participated in an "Ask An Astrobiologist" videoconference with 40 students and teachers from the Chicago Public Schools who were participating in a summer enrichment program with the Adler Planetarium, Shedd Aquarium, and Field Museum. Amanda Quick, Distance Learning Educator at the Adler Planetarium and Astronomy Museum, and Angela Phelps, Pennsylvania Space Grant Consortium and Penn State Astrobiology Research Center, helped to organize the event. The "Ask an Astrobiologist" format consisted of students taking turns asking questions about the field of Astrobiology, evolution, extraterrestrial life and other science topics. The Penn State team took turns answering the questions. Dr. Chris House chaired the event.

Amanda Quick provided this feedback, "The students were so happy to get to talk with the professors and graduate students. The teachers commented afterwards that it was probably the first time that most of the students had ever gotten to speak withUniversity professors and people in the astrobiology field. Although the Prosser students seemed shy, they were bubbling with excitement as soon as the videoconference ended and the camera was turned off."

Publications: Pennsylvania State University

There are **62** publication entries for the Pennsylvania State University

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Kump, L.R., Pavlov, A. & Arthur, M.A. (2005). Massive release of sulfide to the surface ocean and atmosphere during intervals of ocean anoxia. *Geology*, 33:397-400.

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Executive Summary: SETI Institute

Executive Summary: SETI Institute
Principal Investigator: Rocco Mancinelli
Reporting Period: 2005 (7/04-6/05)

The SETI Institute (SI) NASA Astrobiology Institute (NAI) team is conducting a suite of coupled research projects in the co-evolution of life and its planetary environment. These projects address three of NASA's Astrobiology Roadmap fundamental questions: (1) how does life begin and evolve?; (2) does life exist elsewhere in the universe? and (3) what is the future of life on Earth and beyond? These projects begin by examining specific fundamental ancient transitions that ultimately made complex life possible on Earth. They will conclude with a synthesis that will bring many of the team's investigations together into an examination of the suitability of planets orbiting M dwarfs for either single-celled or more complex life.

The astrobiology roadmap calls for a strategy "for recognizing novel biosignatures" that "ultimately should accommodate a diversity of habitable conditions, biota and technologies in the universe that probably exceeds the diversity observed on Earth." Some of our results, especially those concerning abiotic mechanisms for the oxidation of planetary atmospheres, speak to the interpretation of extrasolar planet atmospheric spectra (and in particular, the role of oxygen as a potential biosignature) in terms of the presence of photosynthesizing life. The team's M-star project addresses the roadmap's observation that "although technology is probably much more rare than life in the universe, its associated biosignatures perhaps enjoy a much higher signal-to-noise ratio. Accordingly, current methods should be further developed and novel methods should be identified for detecting electromagnetic radiation or other diagnostic artifacts that indicate remote technological civilizations." As the roadmap recognizes, there is a continuum of investigations that comprise astrobiology, from prebiotic evolution to the evolution of technology. We believe that we are the only NAI team whose investigations span the gamut of the roadmap's range.

The SETI Institute's NAI team's research emphasizes the elucidation of the co-evolution of life and its planetary environment, investigating global-scale processes that have shaped, and been shaped by, both. Throughout, the team recognizes the importance of pursuing the planetary evolution aspects of this research in the context of comparative planetology: since laboratory experiments are impossible over many (but not all) of the time and spatial scales relevant to early Earth, we supplement laboratory data with insights gained by exploring extraterrestrial environments that provide partial analogs to the early Earth environment and its processes.

The SETI Institute team is pursuing two investigations into the oxidation of early Earth's environment. While the biological aspects of this "oxygen transition" have been emphasized, our team is exploring non-biological contributions to this transition. Dr. Friedemann Freund and Dr. Lynn Rothschild are investigating oxidation driven by diffusive loss of hydrogen formed within igneous and metamorphic rocks that incorporate water during crystallization. Subsequent weathering of the rocks released hydrogen peroxide into the environment; the previous loss of the hydrogen indicates that this is a net oxidizing mechanism. During this reporting period we succeeded in completing new physical measurements on igneous rocks, an important step toward the goal of having in hand quantitative analyses of peroxy oxygen in rocks ranging from ultramafic (peridotite, gabbro) to felsic (andesite, granite).

If the oxidation mechanisms being explored were shown to be quantitatively significant—modeling to be done later in the course of this grant—this would suggest that the oxygen transition on an Earth-like world could take place independently of the invention of any particular metabolic pathway (such as photosynthesis or methanogenesis) that have previously been proposed to drive this transition. Since Earth's oxygen transition ultimately set the stage for the oxygen-based metabolism evidently essential for metazoa, understanding this transition is crucial to elucidating both Earth's evolution and the evolution of complex (including intelligent) life. The team's geological investigations are therefore tightly coupled with microbiological experiments, led by Dr. Rothschild, to understand the extent to which the proposed mechanism might have led to the evolutionary invention of oxidant protective strategies and even aerobic metabolism.

In a second investigation, oxidation driven by atmospheric hydrocarbon (and, more broadly, organic) polymerization is being investigated by Dr. Emma Bakes. Dr. Bakes' research for the early Earth builds on

analogies to processes now occurring in the atmosphere of Saturn's moon Titan. She has begun to map chemical sequences for anions, neutrals and cationic nitrogenated aromatic molecules in Titan's organic haze layer. She has also begun to extend her study of molecular charging to Martian regolith dust to determine how this affects the UV radiation penetration to the Martian surface. This UV penetration directly affects the survival or destruction of organic molecules and the irradiation of potential life forms. We have also begun a laboratory study of hydrogen molecule synthesis on aromatics and aerosols to see if the suggested theoretical pathway is a plausible mechanism to the accelerated oxidation of Titan and the early Earth. This foundation enables the next stage of her research, the theoretical building of prebiotic macromolecules from the haze constituents. This work is complemented by ongoing laboratory work performed by Dr. Bishun Khare and Dr. Hiroshi Imanaka on Titan analog materials, and infrared observations of the Titan haze.

Understanding the oxygen balance on early Earth requires attention to sinks as well as sources of oxygen. One major sink for oxygen on early Earth would have been reduced iron. Iron could have simultaneously provided shielding against ultraviolet (UV) light that would have been reaching Earth's surface in the absence of the ozone shield generated by atmospheric oxygen. Nanophase ferric oxide minerals in solution could provide a sunscreen against UV while allowing the transmission of visible light, in turn making the evolution of at least some photosynthesic organisms possible. Dr. Janice Bishop and Dr. Rothschild are testing this hypothesis through coupled mineralogical and microbiological work in both the lab and the field, and examining its implications not only for Earth but for Mars as well, with an emphasis on implications for upcoming spacecraft observations. They have completed a number of lab experiments showing that nanophase iron oxide-bearing minerals facilitate growth of photosynthetic organisms by providing protection from UV radiation. Based on the spectral properties of iron oxides and the results of experiments with photosynthetic organisms, Euglena and Chlamydomonas, they propose a scenario where photosynthesis, and ultimately the oxygenation of the atmosphere, depended on the protection of early microbes by nanophase ferric oxides/oxyhydroxides. Such niches may have also existed on Mars.

They are preparing to evaluate visible/near-infrared (VNIR) spectra of Mars in an effort to characterize deposits of nanophase ferric oxide-bearing minerals that could provide UV protected niches for photosynthetic microbes if they were present on Mars. Concurrent with other projects, we are evaluating the spectral properties of Fe-bearing Mars analog sites on earth and analyzing spectra of Mars for Fe oxide-bearing components. These results are consistent with the hypothesis that early photosynthetic organisms may have existed in specific, perhaps small, niches protected by ferric oxide-bearing material. (See Figures 5, 6 & 7)

The survival of microorganisms in very high UV environments can also be tested empirically through the exploration of Earth's highest altitude lakes and ponds, in Bolivia and Chile. Dr. Nathalie Cabrol and Dr. Edmond Grin (both of whom also this past year served on the Mars Exploration Rover team) have led a series of investigations of these lakes to examine the strategies employed by these microorganisms. This past year they have charcterized the PAR and UV flux, the geology, some microbial mat organisms and the geology and paleobiology of Laguna Blanca and Verde. They have also charcterized the PAR and UV flux of the summit lake of Licancabur as well as developing the first bathymetry map of the lake. The UV flux at those lakes is between 200 and 216% that of sea level and the level of UVB recorded is similar or exceeds that of current UVB on Mars at the equator. (See Figures 1, 2, 3 & 4)

Just as global-scale changes in oxygen (or iron) were critical for the early biosphere, so too would have been global processes involving other key "biogenic" elements such as carbon (for which Dr. Bakes' work provides insight) or nitrogen. Dr. Rocco Mancinelli, Dr. Amos Banin, Dr. David Summers, and Dr. Khare are pursuing coupled laboratory and field research to understand the partitioning of nitrogen on early Earth and on Mars between different possible reservoirs, and (at least for Earth) the abiotic to biotic transition in this cycling.

Dr. Banin has nearly completed the analysis of soil samples from the Atacama desert, an extreme terrestrial environment with very low biological activity. Although not completely clear what properties of the soil and environment are the limiting factors for biology, these soils are nearly devoid of organic material and contain high levels of perchlorate. They have conducted a series of field experiments, which show that at the driest sites (e.g., Yungay) there is virtually no nitrogen cycling even when the samples are wetted. They have begun a series of experiments in which they are searching for the nitrite reductase

gene, a gene critical in denitrification.

Dr. David Summers and Dr. Khare have experimentally verified that the abiotic fixation of NO to nitrite and nitrate would indeed occur, as had been postulated theoretically. It has been shown that two mechanisms exist for this fixation. One proceeds in the presence of liquid was and appears to be consistent with the proposed pathway through HNO. Another proceeds to NO_2 in the absence of liquid water but, in the presence of absorbed water, the NO_2 can be converted to nitric acid. These experiments begin providing a different perspective into the astrobiologically important question of the fate of N on early Mars.

The work described so far examines the evolution of planetary surface habitability. With the recognition that a subsurface ocean likely exists on Jupiter's moon Europa, we know that habitability in possibly entirely subsurface environments must also be explored. Dr. Cynthia Phillips, Dr. Christopher Chyba, and Mr. Kevin Hand (a Stanford PhD student advised by Dr. Chyba) are pursuing spacecraft data analysis and modeling to examine the geology of Europa and its implications for the free energy sources that would be needed to power a europan biosphere. Dr. Phillips and Dr. Chyba are continuing a survey of images of Europa to look for any changes that occurred due to geological activity during the Galileo mission, which if present would indicate active regions of the surface. They are also completing a major project, using Galileo high-resolution imaging of Europa, to quantify the impact cratering “gardening” rate on Europa. This is important in its own right as a fundamental planetary process, but also is important in some astrobiological models because it will allow the quantification of the amount of biologically relevant material, created at Europa’s surface through radiogenic processes, that can be mixed down to the gardening depth, and thereby escape radiolysis.

These results will be coupled with the results of low-temperature laboratory experiments to make predictions about the possible abundance and survivability of any oceanic biomarkers that might reach Europa's surface through active geology, with implications for the astrobiological exploration of Europa from either an orbiter or a surface lander. Mr. Kevin Hand, in collaboration with Dr. Robert Carlson and Dr. Chyba, is pursuing this research in Dr. Carlson’s laboratory at the Jet Propulsion Laboratory. Over the past year, Mr. Hand and Dr. Carlson have constructed the irradiation apparatus (including ice deposition chamber and diagnostics) and have preliminary experiments now underway. Dr. Max Bernstein, in his laboratory at NASA Ames, is performing lab measurements to enable the detection of signs of life and the discrimination between these and false biomarkers have measured IR spectra of Nitrogen Heterocycles, the class of compounds found in meteorites that include nucleobases. Dr. Bernstein has been concentrating on the kind of conditions found on icy outer Solar System bodies such as Europa and has found good agreement between theoretical prediction and experimental observation. Ultimately the behavior—and detectability—of such compounds under europan conditions will also be determined.

Dr. Peter Backus, Dr. Jill Tarter, and Dr. Mancinelli just completed the first workshop that examines the prospects that planets orbiting dwarf M stars are habitable for either microscopic or complex life. The SETI Institute NAI team’s proposal calls for a series of workshops to bring together planetary scientists, biologists, atmospheric modelers, astrophysicists, and SETI scientists to address these issues. They are currently writing up the results of the workshop. In summary nothing about what we currently know about M-dwarfs precludes the possibility of life from originating and evolving on a terrestrial planet orbiting within the habitable zone of an M-dwarf. The results of this project will ultimately help the next generation scientific Search for Extraterrestrial Intelligence (SETI) choose the million target stars that it will survey for signs of technical civilizations using the new Allen Telescope Array (ATA), being built by the SETI Institute in partnership with the University of California, Berkeley.

Finally, during the past year Chyba and Hand completed an invited review article for *Annual Reviews of Astronomy and Astrophysics* titled “Astrobiology: The Study of the Living Universe.” The piece makes mention of the NAI both in the acknowledgments and in the first paragraph of the article itself; it surveys current controversial issues across the span of astrobiology and should serve to introduce many astronomers and physicists that are not (yet) astrobiologists to key ideas and controversies in the field.

Education and public outreach are major and integral parts of the work of the SETI Institute’s NAI team.

Figure 1. Licancabur Summit Lake, 5,916 m. Colony of copepods and ostracods evolving in the lake water column between 0.5 to 4.5 m depth.

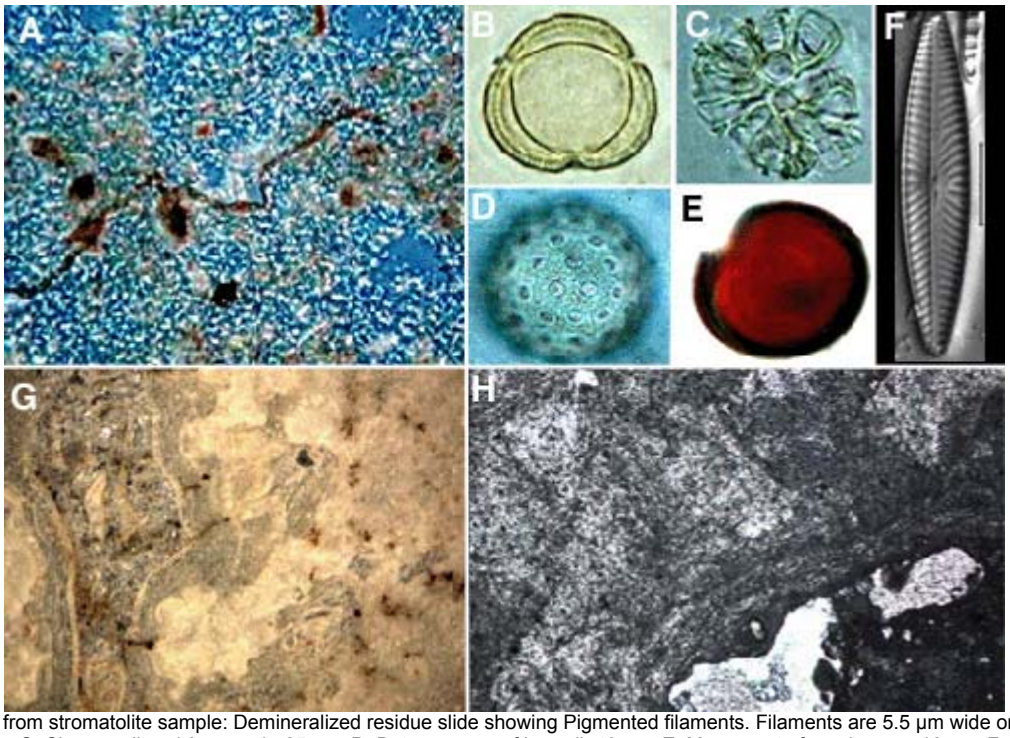
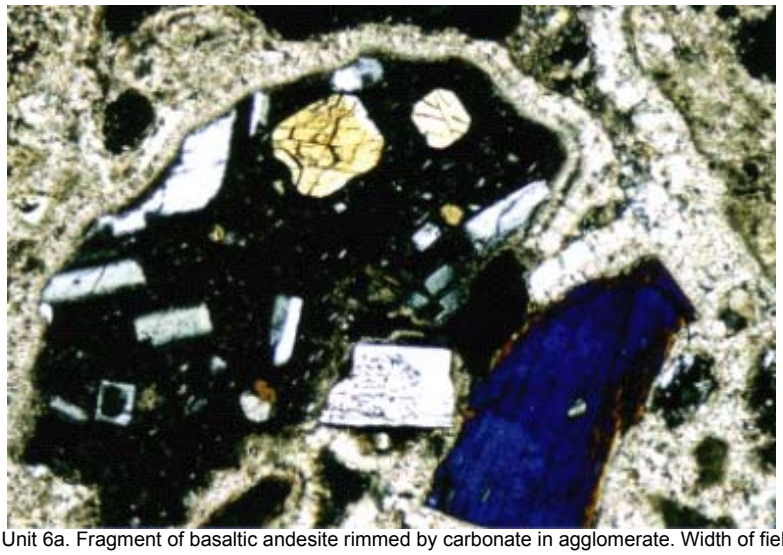


Figure 2. A. Rock Kerogen from stromatolite sample: Demineralized residue slide showing Pigmented filaments. Filaments are 5.5 µm wide on average; B-E: Pollens: B. Ambrosia artemisifolia, 20 µm; C. Chenopodium / Arnaranth, 25 µm; D. Botryococcus cf braunii, 40 µm; E: Monoporate fungai spore, 16 µm; F: Diatom: Navicula radiosa; G-H: Stromatolite thin sections. G: Cyanobacterium of the genus Oscillatoria, and H: Filamentous cyanobacteria.



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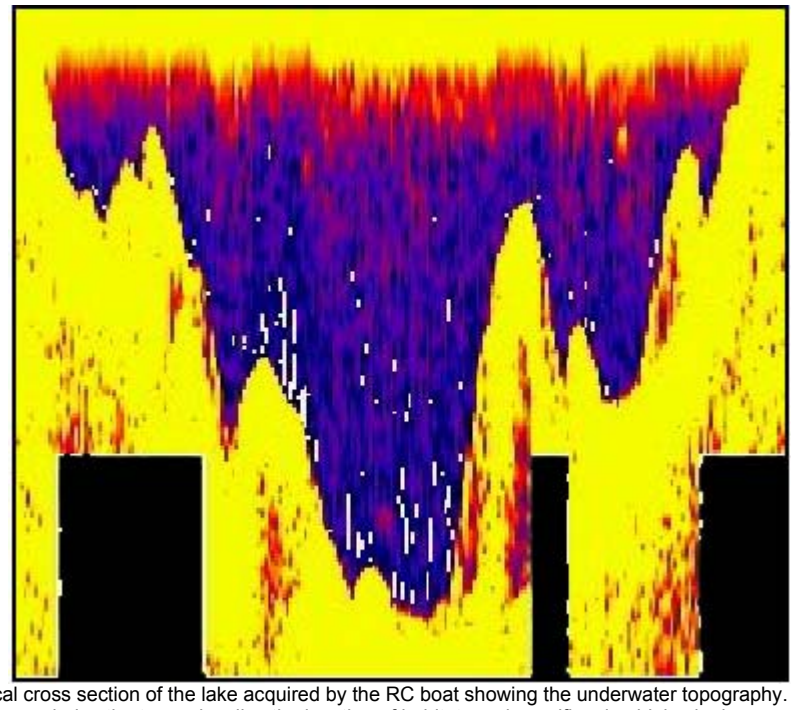

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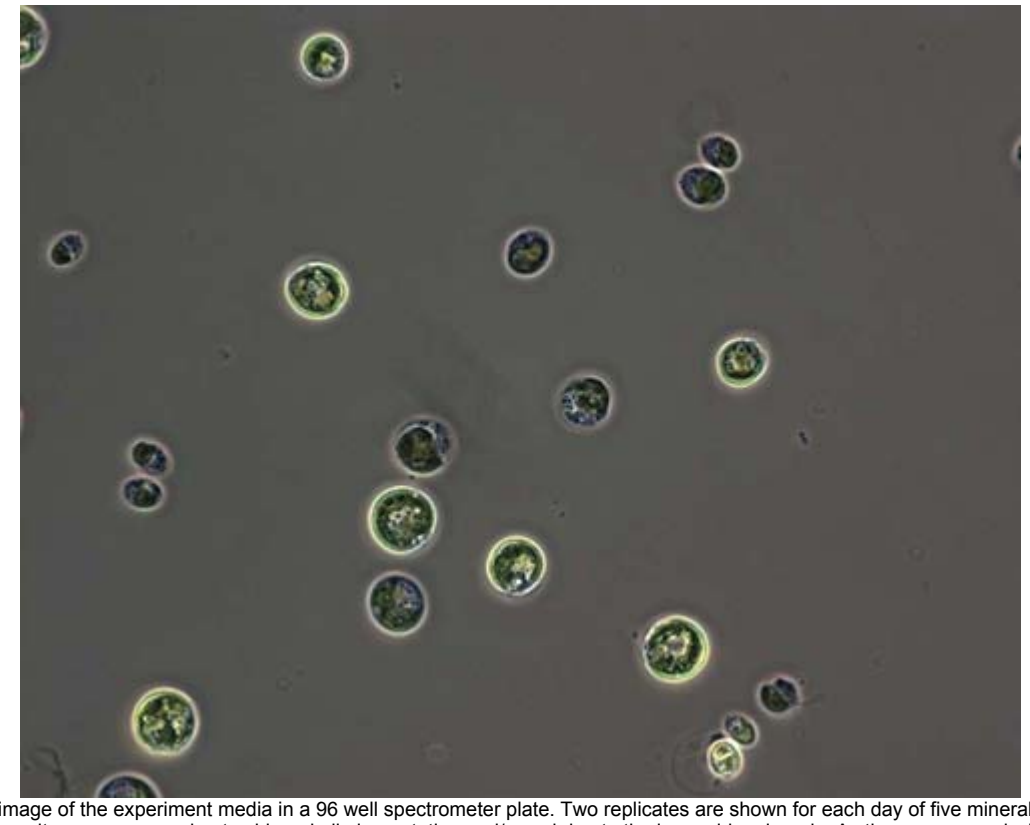

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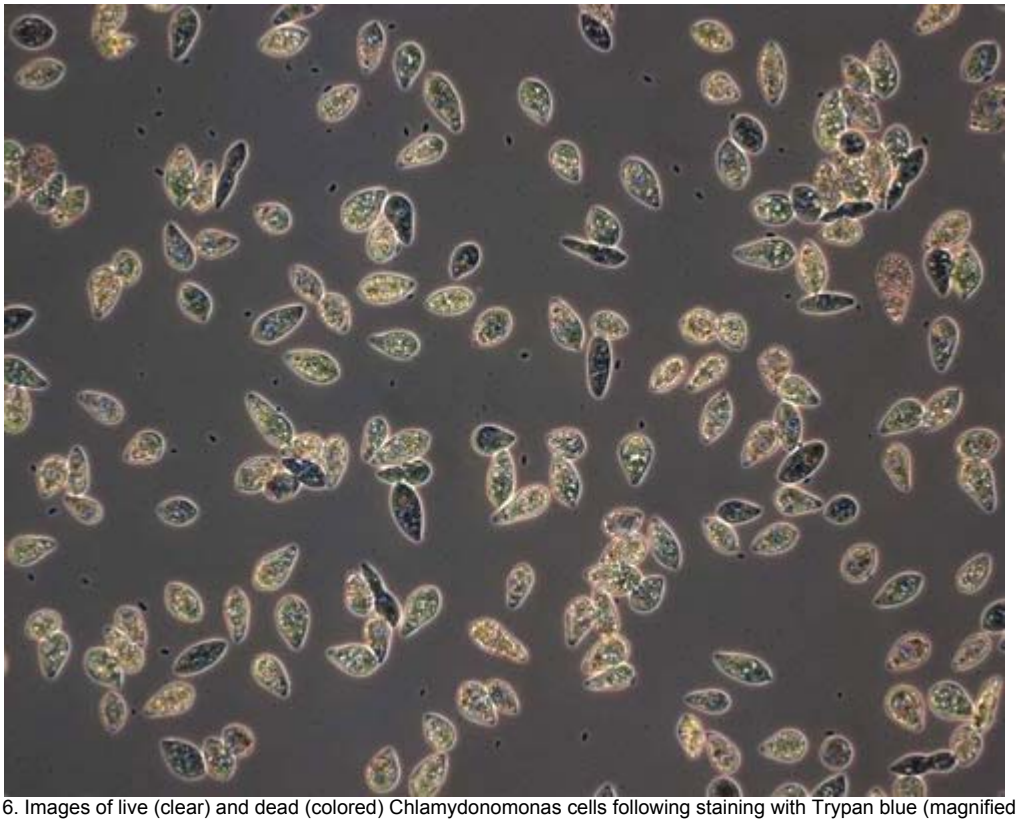

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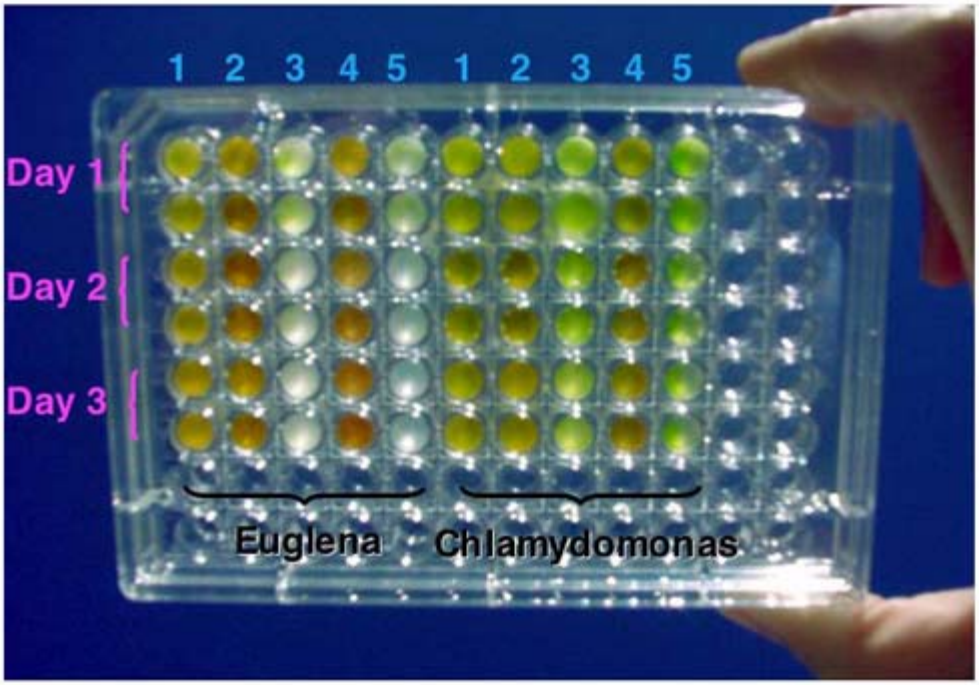

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Project Reports: SETI Institute

Planetary Biology, Evolution and Intelligence (project)

Project Investigator: Chris Chyba

Project Progress

Chris Chyba, Cynthia Phillips, Kevin Hand- The project has two components. The first, an overview of the astrobiological potential of various geological features on Europa, is proceeding well – we are continuing study of various proposed formation mechanisms for different features types such as ridges, bands, and chaotic terrain. The second, a search for current geological activity by comparing Galileo images taken on different orbits, is also in progress. We have performed a first-stage search of the Galileo Europa images to find overlapping images, and are currently working on an automated search method to make sure that we find all possible comparison images. We are also working on automated processing techniques.

Max Bernstein- As part of performing lab measurements to enable the detection of signs of life and the discrimination between these and false biomarkers we have measured IR spectra of Nitrogen Heterocycles, the class of compounds found in meteorites that include nucleobases. We have been concentrating on the kind of conditions found on icy outer Solar System bodies such as Europa.

Rocco Mancinelli- We have collected soil samples from The Yungay region of the Atacama desert and have anayled them for thjier mineralogy and chemical consitiuents, especially salts. Additionally we have condiuced in situ tests in the field for determine potential rates of N-fixation, denitrification, and nitrification. All of these tests were negativeincluding when the soil was wet. This suggests that either there are no organisms capable of N-cyclein in the soil, or the soil contains somethin inhibiting their activity.

Peter Backus, Jill Tarter-We have organized a two and a half day workshop to be held July 18-20, 2005 on the topic of the Habitability of Planets Orbiting M Stars. A total of forty-one scientists from twenty-one institutions in the US and UK will participate. Twenty-two of the participants are from eight NAI Teams. We established a web site to help organize the workshop and provide a focus for post-workshop discussions.

Nathalie Cabrol- All goals set for the 2004 Licancabur expedition were completed, which will allow the team to move on to another high-altitude volcanic lake in 2005 (Poquentica) as planned in our proposal. Achievements include: (1) characterization of Laguna Blanca and Verde geology and paleobiology through sampling (geochemistry, petrography, palynology, diatoms, cyanobacteria, and paleoenvironment); (2) Geochemistry: Sucessful retrieval of 1-year worth of UV data (UVA, UVB, PAR) as well as temperature from our Eldonet UV dosimeters both at the Lagunas and the summit lake of Licancabur. UV at those lakes is between 200 and 216% that of sea level and the level of UVB recorded is similar or exceeds that of current UVB on Mars at the equator. Positioning of two Hobo meterological station (lagunas and summit); (3) Bathymetry of the summit lake (thawed part). This becomes the very first bathymetry of this lake. 4) Biology: Characterization of cyanobacterial colonies building stromatolotic structure; Documentation of life diversity both at the lagunas and summit lake; Discovery of a large colony of ostracods and copepods in the summit lake of Licancabur (sampling and photodocumentation); Successful dives; and (5) Acquisition of physiological data during the expedition.

David Summers & Bishun Khare- This work has experimentally verified that the abiotic fixation of NO to nitrite and nitrate would indeed occur, as had been postulate theoretically. It has been show that two mechanisms exist for this fixation. One proceeds in the presence of liquid was and appears to be consistent with the proposed pathway through HNO. Another proceeds to NO_2 in the absence of liquid water but, in presence of absorbed water, the NO_2 can be converted to nitric acid. We are in the process of preparing a communication for submission to Nature.

Emma Bakes- We have begun to map chemical sequences for anions, neutrals and cationic nitrogenated aromatic molecules in Titan's organic haze layer. At this stage, we require the participation of a quantum chemist to map the chemical energetics and the plausibility of each suggested reaction pathway. We have also begun to extend our study of molecular charging to Martian regolith dust to determine how this affects the UV radiation penetration to the Martian surface. This UV penetration directly affects the survival or

destruction of organic molecules and the irradiation of potential life forms. We have also begun a laboratory study hydrogen molecule synthesis on aromatics and aerosols to see if the suggested theoretical pathway is a plausible mechanism to the accelerated oxidation of Titan and the early Earth.

Friedmann Freund- The major objective of my project is to study the causes for the slow but inextricable oxidation of the Earth over the first 3 Gyr of its history. During this reporting period our work received a boost from progress achieved by performing new physical measurements on igneous rocks, which lead us towards a quantitative analysis of peroxy oxygen in rocks ranging from ultramafic (peridotite, gabbro) to felsic (andesite, granite).

Janice Bishop & Lynn Rothschild- We have completed a number of lab experiments showing that nanophase iron oxide-bearing minerals facilitate growth of photosynthetic organisms by providing protection from UV radiation. Based on the spectral properties of iron oxides and the results of experiments with photosynthetic organisms, *Euglena* and *Chlamydomonas*, we propose a scenario where photosynthesis, and ultimately the oxygenation of the atmosphere, depended on the protection of early microbes by nanophase ferric oxides/oxyhydroxides. Such niches may have also existed on Mars.

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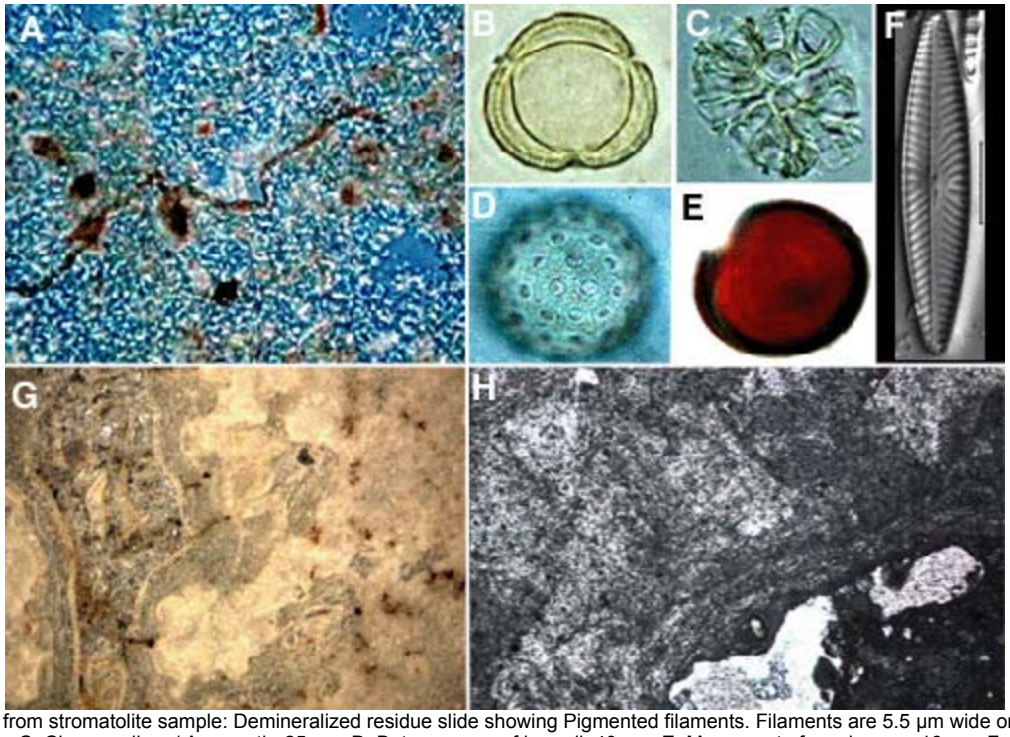

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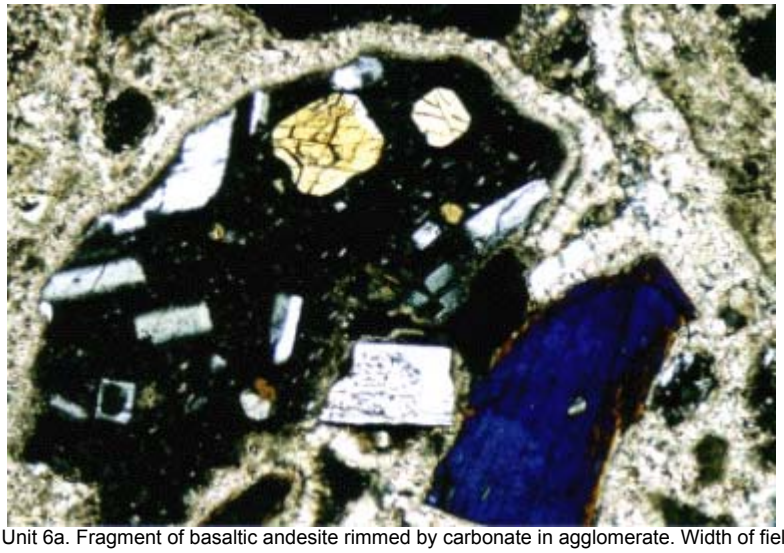

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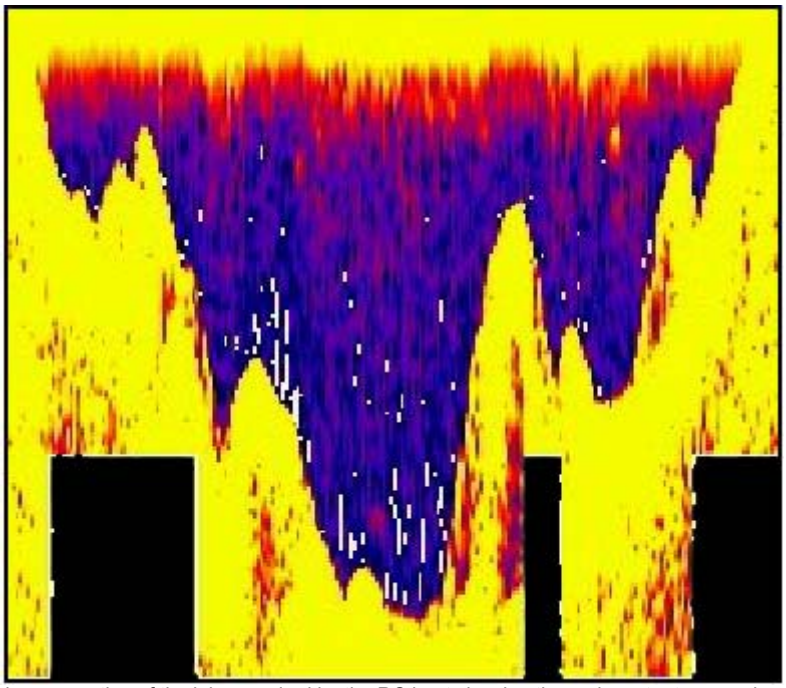

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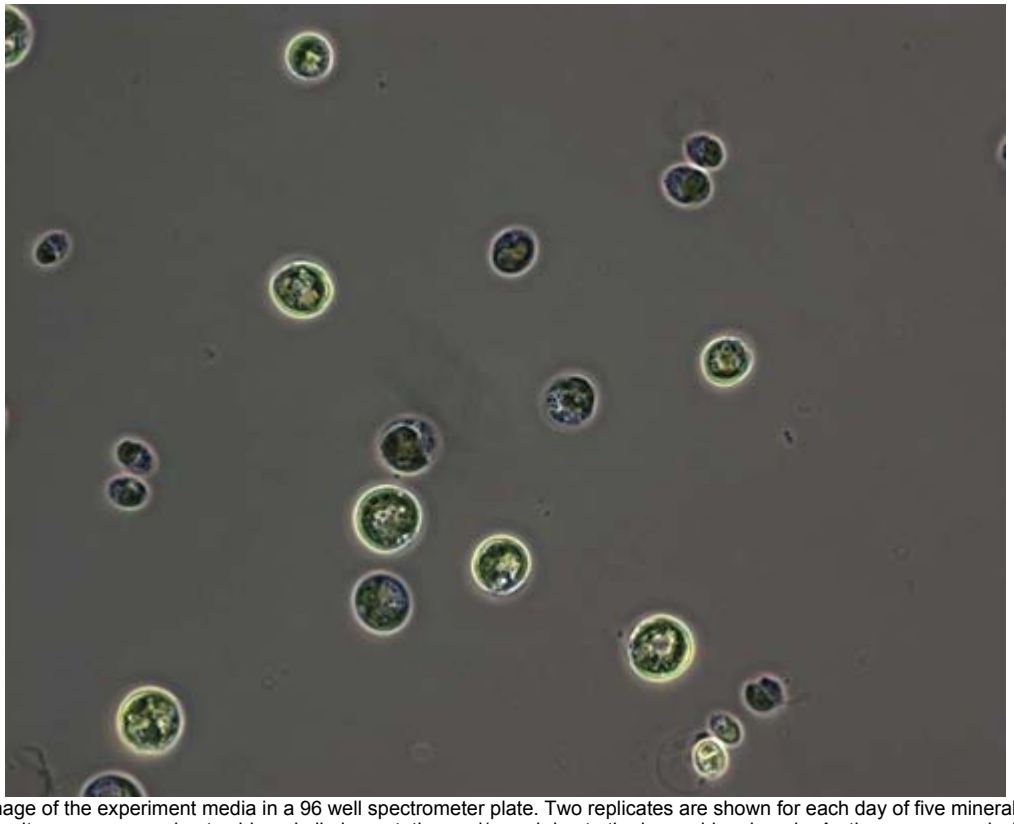

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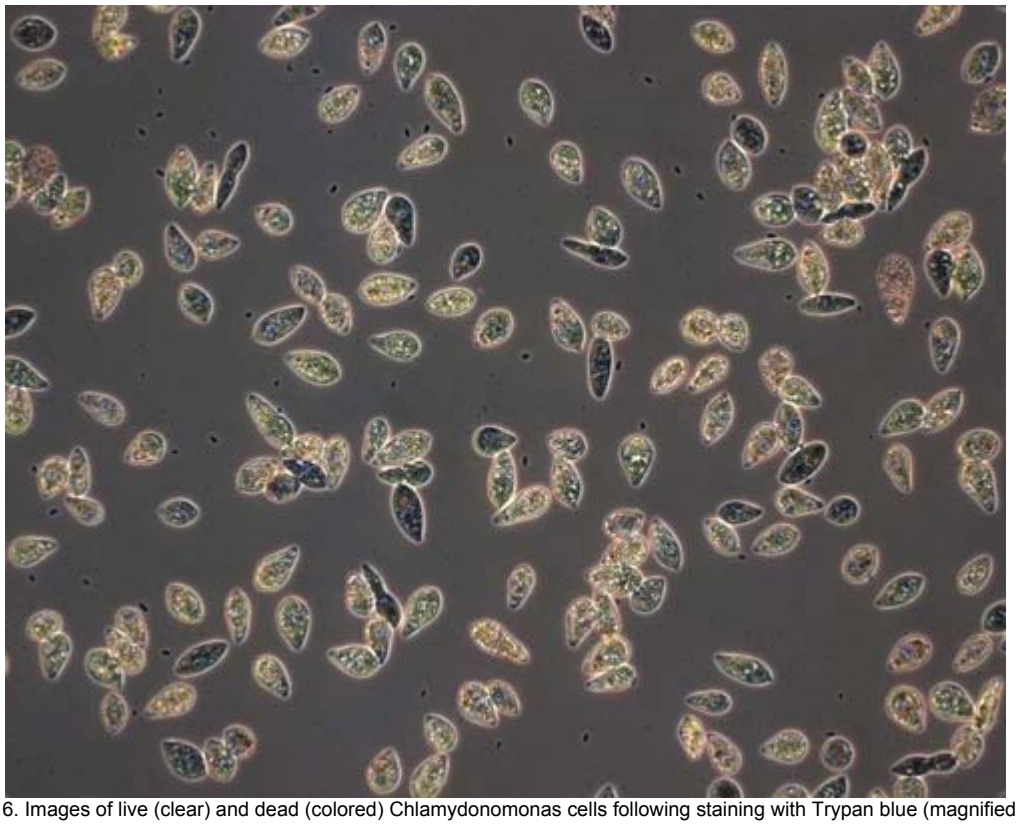

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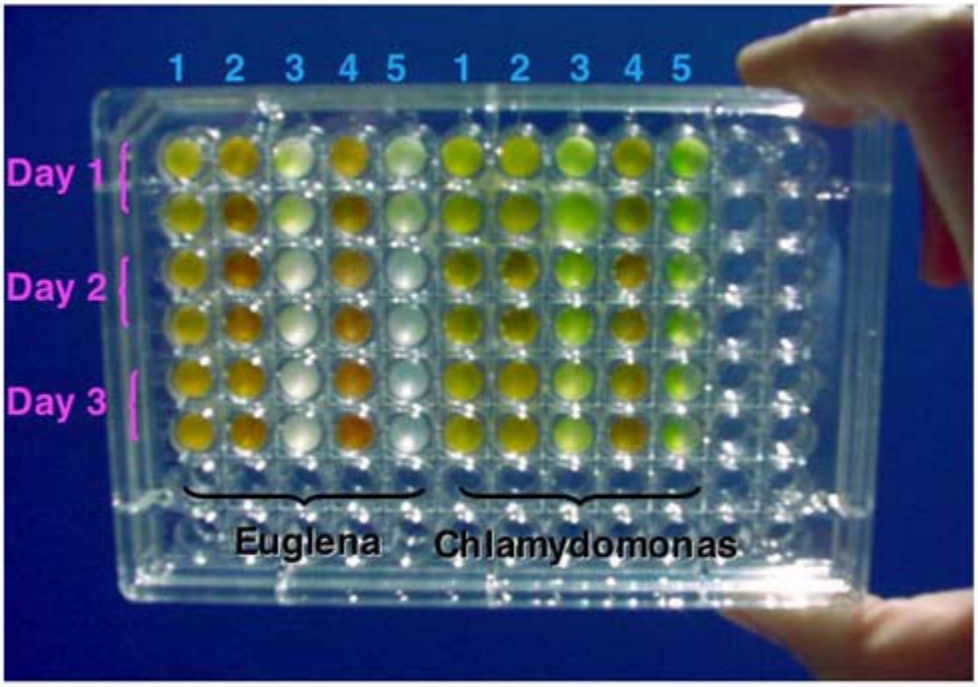

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Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 2.1:** Mars exploration
- **Objective No. 2.2:** Outer Solar System exploration
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 3.2:** Origins and evolution of functional biomolecules
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.2:** Foundations of complex life
- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms

- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
1	CASSINI/HUYGENS	Data Analysis
1	Galileo	Data Analysis
1	Mars Express - OMEGA	Data Analysis
1	MRO - CRISM	Co-Investigator
3	FAR FUTURE MARS	Planning Support

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

IDENTIFIES POTENTIAL ATMOSPHERIC SIGNATURES AND POSSIBILITIES FOR IR BIOSIGNATURES.

This project involves the analysis of existing data taken by the Galileo spacecraft during its mission at Jupiter.

Using OMEGA data to look for iron oxide-bearing minerals on Mars.

Will be using CRISM data to look for iron oxide-bearing minerals on Mars.

Field Expeditions

Field Trip Name: Atacama desert
Start Date: Nov. 2004 **End Date:** Nov. 2004
Continent: S. America **Country:** Chile
State/Province: The Yungay region **Nearest City/Town:** Yungay, Chile
Latitude: 24°S **Longitude:** ~ 70oW longitude
Name of site(cave, mine, e.g.): Atacama desert **Keywords:** N-Cycling, abiotic N-cycle, biotic N-cycle, Mars, Atacama desert
Description of Work: Conducted field tests for N-cycling
Members Involved:

Field Trip Name: 2004 Mars Underwater Expedition (Licancabur)
Start Date: October 27, 2004 **End Date:** November 23, 2004
Continent: South America **Country:** Bolivia
State/Province: Potosi **Nearest City/Town:** San Pedro de Atacama (Chile)
Latitude: 22o50S **Longitude:** 67o.53W
Name of site(cave, mine, e.g.): Licancabur **Keywords:** Mars analog; Lake; UV Radiation; Evaporation; Life
Description of Work: The lakes surveyed during the November 2004 expedition are located in the Bolivian and Chilean Andes. They are: the

Licancabur summit lake (6,014 m), Laguna Verde, Laguna Blanca, and Laguna Colorada (4,350 to 4,500 m). Exploration techniques included diving and shore investigation, geological, geophysical, hydrogeological, and biological sampling. Data acquisition, collection and preliminary results include: (1) Biology: (a) The discovery of a large ecosystem of red and white copepods at the center of the summit lake (Figure 1). Their distribution in the water column seems to indicate that they use water as a their main shield against UV; (b) biological sampling of algae and microorganisms at various depths at all lakes; (c) characterization of the 100 km2 field of fossil stromatolites that surround the paleoshores of Laguna Blanca and Verde. Each main terraces were sampled. Samples have been analyzed for C14, geochemistry, micromorphology, sedimentology, biology and paleoenvironment (pollens, spores, flagellates, diatoms, and cyanobacteria) (Figure 2). Results from these analyses provide a clear vision of the environmental and climate changes from the time the stromatolites were first formed (~18,000 years ago) to the present. The morphological survey of the field shows that stromatolite structure shape, size, and density vary with time, likely following environmental changes to be determined by our analysis. Evaporation may play an important role since those lakes have been receding for the past 10,000 years. The samples helped pin point these critical changes. Located ~100 km North from Licancabur, Laguna Colorada was the focus of a first reconnaissance this year: water and biology samples were collected and are being analyzed. (2) Geology: (a) The completion of the transect through the terraces of Laguna Blanca and Laguna Verde to understand the geological, mineralogical and climate changes going from the formation of the large fresh lake that encompassed both Laguna Blanca and Laguna Verde at the end of the Last Glacial Maximum (LGM) to the now almost separated lagunas, the first one being 10 times saltier than any continental waters and the second three times saltier than sea water; This survey gave us samples that we run through geochemistry and petrography and helped us decipher the intricate history between lacustrine and volcanic activity (Figure 3), which impacted the evolution of environment and life; (3) Geophysics: (a) Data retrieval from two Eldonet stations (UVA, UVB, PAR) that acquired one-year worth of data at the lagunas (collected) and the summit lake. UV data at the lagunas show that UV radiation is about 200% that of see level, 216% at the summit lake; UVB at Laguna Blanca is equivalent to that of Mars at the equator today; (b) biological sample collection under UV plates; (c) setting of two meteorological stations (summit and lagunas); (d) retrieval of one-year worth of water temperature at the summit lake; (d) study of UV attenuation in water at the summit lake. The results are consistent with the observation of the microorganisms density through the water column in the example of the new found ecosystem; and (e) water chemistry. (4) Bathymetry: The first ever bathymetric survey of the Licancabur summit lake was performed by our team using a small RC boat equipped with sonar and GPS and thermal sensors. The lake was half-frozen and bathymetry was completed in the thawed part (Figure 4). (5) Physiology: Physiologists from Stanford and NASA Ames was part of the expedition and performed team monitoring and tests during the expedition to understand the process of adaptation (or lack thereof) for people living and working at high-altitude. (6) Preliminary results have been presented in professional conferences (NAI, GSA) accompanied by abstracts (see reference list). A series of papers relating to the 2004 expedition results are in preparation and will be submitted to JGR and/or Astrobiology in the coming two months.

Members Involved:

Field Trip Name: Yellowstone
Start Date: October 13, 2004 **End Date:** October 14, 2004
Continent: North America **Country:** US
State/Province: Wyoming **Nearest City/Town:** Jackson Hole
Latitude: 43 N **Longitude:** 110 W
Name of site(cave, mine, e.g.): Yellowstone **Keywords:** spring, photosynthesis, iron oxide, hydrothermal
Description of Work: Visited a number of springs, some of which contained photosynthetic colonies. 2) Looking for sites where iron oxide-bearing material formed in association with hydrothermal activity.
Members Involved:

Cross Team Collaborations

We have fourteen scientists from seven other NAI Teams participating in the workshop on the Habitability of Planets Orbiting M Stars. Lynn Rothschild Ames Research Center NAI/ARC Gregory Laughlin UC Santa Cruz NAI/ARC Hector D'Antoni Ames Research Center NAI/ARC Alan Boss Carnegie Inst. of Wash. NAI/CIW Michael Mumma Goddard Space Flt. Ctr. NAI/GSFC Drake Deming Goddard Space Flt. Ctr. NAI/GSFC Antigona Segura Cal Tech NAI/JPL John Scalo U. Texas NAI/JPL Maggie Turnbull Carnegie Inst. of Wash. NAI/JPL/CIW James Tiedje Michigan State U. NAI/MSU James Kasting Pennsylvania State U. NAI/PSU Mike Jura UC Los Angeles NAI/UCLA Jonathan Aurnou UC Los Angeles NAI/UCLA Ferenc Varadi UC Los Angeles NAI/UCLA

Lynn Rothschild, NASA Ames Research Center NAI Team. Lynn was invited to participate to the 2004 Licancabur expedition. Her motivation was to focus on the astrobiological theme? life moving beyond its planet of origin?, a question of evolutionary interest and because the human exploration of space is the movement of life from Earth. Her objective was to try to identify new terrestrial organisms and ecosystems that will survive space radiation and vacuum. During her stay in the field with the team, she sampled Laguna Blanca, Verde, and Colorada. Laguna Colorada, a naturally occurring hypersaline lake in the Bolivian altiplano, provided a novel ecosystem that contains organisms that may have the capacity to survive interplanetary transfer. The name of the lake refers to its intense red color, a result of the dense community of halophiles. Water samples were collected in Nalgene containers and returned to the laboratory. Microscopic analyses revealed the presence of rod, cocci, and pleiomorphic morphological types. This occurrence is unusual, because the dominant morphological type present in hypersaline systems are square organisms, and none were found in this system. This observation suggests that the microbial community structure is different than nearly any other known hypersaline system. Samples were also inoculated into various media. Growth was detected only in halophile medium B containing NaCl 200 g, Hy-Case 5 g. $MgCl_2x6H_2O$ 20 g, yeast extract 5 g, KCl 2 g, $CaCl_2x2H_2O$ 0.2 g, in 1.0 L H_2O. Microscopic observation revealed unusual long rods, short rods, and pleiomorphic rods, but no cocci, squares or cubic organisms. Lynn and her team is currently screening the samples for organisms that are desiccation and radiation resistant.

Janice Bishop visited Lisa Pratt & colleagues at Indiana University in order to discuss ways to integrate isotope analyses at the Geology Dept in Indiana with NAI activities in Bishop?s group for both the SETI Insitute and UCB teams.

EPO Reports: SETI Institute

Are We Alone? Radio Program

"Are We Alone?" is a weekly, one-hour radio broadcast produced by the SETI Institute that covers science (primarily astrobiology related topics) and skepticism. The format for the show is primarily interviews of topic experts by the host, Seth Shostak, and the producer, Molly Bentley. Shostak is an astronomer at the Institute, and Bentley is a science reporter for the BBC. The guests are usually from academia, NASA, or research organizations. Once a month, the program presents "Skeptical Sunday," where we take on pseudoscience by discussing topics such as Intelligent Design, the UFO phenomenon, remote viewing, etc. with skeptics and experts. The show has active participation by CSICOP and the American Physical Society, as well as several "personalities" (e.g., astronomer Phil Plait) who contribute regularly to the program. Guests have included Michio Kaku, Craig Venter, Ray Kurzweil, Laurance Krauss, Richard Dawkins, Neil de Grasse Tyson, Paul Davies, and countless researchers and headquarters staff from NASA. The show is broadcast live on approximately three-dozen AM stations by Radio America, but is also heard on Sirius Satellite Radio and on the internet, either live, or via downloads of archived shows. More than 70 such archived shows are available for podcast downloading -- principally via Apple's iTunes -- and as of the beginning of August, the number of downloads is running 10 to 20 thousand per show. This number seems to be increasing. On the basis of polls, we estimate that the total audience per show is currently 20 to 50 thousand. The intention is to at least double this number within a year.

Voyages Through Time (VTT) Dissemination

Voyages Through Time: A High School Astrobiology Curriculum: In partnership with NASA Fundamental Biology, the NASA Astrobiology Institute, The National Science Foundation, The California Academy of Sciences, and San Francisco State University, the SETI Institute developed Voyages Through Time (VTT), a National Science Education Standards (NSES)-based integrated science curriculum for high school centered on the unifying theme of evolution. Scientists, teachers, curriculum writers, and media specialists produced six CD-ROM modules that integrate astronomical, geological, and biological sciences. The sequence of lessons in each module is designed to promote students' understanding of science and skills as defined by the NSES and American Association for the Advancement of Science (AAAS) Benchmarks for Science Literacy. The six modules, Cosmic Evolution, Planetary Evolution, Origin of Life, Evolution of Life, Hominid Evolution, and Evolution of Technology, use the constructivist approach of engage, explore, explain, elaborate, and evaluate (Biological Sciences Curriculum Study, 1996) as an instructional framework. NAI Central funded the revision and production of the CD-ROM samplers of the curriculum. The samplers provide astrobiology activities for the classroom. The VTT national field test took place from September 2001 through July 2002 in over 60 classrooms in 28 states. Teacher feedback was very positive, and the curriculum was revised following the national test evaluation summary reports. The curriculum was published in August 2003.

NAI EPO Astrobiology Summer Science Experience for Teachers (ASSET)

The second Astrobiology Summer Science Experience for Teachers (ASSET) program was held July 10 - 16, 2005. ASSET is a science, pedagogy and leadership institute with presentations by leading astrobiology researchers from the SETI Institute, NASA, and the California Academy of Sciences. Scientists share the latest in astrobiology research on the origin of life on Earth, the extreme conditions in which life exists, Mars exploration, the formation of planetary systems around Sun-like stars, and the search for life in the universe. ASSET features a combination of cutting edge science, inquiry-based teaching and learning, and leadership skills development in alignment with National Science Education Standards Professional Development Standards.

ASSET participants received the entire Voyages Through Time (VTT) curriculum and complementary astrobiology materials, developed by NASA's Astrobiology Institute, for use in their classrooms. VTT is a standards-based integrated high school science curriculum, delivered on CD-ROMS. VTT consists of six modules: Cosmic Evolution, Planetary Evolution, Origin of Life, Evolution of Life, Hominid Evolution, and Evolution of Technology. Together these modules comprise a yearlong, integrated science course; or they

may be used individually in discipline-specific courses. ASSET participants will implement at least one curriculum module, and conduct and report upon two significant outreach activities within two years. First year ASSET teachers implemented the curriculum and hosted outreach events ranging from teacher workshops to community astrobiology events.

Astrobiology Professional Development Workshops and Short courses for teachers

Professional development workshops and short courses are conducted for educators. Events feature Life in the Universe curriculum guides by theSETI Institute, the NAI Life on Earth and Elsewhere educator resource guide, as well as Voyages Through Time high school science curriculum. The workshops are aligned with National Science Education Standards, and provide astrobiology science content and pedagogical content knowledge.

NAI Team Public Science Talks

SETI Institute NAI scientists conducted public talks and lectures in several national and international venues. Elementary, middle school, high school, undergraduate, and graduate student groups are addressed, as well as the general public. Over 100 talks were given by 13 NAI team members to a total audience of more than 9000.

Alien Earth Exhibit Science Talks at Lawrence Hall of Science

SETI Institute's NAI EPO team organized the science speaker series for the Alien Earths exhibit at Lawrence Hall of Science, UC Berkeley, CA February 5, through March 8, 2005. Alien Earths is an astrobiology-themed interactive science exhibit designed for the public, and LHS was the first venue for this traveling exhibit. Approximately 300 visitors attended the speaker series.

Publications: SETI Institute

There are **29** publication entries for the SETI Institute

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27 members found.

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Projects | Publications | Update Profile

Executive Summary: University of Arizona

Executive Summary: University of Arizona
Principal Investigator: Neville Woolf
Reporting Period: 2005 (7/04-6/05)

This year has been an extremely productive year for the Arizona NAI team. We have not only had significant progress in instrumentation and research but have made great advances in administrative and collaborative areas within our local community, within NAI, nationally and internationally.

Collaborations

In July 2005, the Arizona Board of Regents approved the establishment of the Life and Planets Astrobiology Center – *LAPLACE* – establishing a formal commitment to the pursuit of astrobiology and its primacy in research activities. This LAPLACE complements and overlaps with the entity within the NAI team structure, also known by the acronym LAPLACE. This center within the University of Arizona (UA) system will provide the administrative means to expand our study of astrobiology to complement the astronomical focused NAI team. Additionally, the UA's College of Science hired its first astrobiology-designated faculty position under LAPLACE. Alex Pavlov (an NAI Ph.D. product) will begin his work at UA in January 2006.

LAPLACE has had a year of growing collaborative efforts within the local community and throughout the astrobiology community. Members of LAPLACE have been invited to participate in seminars and other forums at many institutions and these have included NAI Director's Seminars by Jonathan Lunine and Michael Meyer. Lunine was Program Director and Chris Impey and Nick Woolf were faculty members of the Vatican Observatory 2005 Summer School in Observational Astronomy and Astrophysics, its topic was *Astrobiology: The Search for our Origins and Life Elsewhere*. This school promotes the education of students from the developing world and funds their study at Castel Gandolfo Italy for four weeks in June. [http://clavius.as.arizona.edu/vo/R1024/VOSS2005.html].

LAPLACE has also been involved with the *Astrobiology and the Sacred: Implications of Life Beyond Earth* project at UA [http://scienceandreligion.arizona.edu/fellows.html]. We have participated in the lecture series and sponsored several of the visiting speakers. [A list of colloquia at UA and by LAPLACE researchers is submitted with this report]. In addition, the theme of our Biology/Medicine/Agriculture BIO5) symposium this year was Astrobiology. Further, we have participated in meetings of a U Arizona group on Quantitative Biology.

Collaboration with other NAI teams continued this fiscal year. In 2004 Carol Oliver of the Australian Centre for Astrobiology visited to work with the Education and Public Outreach researchers in Steward Observatory at UA. During her visit, she met with the LAPLACE team as part of one of its monthly group meetings to brief us on working with the media more effectively. Graduate researchers Danial Apai and Murray Silverstone participated in the NAI FAR seminar series with Apai serving on the organizing committee. Additional faculty members with Arizona team members in the Vatican Observatory Summer School were Baross and Sullivan from the NAI Washington team, part of a continuing Arizona-Washington collaboration. Woolf has participated in a joint NAI/TPF meeting to discuss Biomarkers, with Meadows, Crisp, Des Marais, and Kasting as well as additional Terrestrial Planet Finder (TPF) user group and SWG members.

In March 2005 LAPLACE hosted students from the University of Washington and non-astronomy departments of the University of Arizona for a five-day hands-on observing course on UA campus and at Kitt Peak National Observatory. The materials and format of this exchange was so successful that the UA Astronomy Camp used portions during their summer program 2005 and LAPLACE will implement a similar program open widely to graduate students in January 2006. The second phase of the exchange will occur in Fall 2005 when LAPLACE students and faculty travel to UW to learn about the biology aspect of astrobiology.

Finally, in our effort to bring astrobiology into the science departments at University of Arizona, the team has provided resources to bring in colloquium speakers, William Klemperer for both Astronomy and Chemistry colloquia, Steve Benner for a Chemistry colloquium and Gerry Joyce for a colloquium in Molecular and Cellular Biology.

The interest in astrobiology throughout the college of science has resulted in additional talks supported by the departments, for example Biochemistry had a colloquium by Robert Blankenship, and the BIO5 collaboration between Life Sciences and the Medical College had a one day symposium that included talks by Jack Szostak, Steve Benner and Jonathan Lunine.

Research

Module 1: The Building Blocks of Life succeeded in many areas during the year – in the lab, observationally and collaboratively. Aldo Apponi in the module completed construction of a pulsed molecular-beam Fourier transform microwave spectrometer. Results of analysis doubled the microwave data set for microwave spectrum of acetol. Researchers completed survey results of molecular cloud Sgr B2 (N) cover about half of the 2 and 3 mm (70 – 170 GHz) spectrum absolutely confirmed the identification of the interstellar molecules glycolaldehyde, vinyl alcohol and ethylene glycol; tentative detections of propenal and propanal have been made. Calculations performed on conformational behavior of sugars (ribose) showed multitude of structural isomers of these systems that differ little in terms of their stability. Observations of comets, Q4/NEAT and T7/LINEAR detected H_2CO towards both these comets at 1mm.

Module 1 scientists completed a study of $^{12}C/^{13}C$ ratios using the N=1_0 transition of CN produced results from CN are in reasonable agreement with previous ratios established independently from CO and H_2CO.

This module's work expanded collaborations within the University of Arizona between the astronomy and chemistry departments.

Module 2: Formation and Evolution of Habitable Worlds

This module aims to use observations of the gas and dust in (a) planet-forming accretion disks surrounding young stars; and (b) debris disks surrounding more mature stars to understand key steps and timescales in the formation of planetary systems and their evolution, and to constrain outcome planetary system architectures. Another objective of the module is to provide candidate targets for direct detection and characterization of planets.

Researchers used various telescopes, both ground- and space-based to further our understanding of habitable worlds. Joan Najita calculated the thermal-chemical structure of the gaseous atmospheres of the inner disks of accreting solar-like pre-main sequence stars then used these to predict the relative column densities of key molecular tracers used to characterize the gas content of PMS star disks. Detection of apparently abundant gas clearly lying within the apparent opacity hole – perhaps indicates an absence of small (r < 1 micron) grains in the inner disk Results from the Spitzer Space Telescope continue to inform our research program within Module 2. One of the striking Spitzer results has been the deviation from a steady decrease of dust with age of system, as in observations of HD12039, a rare 30 million year old star with a mid-infrared excess of emission by warm dust. These seem likely caused by rare early collisions between planetismals or late collisions between asteroids. In a related study, Steve Strom, Renu Malhotra, Toshi Ito, and David Kring (2005) argue that the late-heavy bombardment in the inner solar system was due in part to an influx of asteroids created through migration of the giant planets – with profound effects predicted dust generation rates in debris disks observed, and so there would not have been an earlier heavy impact phase, and the origin of life could possibly be moved back to 4.4 Gya. Najita and Williams' results of the 850 micron James Clerk Maxwell Telescope/ bolometer array survey suggest that the mass in small grains declines significantly on a ~200 Myr timescale. Paola D'Allessio et al. model accounting for the Spitzer Space Telescope Infrared Spectrogarph observations of CoKu Tau/4's "transition disk".

Module 3: Nature of Planetary Systems Direct detection for extrasolar planets is fast becoming a reality, and LAPLACE is well-poised to be in the forefront of this new area of research. Using multiple techniques researchers in this module are now in the process of carrying out surveys for young planets as well as developing new techniques which will push our sensitivity to older planets around more nearby stars. Module 3 work has developed new instrumentation to detect these planets, begun surveys using existing adaptive optics techniques and furthered modeling work to enable the interpretation of detections from a range of observatories, including, the Hubble Space Telescope (HST), Spitzer Space Telescope, and the James Web Space Telescope (JWST). This work is laying the foundation for understanding what other stellar systems may be hospitable to life and how we identify such systems. One of the most exciting discoveries was the discovery of close companion to AB Dor using Simultaneous Differential Imaging and

the determination that current theoretical models overestimate the brightness of substellar objects at young ages. Researchers have been working on improved sensitivity of MMT adaptive optics system to allow detection of planets of significantly smaller masses than other systems. Finally Burrows completed of comprehensive invited review for *Nature* by Adam Burrows that provides the best theoretical guide for the search for planets outside the Solar System.

EPO

The EPO effort on teaching teachers, and exploring conceptual difficulties of students has been making excellent progress as detailed in the separate report of the team. Here, special attention is paid to two collaborative projects, first in the University of Washington graduate student visit. The problems for transferring information across disciplines has some resemblances to the problems experienced with non-major undergraduates. We were therefore very appreciative of help from Dr. Tom Olien in the UW graduate student visit, where he participated in the teaching.

Secondly, the talks in the Astrobiology and The Sacred series has been used by the EPO team as an opportunity for continuing education of teachers. The teachers have both had special meetings with the speakers, and have been helped in preparation for the talks by the EPO team.

Future Plans

LAPLACE will continue to expand its collaborative efforts within local communities and internationally. Now that the Arizona Board of Regents has made LAPLACE an official center, one of our goals is to expand our teaching role, and in particular to organize the possibility of Astrobiology minors for Ph.D. programs. As part of the planning for this, Woolf will be visiting the University of Washington, to study how their astrobiology teaching program works, since it seems to have been the most successful to date.

We are currently planning the January 2006 Winter School in Astrobiology, where we intend to have 20 astrobiology students from other institutions and five from Arizona. We see this as the optimal number of students for the observing experience we can provide at Kitt Peak.

Among the new developments related to Astrobiology has been the casting of the first 8.4m mirror for the Giant Magellan Telescope, a 20m class optical/infrared telescope with a light gathering power 19 times the Palomar Telescope [http://www.gmto.org/]. A workshop to discuss the possibilities for observing extrasolar planets with this telescope is being organized with the Carnegie Institution of Washington astrobiology group.

Plans for research collaboration beyond the Arizona group is progressing, Arizona (L. Ziurys) has submitted a program “Follow the Carbon” with external collaborators S. Benner, D. Brownlee, S. Pizzarello, to explore the transportation of carbon from its sources into the solar system and the Earth, to explore its molecular modifications, and to study the possible processes whereby modestly changed material may have been available for the origin of life on Earth, either as a catalyst, or as a complex ingredient ahead of the development of catabolic pathways.

Project Reports: University of Arizona

An Astronomical Search for the Essential Ingredients for Life: Placing Our Habitable System in Context.

Project Investigator: Neville Woolf

Project Progress

Module 1: The Building Blocks of Life This module is concerned with examining the contribution of interstellar chemistry to the biochemistry that led to living systems on Earth. The focus of this investigation is the simple sugar ribose and its precursors, starting with formaldehyde. This module is attempting to accurately establish the presence of simple sugars and their precursors in interstellar gas, examine possible gas-phase mechanisms leading to such sugars, and investigate how such precursors might have found their way to a planet surface. This module therefore combines high resolution laboratory spectroscopy, radio astronomy of interstellar molecules, synthetic organic chemistry in the gas-phase, theoretical calculations of reaction pathways, comet studies, and investigations of carbon isotope ratios.

This module addresses

- Goal 3 of the Astrobiology Roadmap, Understand how life originates from cosmic and planetary precursors, Objectives 3.1 (sources of prebiotic materials) and 3.2 (origins and evolution of functional biomolecules), and
- Goal 4 of the Astrobiology Roadmap, Understand how past life on Earth interacted with its changing planetary and Solar System environment, Objective 4.3 (effects of extraterrestrial events upon the Biosphere).

Highlighted Accomplishments

- Completed construction of a pulsed molecular-beam Fourier transform microwave spectrometer.
- Measured the microwave and millimeter spectrum of the lowest energy conformer of acetol.
- Conducted survey of molecular cloud Sgr B2(N), covering about half of the 2 and 3 mm (70 – 170 GHz) spectrum; absolutely confirmed the identification of the interstellar molecules glycolaldehyde, vinyl alcohol and ethylene glycol; tentative detections of propenal and propanal have been made.
- Calculations performed on conformational behavior of sugars (ribose), showing the multitude of structural isomers of these systems that differ little in terms of their stability.
- Observations of comets, Q4/NEAT and T7/LINEAR; detected H_2CO towards both these comets at 1mm.
- Completed study of $^{12}C/^{13}C$ ratios using the N=1_0 transition of CN; results are in reasonable agreement with previous ratios established independently from CO and H_2CO, suggesting that chemical fractionation is not important.
- Expanded collaborations within the University of Arizona between the astronomy and chemistry departments.
- Performed 700 hours of observations using the Arizona Radio Observatory's 12-meter telescope at Kitt Peak, Arizona.

Laboratory Spectroscopy

In order to examine which molecular species are present in interstellar clouds, the pure rotational spectra of such compounds must be well-known. Because the molecules of interest are relatively heavy species with

complicated spectra at room temperature, Staff Scientist Aldo Apponi constructed of a pulsed molecular-beam Fourier transform microwave spectrometer in order to study these species. The supersonic jet nozzle, which is the source of molecular gas for this system, enables the species of interest to be cooled to low rotational temperatures, greatly simplifying a complex spectrum. This spectrometer is now complete and fully functional through our phase 1 goals of 3.5-18.5 GHz, and its sensitivity is within a factor of five of the design specifications. This spectrometer, used in conjunction with any of three direct absorption millimeter wave spectrometers of the Ziurys lab, has for the first time enabled us to characterized the complex gas phase spectra of prebiotic sugars, their derivatives and other prebiotic molecular precursors.

The first program in this study is the 3-carbon sugar hydroxyacetone. Hydroxyacetone, or acetol, is the simplest ketose. Identification of this sugar in interstellar environments will provide important clues on the chemical processes that form simple sugars. The well known interstellar sugar glycolaldehyde is thought to form via the condensation of formaldehyde- a process that is still not well understood. Hydroxyacetone, on the other hand, must form through a completely different mechanism. The contrast between these two mechanisms will place constraints on the models of interstellar organic chemistry.

The microwave spectrum of acetol was first studies by Kattija-Ari and Harmony (1980, *International Journal of Quantum Chemistry*, **14**, 443). Unfortunately, their dataset was not large enough to accurately predict any lines in the millimeter wave region. With our new microwave spectrometer, we have already doubled the microwave data set, a sample spectrum is shown in Figure 1. The constraints provided by these new measurements have enabled us to begin assigning the millimeter wave spectrum of acetol. So far, we have covered the full 3mm wave spectrum- the frequencies most relevant to an astrophysical search for this molecule- and we will begin searching for it in Sgr B2(N) in the Fall of 2005 using the ARO 12 meter telescope.

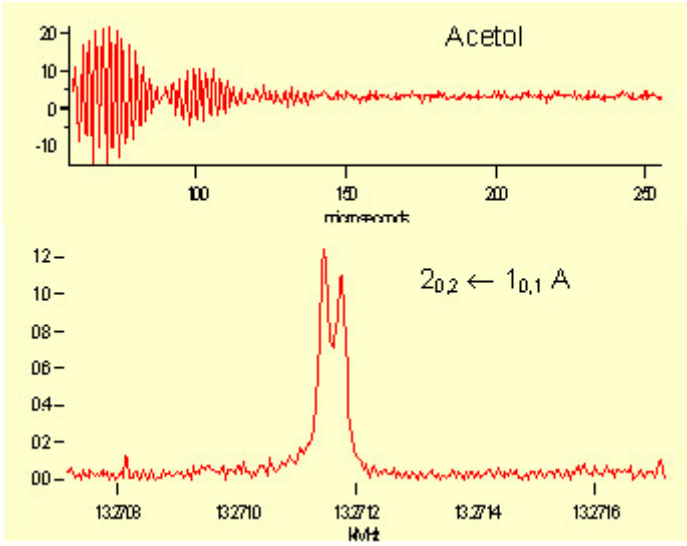

Figure 1: The $2_{0,2} - 1_{0,1}$ transition of acetol taken with the new FTMW spectrometer. The top figure shows the Free Induction Decay (FID), while the lower one is the actual spectrum.

Radioastronomy Searches for Prebiotic Molecules

Over the past two years, Apponi, Halfen, and Ziurys have begun an intensive interstellar survey towards the famous Sgr B2(N) molecular cloud near the Galactic center. This source harbors the most complex organic molecules, many of which have biologically important functional groups, i.e. aldehydes, acids, sugars, etc. Identification of molecules in the interstellar gas is vital for understanding the processes that occur in the condensed phase. For instance, much of the material found on the meteorites is closely related to the abundant molecules found in the interstellar gas, e.g. hydroxyl acids are related to aldehydes and hydrogen cyanide, amino acids are related to aldehydes, hydrogen cyanide and ammonia.

The millimeter wave spectrum of Sgr B2(N) is quite complicated, and has proven difficult to elucidate. For instance, two recently claimed detections, glycine and dihydroxyacetone, have subsequently been proven false. The only way to fully characterize these spectra is through highly sensitive surveys over the entire region where these molecules emit. We have thus far covered about half of the 2 and 3 mm (70 – 170 GHz)

spectrum of Sgr B2(N) and will complete the survey over the next 2 years. Additionally, a 1 mm survey (210 – 270 GHz) is also planned to start in the Fall 2005 using the ARO 10 meter telescope. Thus far, we have absolutely confirmed the identification of the interstellar molecules glycolaldehyde, vinyl alcohol and ethylene glycol; tentative detections of propenal and propanal have been made (see Figure 2). On the other hand, we see no evidence for dihydroxyacetone, glycine, propynal, or vinyl isocyanide. The results from this survey will greatly constrain the interstellar processes governing the production of prebiotic molecules.

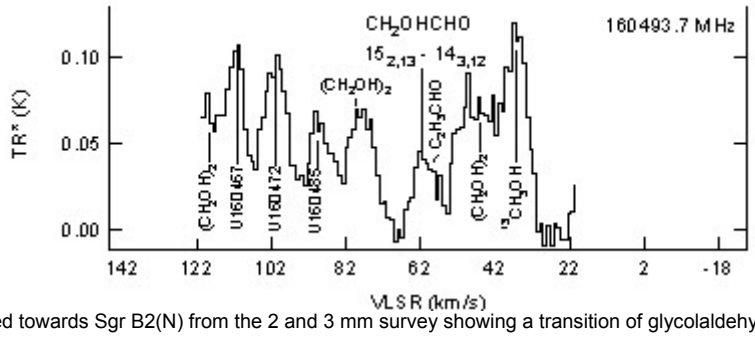

Figure 2: A sample spectrum measured towards Sgr B2(N) from the 2 and 3 mm survey showing a transition of glycolaldehyde. A tentative line of propynal is indicated.

Gas-Phase Synthetic Organic Chemistry

The prebiotic source of ribose is thought to be the so-called formose reaction, which leads from formaldehyde ($H_2C{=}O$) to glycolaldehyde or diose ($HOCH_2CH{=}O$), and eventually ribose $(CH_2O)_5$. A detailed aldol mechanism for the formose reaction sequence from the two-carbon diose onwards to the five-carbon ribose was proposed by Breslow (*Tetr. Lett.* **21**, 22, 1959). However, the mechanistic details of the first, and most crucial carbon-carbon bond-forming step from formaldehyde to diose remain murky.

In January, 2005 research scientist Leif Abrell started to examine acid-catalyzed, gas phase variants of the formose reaction using a drift tube instrument at 2.0 mbar. Formaldehyde gas in an argon stream was generated from paraformaldehyde. With access to a proton transfer reaction-mass spectrometer (PTR-MS) instrument, gaseous H_3O^+ was generated, and H^+ was transferred to formaldehyde ($CH_2{=}O$) in a drift tube (reaction chamber) at 2.0 mbar and 70°C. Collision reaction products with higher $(CH_2O)_n$ masses at 60, 90, and 120 amu were observed by quadrupole detection downstream from the PTR-MS drift tube. Multiple isobaric compounds with masses 60, 90, and 120 amu are possible, but could not be distinguished by the quadrupole mass spectrometry measurements. For example, quadrupole detection of protonated ion m/z = 61 may correspond to the following isobaric compounds with molecular formula $C_2H_5O_2^+$: acetic acid ($CH_3COOH_2^+$), methyl formate ($CH_3OCH{=}OH^+$), or the formaldehyde dimmer ($H_2C{=}O\text{-}H\text{-}O{=}CH_2^+$), in addition to diose ($HOCH_2CH{=}O\text{-}H^+$).

Structural information in the form of fragmentation patterns to distinguish between isobaric compounds with protonated masses 61, 91, and 121 amu will be used to identify possible formose reaction species. Preliminary results using the atmospheric pressure chemical ionization tandem mass spectrometry (APCI-MS/MS) in the Proteomics Core Facility at the UA College of Pharmacy indicated weak ionization. New sample conditions for APCI-MS/MS are being evaluated, and new experiments with the same samples in the gas phase are being planned using a direct batch inlet (DBI) method based on chemical ionization of sublimed samples and spectral measurement with a high resolution time-of-flight mass spectrometer (TOFMS) analyzer.

Theoretical Calculations

Work conducted by L. Adamowicz and students has centered on the study of structures and stabilities of some biologically-relevant sugars. Work has also started on mechanistic studies of the sugar formation reactions. The application calculations performed on conformational behavior of sugars (ribose) showed multitude of structural isomers of these systems that differ little in terms of their stability. The stability relations will help identify the most likely mechanism for sugar formation out of simpler systems. The group has started investigation of such mechanisms by performing calculations on the Nazarov-type reaction

concerning addition of two aldehydes mediated by a hydronium cation. This is a possible reaction contributing to the process of the gas-phase formation of simple sugars.

Cometary Studies

Comets are considered to be composed of pristine interstellar material from the molecular cloud from which our solar system was originally formed. As a comet orbits the solar system, it becomes significantly close to the sun's radiation at which point it begins to sublimate, ejecting ancient material into the solar system in the form of small particles and gases. These vaporizing gases trace the conditions of the molecular cloud from which our sun was formed 4.6 Gyr ago. Radioastronomy provides a mechanism by which cometary gases can be analyzed.

Two new comets appeared during 2004: Q4/NEAT and T7/LINEAR. Using the ARO 12-meter telescope, H_2CO was detected towards both these comets at 1mm. In the spectra observed towards LINEAR, a second velocity component appears to be present in the data (see Figure 3). This component could arise from thermal degradation of "POM" material that is thought to surround the comet nucleus, while the main component probably comes from direct sublimation of the water-ice matrix of the nucleus. These data are currently being analyzed, and compared with H_2CO spectra obtained from Hale-Bopp. CH_3OH and CH_3CN spectra observed towards comet Hale-Bopp are also being studied. This work is being conducted by S. Milam, L. Ziurys, and S. Wyckoff.

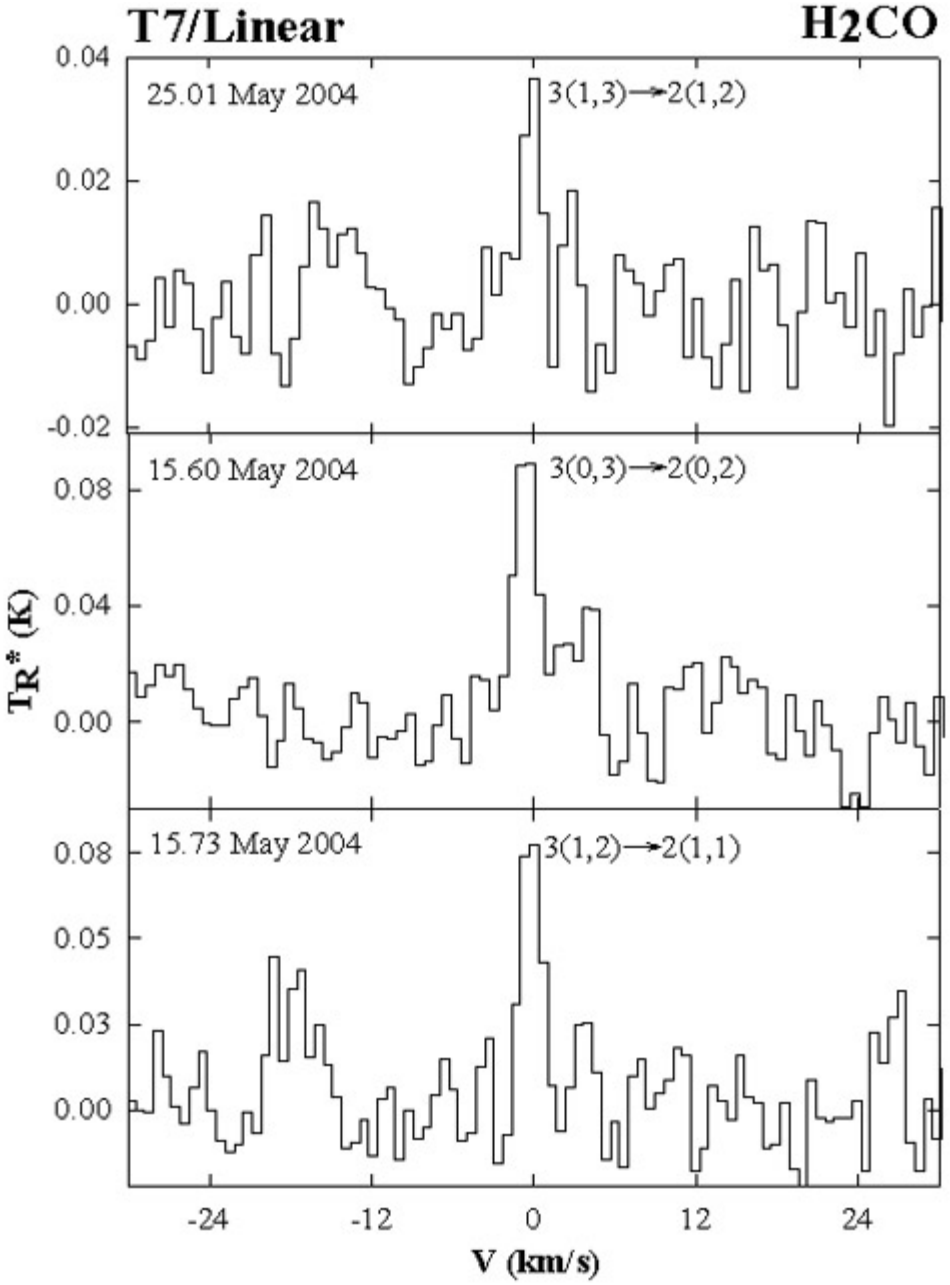

Figure 3: Observations of H_2CO towards comet T7/LINEAR in 2004. A feature is present in the May 15 data at ~3 km/s, believed to be a second component from a comet fragmentation event.

$^{2}C/^{13}C$ Isotope Ratios

One of the clear signatures of extra solar origins of material are isotope ratios. That of carbon is particularly important since organic chemistry is the chemistry of life. It is clearly necessary to establish this isotope ratio accurately outside our solar system. During this past year Milam, Ziurys, and Wyckoff have completed their study of $^{12}C/^{13}C$ ratios using the N=1_0 transition of CN; observations have been conducted with the ARO 12-m telescope. The results from CN are in reasonable agreement with previous ratios established independently from CO and H_2CO. These molecules all indicate a gradient across the Galaxy, as shown in Figure 4. The remarkable result is the agreement between the ratios obtained from these three molecules, which suggests that chemical fractionation is not important. Therefore, the $^{12}C/^{13}C$ ratios obtained are a true indicator of the relative amounts of ^{12}C and ^{13}C. Ratios obtained from organic compounds in meteorites and IDP's can be compared to interstellar values with some certainty and therefore be used to trace the origins of these materials.

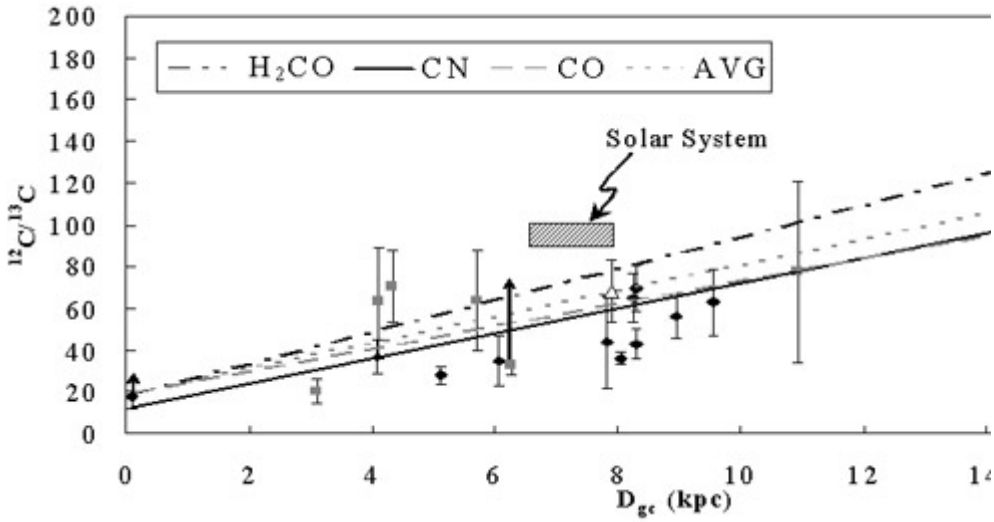

Figure 4: Plot of $^{12}C/^{13}C$ isotope ratios as a function of distance to the Galactic Center, D_{gc} (kpc). The gray squares are values of $^{12}C/^{13}C$ ratios derived in the current work and the black diamonds are values from Savage et al. (2002), both from CN: N=1_0 measurements conducted at the ARO 12m. A linear fit of the ratio derived from CN is plotted as a solid black line. The isotope gradient derived from CO is indicated by the gray dashed line and the black dash-dot line represents that resulting from H_2CO data. The gray dotted line represents the average from all three molecules.

Module 2: Formation and Evolution of Habitable Worlds

This module aims to use observations of the gas and dust in (a) planet-forming accretion disks surrounding young stars; and (b) debris disks surrounding more mature stars to understand key steps and timescales in the formation of planetary systems and their evolution, and to constrain outcome planetary system architectures. Another objective of the module is to provide candidate targets for direct detection and characterization of planets.

This module addresses:

- Goal 1 of the Astrobiology Roadmap, Understand the nature and distribution of habitable environments in the Universe.

Highlighted Accomplishments

- Detection of abundant gas lying within apparent opacity holes – perhaps indicating an absence of small (r < 1 micron) grains in inner disks.

- Results from the Spitzer Space Telescope continue to inform our research program within Module 2 concerning the evolution of inner dust disks, search for warm debris disks analogous to our solar system's asteroid belt, constraints on remnant molecular gas in debris disks, and the frequency of cold outer debris disks.

- Najita and Williams' results from the 850 micron JCMT/SCUBA survey suggest that the mass in small grains declines significantly on a ~200 Myr timescale.

Gas Content of Disks

Understanding the evolution of the gas in disks can provide insight into the processes of giant and terrestrial planet formation. In the context of giant planet formation, both total disk masses (which are dominated by the gaseous component) and the lifetime of gas in the giant planet region of the disk can be used to constrain the dominant mode(s) of giant planet formation.

The lifetime of gas in the terrestrial planet region of the disk is also of interest. This is because residual gas in this region of the disk can affect the outcome of terrestrial planet formation, i.e., the masses and eccentricities of planets, their speed of formation, and their consequent habitability. Only a narrow range of gas column densities is expected to produce terrestrial planets with the Earth-like masses and low

eccentricities that we associate with habitability on Earth.

These considerations motivate the characterization of the gaseous component of disks over a range of radii, in both the giant and terrestrial planet regions of the disk (1– 20 AU) and over a range of masses, from the large gas masses characteristic of giant planet formation ($1M_J$) down to the residual gas masses of interest for the outcome of terrestrial planet formation. The availability of sensitive near- and mid- IR high resolution spectrographs on 8-10m class telescopes provides a powerful tool for probing the gas content of disks and the radial distribution of gas within disks complementary to surveys for gas with the Spitzer Space Telescope and ground-based sub-mm facilities.

Module 2 members Najita and Chen have continued to carry out studies aimed at constraining the gas content and radial distribution of gas around solar-like and intermediate mass stars. In collaboration with Glassgold and Igea, Najita calculated the thermal-chemical structure of the gaseous atmospheres of the inner disks of accreting solar-like pre-main sequence stars, taking into account processes such as X-ray irradiation or mechanical heating of the surface layers, and calculating the vertical gas temperature structure in the neighborhood of 1 AU. These calculations are then used to predict the relative column densities of key molecular tracers used to characterize the gas content of PMS star disks (Glassgold, A., Najita, J. and Igea, I. 2004, ApJ 615, 972) – a key first step toward deriving gas masses from observations of tracers such as CO.

As part of the FEPS project, Hollenbach et al. (2005, ApJ in press) report infrared spectroscopic observations with the Spitzer IRS of HD 105, a nearby (d ~ 40 pc) and relatively young (t ~ 30Myr) G0 star with excess infrared continuum emission, which has been modeled as arising from an optically thin circumstellar dust disk with an inner hole of size r ~13 AU. The observations provide upper limits to the fluxes of H_2 S(0) 28µm, H_2 S(1) 17µm, H_2 S(2) 12 µm, [FeII] 26µm, [SiII] 35µm, and [SI] 25µm infrared emission lines. These authors compare the line flux upper limits to predictions from detailed thermal/chemical models for several assumed gas distributions in the disk and conclude that the gas content must be considerably below the value for a minimum mass solar nebula. Therefore, it is unlikely that there is sufficient gas for gas giant planet formation to occur in HD 105 at an age of 30 Myr.

Najita continued her studies (in collaboration with John Carr) of CO emission arising from circumstellar accretion disks surrounding classical T Tauri stars and a subset of classical TTS, so-called ‘transition disks’ which have exhibit spectral energy distributions suggestive of inner opacity holes extending from near the stellar surface to distances of several astronomical units. Of particular interest is the detection of apparently abundant gas clearly lying within the apparent opacity hole – perhaps indicating an absence of small (r < 1 micron) grains in the inner disk. Najita and collaborators are pursuing a variety of diagnostic observations aimed at understanding whether transition objects require the formation of planetary mass bodies both within the inner hole, and at the outer edge of the hole.

Chen is initiating studies of the gas content among a group of stars in the 5-10 Myr old Sco-Cen association whose spectral energy distributions suggest the presence of inner disk holes. These observations aim to place robust upper limits on accretion rates, and to attempt direct detection of gas in the inner disk regions.

Dust Content of Disks

Results from the Spitzer Space Telescope continue to inform our research program within Module 2. Recent highlights from the Spitzer Legacy Science Program entitled *Formation and Evolution of Planetary Systems* (http://feps.as.arizona.edu) include:

1. constraints on inner (R < 0.1 AU) disk lifetimes from a 3-8 micron survey of over 70 stars with ages from 3-30 Myr (Silverstone *et al*. 2005);
2. discovery of an unusual debris ring surrounding the star HD 12039 (Hines *et al*. 2005);
3. census of cold outer debris disks (R > 30 AU) surrounding sun-like stars (Kim *et al*. 2005); and
4. constraints on debris disk evolution in the 100 Myr old Pleiades open cluster (Stauffer *et al*. 2005). Additional studies undertaken by members of the MIPS Instrument Team as well as NASA grant LAPLACE Team Members Chen and Najita (Watson *et al*. 2005; Chen *et al*. 2005) complement this work.

The NAI grant to Arizona provides support for ground-based telescopic observations crucial to following-up this work. Research Associate Daniel Apai is leading efforts to:

1. resolve mid-infrared emission from debris disks surrounding FEPS targets using the techniques of direct imaging and nulling interferometry with the 6.5m MMT telescope as well as the Gemini Observatory; and
2. detect directly gas giant planets hypothesized to surround FEPS targets with debris disks that sport large inner holes in their dust distributions. Additional work focusing on whether brown dwarf objects, failed stars with masses less than that required to sustain energy-producing nuclear reactions in their interiors, form with circumstellar disks from which planets might form (Apai *et al*. 2005).

Models of Dust Evolution

Taking advantage of the interdisciplinary nature of research conducted within LAPLACE, team members Hinz, Kring, Malhotra, and Meyer are working to build models of solar system evolution that can be compared to observations of ensembles of sun-like stars in the disk of the Milky Way. For example, in a recent paper, Strom, Malhotra, Ito, and Kring (2005) argue that the late-heavy bombardment in the inner solar system was due in part to an influx of asteroids created through migration of the giant planets. Such an event would have profound implications for predicted dust generation rates in debris disks observed. In Figure 5, we compare a toy model for the evolution of our solar system to recent observations of debris disks surrounding sun-like stars as a function of age, as well as current observational limits and predictions for new capabilities under development.

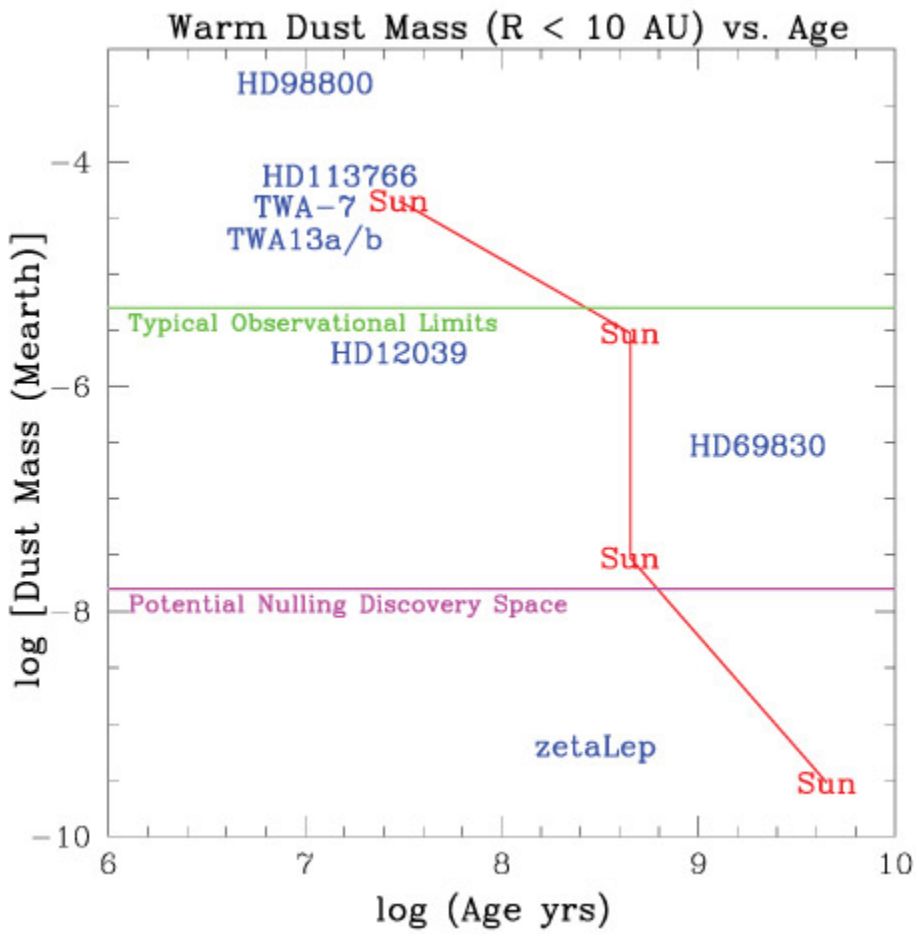

FIGURE 5: We compare recent debris disk detections to a toy model for the evolution of dust production in the inner zodiacal dust belt of our solar system which includes P-R drag at t^{-2} for late times, changes due to the late-heavy bombardment, and t^{-1} due to collision blow-out removal at early times. Also shown are current observational detection limits as well as the predicted performance of nulling interferometry on the MMT.

Finally, for his senior honors thesis, undergraduate student Praveen Kundurthy completed a study of the dependence of stellar rotation on the presence or absence of a disk from 0.1-1.0 AU traced by near- and mid-infrared excess emission. He presented this work at the NAI 2005 meeting in Boulder, CO and a final manuscript in being readied for submission to the PASP.

Workshops for Module 2

Module 2 members have instituted a series of all day workshops that cover aspects of planet formation including reviews of recent results from space- and ground-based observations, as well as advances in theory. In February, 2004, well-known planet formation theorist Professor D.N.C Lin visited LAPLACE from the University of California, Santa Cruz and participated in one of these workshops during an extended visit to the Tucson area.

Module 3: Nature of Planetary Systems

Direct detection for extrasolar planets is fast becoming a reality, and LAPLACE is well-poised to be in the forefront of this new area of research. Using multiple techniques researchers in this module are now in the process of carrying out surveys for young planets as well as developing new techniques which will push our sensitivity to older planets around more nearby stars. Module 3 work has developed new instrumentation to detect these planets, begun surveys using existing adaptive optics techniques and furthered modeling work to enable the interpretation of detections from a range of observatories, including, the Hubble Space Telescope (HST), Spitzer Space Telescope, and the James Web Space Telescope (JWST). This work is laying the foundation for understanding what other stellar systems may be hospitable to life and how we identify such systems.

This module addresses:

- Goal 1 of the Astrobiology Roadmap, Understand the nature and distribution of habitable environments in the Universe, objectives 1.1 (models of formation and evolution of habitable worlds) and 1.2 (indirect and direct astronomical observations of extrasolar habitable planets.

Highlighted Accomplishments

- Discovery of close companion to AB Dor using Simultaneous Differential Imaging.

- Determination that current theoretical models overestimate the brightness of substellar objects at young ages.

- Creation of self consistent models for the light curves and phase functions of giant planets at a broad range of orbital separations.

- Improved sensitivity of MMT adaptive optics system allows detection of planets of significantly smaller masses than other systems.
- Completion of comprehensive invited review for *Nature* by Adam Burrows that provides the best theoretical guide for the search for planets outside the Solar System.

Ongoing Near-Infrared Survey

Laird Close is leading an adaptive optics survey at H (1.65 micrometers) band to look for young companions using both the 8.2-meter Very Large Telescope (VLT) in the southern hemisphere and the 6.5-m MMT in the northern hemisphere. Graduate student Eric Nielsen is carrying out the survey. Their approach uses the technique of Simultaneous Differential Imaging (SDI) in and out of methane to enhance sensitivity to giant planets in the presence of scattered light of the parent star.

One of the significant early results from this survey is the discovery of a close companion to AB Dor (Close *et al*. 2005). Dynamical determination of the mass, combined with the brightness measurement at H band indicates that current theoretical models overestimate the brightness of substellar objects at young ages. Calibration of these models is important for understanding the sensitivity to giant planets of the ongoing surveys.

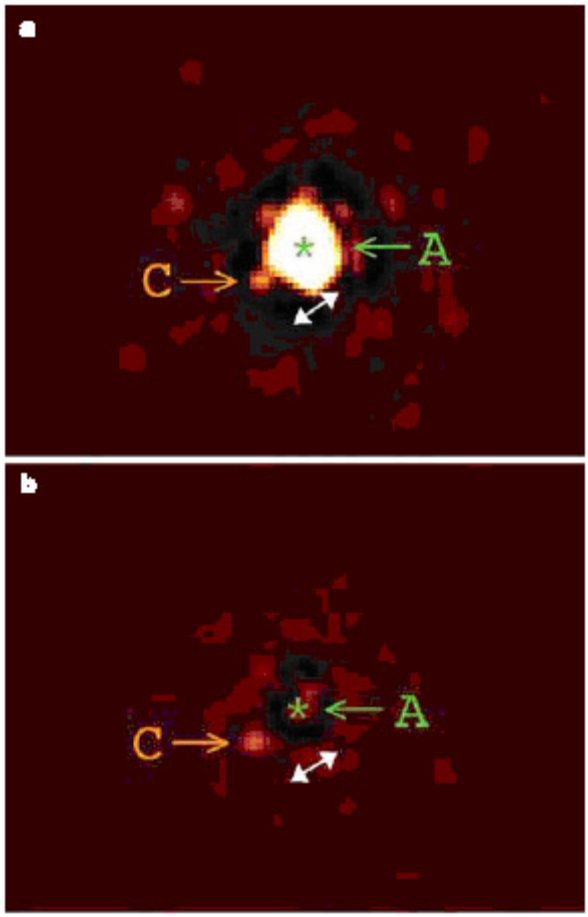

Figure 6: Discovery image of AB DOR C with the NACO SDI high contrast camera. a. The 1.625-µm image. **b**. The SDI of the 1.625-1.575 µm images illustrates how the SDI camera enables the subtraction of the scattered light from AB Dor A to reveal the significantly redder source AB Dor C (contrast enhanced in **b**). The white scale bar is the system separation of just 0.156'. Both images have had the lowest spatial frequencies removed (unsharp-masked) to help highlight the 'point-like' sources in the field. AB Dor C is the faintest companion ever imaged within 0.16' of a star.

Adaptive Optics Development

The MMT Adaptive Optics (MMTAO) system is the only such system integrated into the telescope itself. This allows a uniquely smooth point spread function and much lower background in the infrared. Both of these increase the system's sensitivity for extrasolar planets.

Work this past year has focused on developing techniques of improving the correction of the adaptive optics system. Currently we only correct for aberrations which manifest themselves on spatial scales larger than ~1 meter. By improving calibration of our system we expect to be able to correct for aberrations down to size scales of approximately 0.5 m. Progress in this area is summarized in Brusa et al. (2004) and Kenworthy et al. (2004).

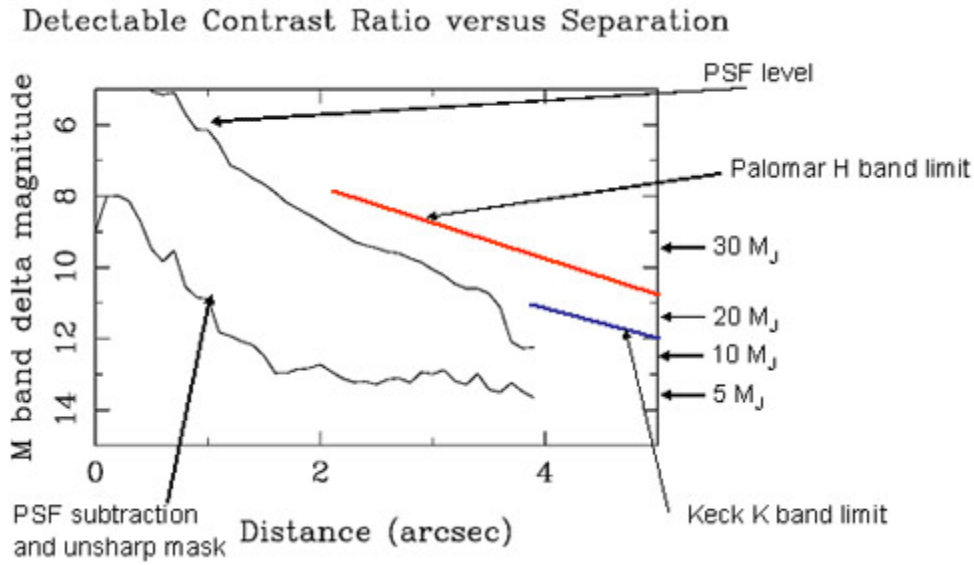

Figure 7: The detectable contrast achievable versus separation for the 6.5 m MMTAO system at 4.8 microns wavelength for the star Vega. The top black line is the level of the Point Spread Function (PSF) for the instrument. The lower black line is the detectable contrast of an object when the PSF is subtracted from the original image and spatially filtered to remove low order terms (unsharp masked). The scale on the right axis shows this M band contrast in terms of planets around Vega. The red and blue lines show similar limits at shorter wavelengths using two other AO systems, The 5 m Palomar AO system at H (1.65 micron) band and the Keck 10 m AO system at K (2.2 micron) band).

3-5 micron Camera Development

The unique sensitivity of the MMT AO system has been demonstrated this past year using a newly developed 3-5 micron imager (see Freed *et al*. 2004), called Clio. Phil Hinz has lead this effort. An early result suggests that we can detect giant planets down to nearly 5 Jupiter masses around the nearby star Vega (Hinz *et al*. 2005, in prep.). Figure 2 shows the expected contrast ratio achievable with the MMT AO system and Clio. Comparison to AO systems working at shorter wavelengths on Keck and Palomar telescopes suggests that the system is sensitive to planets of significantly lower mass.

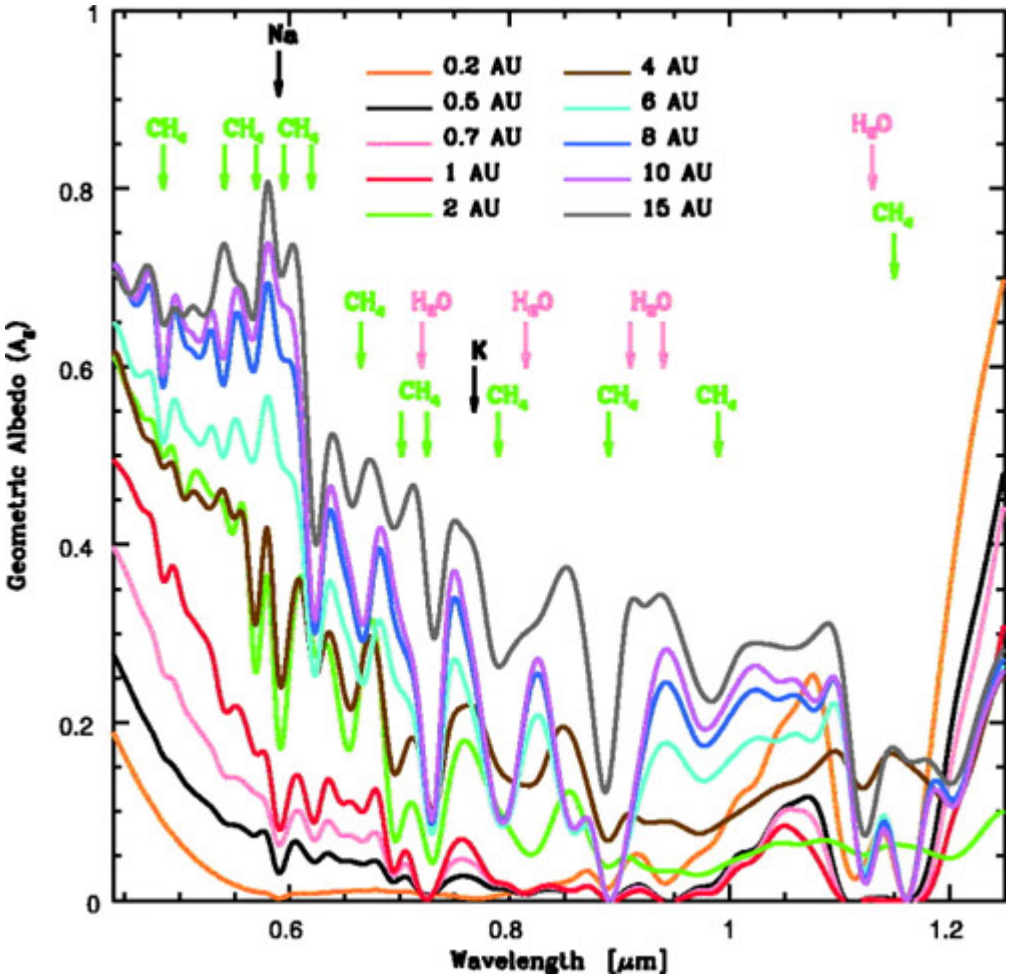

Figure 8: Low-resolution, wavelength-dependent geometric albedos of 1M_J, 5 Gyr Extrasolar Giant Planets (EGPs) ranging in orbital distance from 0.2 to 15 AU about a G2 V star. Cubic splines are fit to all albedo data.

Modeling Work

Lead by Adam Burrows, work on planet modeling this past year has focused on how planets detected by transits compare to existing models (cf. Burrows, Hubeny, and Sudarsky, 2005 and Burrows *et al*. 2004), as well as creating self consistent models have for the light curves and phase functions of giant planets at a broad range of orbital separations (Sudarsky *et al*. 2005).

Adam Burrows contributed a comprehensive invited review to Nature, entitled "A theoretical look at the direct detection of giant planets outside the Solar System". The paper lays out the most attractive spectral regions and techniques for detection based on the theoretical modeling. This work is currently our best guide to aid ongoing searches.

Module 4: Winter School Institute

LAPLACE has modified the original proposal's plan to conduct a semester long winter school. Instead we have implemented more innovative approaches to training the next generation of astrobiologists. In the last year's annual report, we discussed the initiation of a Graduate Student Conference. This year LAPLACE worked with another NAI team, the University of Washington, to initiate an exchange of students between the two institutions to participate in hands-on work in a subdiscipline different from their area of expertise. Additionally Nick Woolf and Michael Meyer hosted a Journal Club for graduate students focusing on astrobiology. LAPLACE also participates in the *Templeton Lecture Series: Astronomy and the Sacred.*

Highlighted Accomplishments

- LAPLACE hosted students from the University of Washington and non-astronomy departments of the University of Arizona for a five-day hands-on observing course on UA campus and at Kitt Peak National Observatory.
- Development of materials and establishment of format for effective teaching across disciplines in astrobiology.

- Completion of a semester of Astrobiology Journal Club.
- Participation in the Templeton Lecture Series: Astronomy and the Sacred.

- Participation in the Vatican Observatory Summer School.

LAPLACE-UW Exchange – Phase 1

To carry out our goals of educating the next generation of astrobiology researchers, the NAI Arizona (University of Arizona (UA) and National Optical Astronomy Observatory (NOAO)) team is collaborating with the NAI University of Washington (UW) team to hold a hands-on, bilateral exchange program in which students in both teams participate in scientific research at each site. We believe that in order for astrobiologists to make significant and comprehensive discoveries in a specific area of expertise, they must have an appreciation and understanding of the techniques, limitations and power of disciplines other than their own. How effectively this occurs can be problematical. This Exchange brings together Arizona and UW researchers to learn and share information, methods and questions to promote greater appreciation and understanding of what other astrobiologists do and how they do it.

The first phase of this joint activity brought fourteen graduate students from UW and three non-astronomy graduate students from UA to Kitt Peak, Arizona for three days and nights of astronomical observing in March 2005. Arizona faculty and staff, working in close concert with Woody Sullivan of UW, created a curriculum that included hands-on laboratories at five telescopes – three concentrating on optical and infrared night-time observations, one on millimeter wave molecular line observations of interstellar clouds and one on observations of the Sun. The curriculum included information for non-astronomers and ample time for informal discussion and collaboration. Preparatory sessions prior to the March site activities benefited from the use of televideo equipment for meetings as well as postings on web sites.

Work at the telescopes focused on two themes: the Sun as a star through time and the formation of solar-type stars. Despite less-than-optimal weather, the activity was a great success. Members of the Exchange staff were: Daniel Apai, Aldo Apponi, Cathi Duncan, Mark Giampapa, Jonathan Lunine, Michael Meyer, Erika Offerdahl, Tom Olien, William Sherry, Nick Siegler, Paul Smith, Anna Spitz, Woody Sullivan, Nick Woolf%, Lucy Ziurys and telescope scientists, telescope operators, website developers and student workers. Participant exit surveys rated the labs, organization, instruction, logistics, facilities and overall experience. Many students found the discussion sessions among biologists, astronomers and planetary scientists to be some of the most worthwhile times. Most students stated that they learned a great deal from the experience gaining a greater appreciation for their astrobiological colleagues' fields of research that will enrich their own research.

The second phase of this exchange will be a trip for LAPLACE graduate students and faculty to UW to participate in marine biology research in October, 2005.

The materials developed for this exchange are available online and will be used for future programs. The UA Astronomy Camp modified the radio astronomy portion of the curriculum for use in its summer program for 2005. LAPLACE will use these materials and format (with modifications) to host a Winter School in January 2006.

Astrobiology Journal Club

This year Woolf and Meyer instituted and hosted the Astrobiology Journal Club. This forum provides research and discussion about recent journal articles. In addition, Michael Meyer delivered a series of lectures to and international group of graduate students assembled for the 2005 Kobe International Summer School on Planetary Sciences (http://www.kobe-u.ac.jp/21COEPS/SCHOOL/2005/2005_ischool.html). Students became the primary drivers of the journal articles selected and the discussion forum. The group established a website for distribution and interaction, http://gould.as.arizona.edu/~meyer/grad/astrobio. The Journal Club format proved very effective in extending students' field of expertise into other areas of interaction. Interactions among researchers with different areas of concentration were most beneficial.

Collaborations

LAPLACE Director, Nick Woolf, and Jonathan Lunine were part of the Vatican Observatory Summer School faculty during the month of June. This program (http://clavius.as.arizona.edu/vo/R1024/VOSS2005.html) targets students from developing nations and funds their four-week study at the Vatican Observatory in Rome. The exchange of ideas about materials, techniques and formatting will be useful in consideration of the Winter School at LAPLACE in 2006.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 3.2:** Origins and evolution of functional biomolecules
- **Objective No. 4.3:** Effects of extraterrestrial events upon the biosphere

Cross Team Collaborations

EPO Reports: University of Arizona

Integrating Math & Science: The Universe is a Really Big Place

One-hour workshop and curricular materials presentation at the Arizona Science Teachers Association conference. The topic focused on size and scale within the context of Astrobiology. 15 middle school/high school teachers were in attendance.

Teaching Interdisciplinary Science: Voyages Through Time

One-hour workshop and curricular materials presentation at the Arizona Science Teachers Association conference. The topic focused on familiarizing teachers with the Voyages Through Time curriculum. In particular, teachers completed an activity on Habitable Zones borrowed from the Planetary Evolution Module. 16 high school teachers were in attendance.

Teaching Astronomy and Astrobiology from a Learner-Centered Perspective

Astronomy and its interdisciplinary partner, astrobiology, provide a unique and interdisciplinary environment for teaching the excitement of scientific inquiry to college students. At the same time, high quality teaching presents an ardent challenge because students who most often elect to take interdisciplinary science courses are frequently apprehensive of science and mathematics courses in general. Offered as a part of the Chautauqua Short Courses for College Teachers NSF sponsored program, this three-day, interactive teaching excellence workshop focused on the content and pedagogical dilemmas faculty encounter and develop practical solutions for the troubling issues in curriculum, instruction, and assessment. After reviewing the latest research in the study of the origin and evolution of life on Earth, the search for earth-like extra solar planets, cognitive research on how students learn, participants defined and set measurable student learning goals and objectives for students in their interdisciplinary astrobiology courses and learned to construct effective course syllabi. To improve instruction, participants learned how to create productive learning environments by using interactive lectures, peer instruction, engaging demonstrations, collaborative groups, tutorials, computer-based laboratories, and observational projects. Participants also learned how to write more effective multiple-choice tests and implement authentic assessment strategies including portfolio assessment, performance tasks, and concept maps.

Astrobiology for Teachers

This is an on-line course for middle and high school science teachers. The course topics cover the discovery of planetary systems around other stars, the nature of habitable zones around distant stars, the existence of life in extreme environments including the hydrothermal ecosystems of Yellowstone National Park, and the cryogenic ecosystems of Antarctica. These concepts serve as a foundation to study possible extraterrestrial ecosystems on objects like Mars and Europa. The teachers also investigate the methods used in the ongoing search for extra-terrestrial intelligence (SETI). The overarching theme of the course is to align the teaching of astrobiology concepts with the National Science Education Standards and the NASA Roadmap for Astrobiology Research. Sponsored by NASA Astrobiology Institute. Teachers develop strong pedagogical content knowledge in astrobiology. 23 middle and high school teachers completed the course.

Astrobiology and the Sacred - Educator's Forum

This Educators Forum was an extension of "Astrobiology and the Sacred: Implications of Life Beyond Earth", the theme of a public lecture series at the U of A, sponsored by Templeton Foundation for the Constructive Engagement of Science and Religion and the Life and Planets Astrobiology Center (LAPLACE), the NAI node at U of A. 32 teachers attended over 4 different sessions. The purpose of the forum was to explore the needs of science teachers to deal creatively with issues of spirituality and religion in the

classroom.

Astrobiology and the Sacred: Implications Beyond Earth

This twin lecture series is co-sponsored by Templeton Foundation for the Constructive Engagement of Science and Religion and the Life and Planets Astrobiology Center (LAPLACE), the NAI node at UA. It builds on local expertise in the emerging field of astrobiology, with a program that extends the discussion to include scholars in the Arts, the Humanities, and the social sciences. In addition to acting as the primary vehicle for an annual series of research lectures, the program engages in outreach and create curriculum materials for non-science majors, astronomy majors, and for high school science teachers and their students. Lectures from each series will be reviewed and published in book form. Each entire lecture series will be disseminated via delayed Internet web-cast, and will be made available on DVD.

Voyages Through Time (VTT) Collaboration

NAI EPO team member from University of Arizona attended a Voyages Through Time teacher training workshop to become acquainted with the curriculum. The member will then be responsible for contributing to VTT dissemination efforts via workshops, short courses, and professional development experiences for teachers.

Sabbatical Astrobiology Collaboration

Professor of Biophysics arrived at the University of Arizona Life and Planets Astrobiology Center from Canada. He collaborated with the Conceptual Astronomy and Physics Education Research (CAPER) group to learn sound pedagogical teaching and research methods in the field of astrobiology. He was a lead instructor for the on-line astrobiology course co-sponsored by NAI.

University of Washington Graduate Student Exchange

Graduate students from the University of Washington visited the University of Arizona with the intent of gaining valuable background content knowledge in astronomy. While in attendance, graduate students went on observing runs at Kitt Peak National Observatory.

Not Your Brother's Science Camp

This interdisciplinary summer science camp was targeted at middle school girls. 8 girls total attended the 10-day summer camp. Girls explored astrobiology topics such as cell structure, spectroscopy, importance of water for life, as well as took a visit to the upcoming Mars Phoenix Mission "headquarters".

Publications: University of Arizona

There are **42** publication entries for the University of Arizona

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Executive Summary: University of California, Berkeley

Executive Summary: University of California, Berkeley
Principal Investigator: Jill Banfield
Reporting Period: 2005 (7/04-6/05)

Research and education/outreach efforts of our team center around the question of life detection on Mars. Thus, we have analyzed when and where habitable environments may have formed over Mars' history. This has included atmospheric chemical studies that have revealed that organic aerosols may have had a larger influence on the climate than previously estimated early in Mars history. Through study of the interaction between Martian geodynamic and hydrologic processes and via modeling, we deduce that features mapped as potential shorelines up to 2 km high could indeed be paleoshorelines from large, vanished oceans. We conclude that Martian landslides in Valles Marineris were probably dry and propose that at least some of the Martian outburst floods were triggered by large impacts. Examination of several terrestrial channels that share features with channels on Mars has ruled out channel formation by groundwater discharge alone. These analyses provide important constraints for development of plausible models for Martian topography, information that is being used to predict sites with long term water that may have sustained life.

Given water, the next consideration for habitable environments is a readily utilizable energy supply. Thus, we have turned to Earth-based biomes that are populated by chemoautotrophic organisms that utilize iron and/or sulfur to provide possible analogs for present or past Martian biomes. Our study sites include groundwater seeps, one of which is a channel site chosen for its apparent geomorphological similarity to channels on Mars, and surface, subsurface, and sub-oceanic sites characterized by geochemical disequilibria involving iron and/or sulfur. We have defined the membership of microbial communities at these sites, quantified organism activities *in situ*, and monitored population dynamics. We have uncovered certain biogeochemical processes that underpin these systems, including the role of inorganic aqueous molecular clusters as substrates for microbial growth. This work has included analysis of fine scale and molecular biomarkers and has taken advantage of newly developed culturing strategies and state-of-the art geochemical, isotopic, genomic, biochemical, and proteomic methods.

Our EPO efforts integrate aspects of this research into educational modules for middle, and high school classes and after school groups. We have begun field-testing materials in schools and community centers in northern California communities that contain large African American, Latino, and Asian/Pacific Islander populations, including Berkeley, Oakland, and Richmond. Our hope is that the excitement associated with ongoing Mars exploration can be harnessed to motivate students to understand scientific concepts central to the problems of detecting life in a foreign world.

Project Reports: University of California, Berkeley

Iron and sulfur-based biospheres and their biosignatures

Project Investigator: Jill Banfield

Project Progress

We have examined the chemical and microbiological composition of groundwater Fe seep material from Tuscaloosa, AL and weathered basalt materials from Box Canyon, ID. Significant numbers of both Fe(III)-reducing and Fe(II)-oxidizing microorganisms were detected in both materials, which suggests the potential for microbially-catalyzed Fe redox cycling. Several highly-purified Fe(III)-reducing and Fe(II)-oxidizing cultures have been obtained and are currently being physiologically and phylogenetically characterized. A 16S rRNA gene clone library indicated the presence of a variety of lithotrophic ammonium- and Fe(II)-oxidizing phylotypes in the Fe seep community, and additional clone libraries have been constructed for both the Fe seep and weathered basalt communities. Incubation of amorphous Fe(III) oxide-rich seep material under anaerobic conditions demonstrated the potential for rapid Fe(III) oxide reduction. These results are conceptually consistent with previous studies with cocultures of Fe(III)-reducing and Fe(II)-oxidizing bacteria, and suggest that tight coupling of microbial Fe oxidation and reduction takes place in the seep environment. Similar results were obtained with the weathered basalt materials, which are unique in that they contain magnetic Fe(III) oxide phases (presumably maghemite), which appear to be converted to the magnetite during microbial reduction. The Fe seep and weathered basalt systems provide models for how microbially-catalyzed Fe redox cycling could take place in subsurface Martian environments where reduced fluids/solids contact oxygen-bearing water or water vapor. Simultaneous operation of Fe(III) oxide reduction and Fe(II) oxidation reactions could in principle support a self-sustaining Fe redox cycle-based microbial life system that could be sustainable over geological time scales.

Roadmap Objectives

- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
1		Co-Investigator

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Mission involvement: Co-I Bishop is also a Co-I on the CRISM spectrometer (http://crism.jhuapl.edu/) that just launched to Mars on MRO (http://marsprogram.jpl.nasa.gov/mro/). She is collecting VNIR spectra of S and Fe-bearing rocks and minerals in an effort to identify these important indicators of aqueous processes on Mars with CRISM in the coming months.

Field Expeditions

Field Trip Name: Loihi Seamount

Start Date: October 15, 2004
End Date: October 24, 2004
Continent: Pacific Ocean 25 miles SI of Hawaii
Country: USA
State/Province: Hawaii
Nearest City/Town:
Latitude: 155.5 degrees W
Longitude: 19.5 degrees N
Name of site(cave, mine, e.g.): Loihi Seamount
Keywords:
Description of Work: Sampling and experiment deployment and recovery using University of Hawaii R/V Kaimikai O Kanoloa and DSV Pisces V. Collected microbial Fe mat samples for culturing and molecular studies; deployed and collected in situ samplers.
Members Involved:

Field Trip Name: Prince William County iron seeps
Start Date: December 2004
End Date: December 2004
Continent: North America
Country: USA
State/Province:
Nearest City/Town: Prince William County
Latitude:
Longitude:
Name of site(cave, mine, e.g.): Iron seeps
Keywords:
Description of Work: Emerson Group: To collect samples of freshwater Fe mats for laboratory studies.

Luther Group: To perform in situ Fe(II) oxidation measurements on samples of freshwater Fe mats.
Members Involved:

Field Trip Name: Lau Basin
Start Date: June 2005
End Date: June 2005
Continent: Pacific Islands
Country: Fiji
State/Province:
Nearest City/Town:
Latitude:
Longitude:
Name of site(cave, mine, e.g.): Lau Basin
Keywords:
Description of Work: Research cruise, funded by NSF, using Jason II
Members Involved:

Field Trip Name: Snake River Plain / Box Canyon
Start Date: November 6, 2004
End Date: November 8, 2004
Continent: North America
Country: USA
State/Province: Idaho
Nearest City/Town:
Latitude:
Longitude:
Name of site(cave, mine, e.g.): Box Canyon
Keywords:
Description of Work: Description of work: Dietrich Group: Researched the possible role of groundwater sapping in Martian channel development.

collected samples for cultivation of Fe-oxidizing bacteria

Yim Group: This site provided an example of the types of terrain that robots may need to traverse and the opportunity to observe scientists obtaining samples providing input for future development criteria for robot technology. Banfield group; examination for relevance for geomicrobiology studies; Roden and Emerson Groups: microbiology sample collection.
Members Involved:

Field Trip Name: Alum Rock State Park
Start Date: Several trips in 2004-5 **End Date:** 2004-5
Continent: USA **Country:** USA
State/Province: California **Nearest City/Town:** Hayward
Latitude: **Longitude:**
Name of site(cave, mine, e.g.): Alum Rock State Park **Keywords:**
Description of Work: The Manga, Banfield, Emerson, and Luther groups participated in a field trip to Alum Rocks State Park near Hayward, CA that has numerous small sulfureta associated with groundwater flows from the host rock. Emerson has subsequently worked with one of Banfield?s students, Jonathon Giska, and performed MPNs for S-oxidizing bacteria from this site as well as direct counts of total cell numbers. Initial results suggest there is significant variability between localized sites. This work is being followed up on with more culture studies as well as molecular analysis. (relates also to subproject 2)
Members Involved:

Cross Team Collaborations

Emerson Lab: Cross Team Collaborations: We have collaborated quite extensively with the NAI team at the Carnegie Institute of Washington, Dr. Sean Solomon, PI. The most exciting aspect of this collaboration is with Dr. Andrew Steele of CIW and Dr. Ed Vincenzi of the Smithsonian Institution. Together we have begun to undertake a detailed analysis of bacterial iron biominerals at very high resolution using Raman Spectroscopy and TOF-SIMS coupled with microscopy to both image and identify mineral states and chemical bonds, qualitatively and quantitatively. This work has yielded some exciting initial results and we are proceeding to do more systematic studies. In addition, we collaborate extensively with Dr. Katrina Edwards who is part of the MBL team on studies at Loihi. We have a separate NSF grant for studying this site with Dr. Edwards and other colleagues.

Luther Lab: Efforts to study in situ Fe(II) oxidation in the microbial mats at Chocolate Pots shows that Fe(II) oxidation is mainly caused by photosynthetic O2 production and 10% or less by chloroflexus, a Fe(II) oxidizing organism. This work was done in collaboration with Dr. Beverley Pierson of the University of Puget Sound, who is a member of the Arizona U. NASA NAI. We have also transfered electrode technology to the U. Hawaii NASA NAI, as one of my former graduate students is now a postdoctoral student there.

The Banfield Lab: In addition to interactions with other NAI teams, the Banfield lab has intiated discussions and meetings with the Spanish and Australian Astrobiology institutes. In the former case, a trip to Spain to investigate paralellisms between the Iron Mountain and Rio Tinto acid mine drainage (iron sulfur biosphere) systems is planned in the near future. In the case of the Australian institute, funds have been secured for reciprocal team visits. An initial field trip to a potential joint field site in Australia (Mars analog site) was undertaken and samples collected for preliminary analysis. We have also participated in discussions with several other teams under the Microbial Systems Initiative.

Relationship between hydrogeology and microbiology at active springs

Project Investigator: Michael Manga

Project Progress

This project examines relationship between hydrological and biological diversity within a mesophilic, sufide-rich spring system. We are focusing on a set of springs in which the water composition, temperature and discharge are variable because of the mixing of groundwater from different sources. These springs are terrestrial analogues for late-stage groundwater discharge at the Martian surface. The site was chosen chosen based on geologic history, extant biology, and the accretion of large calcite 'mounds' created by spring water discharge. The mounds allow us to relate the extant biological communities to that preserved in the calcite mounds and to discern taphonomic processes affecting biosignature preservation. This allows us to identify the potential and challenge of finding a fossil record of life at spring deposits on other planets.

Even though the springs all lie within a few tens of meters of each other there is a wide range of hydrogeochemical properties and this is reflected in the biological communities that inhabit the springs. The dominant biology present at each spring is composed of sulfur-oxidizing members of both the Epsilon- and Gammaproteobacteria as revealed by 16S rRNA analysis; lipid analysis of the biomass confirms this observation. To date wee have been monitoring the hydrology of these springs for two years (discharge, temperature, geochemistry, water source as identified with stable isotopes of O and H). These measurements allow us to develop theoretical models for the hydrogeology associated with the springs and hence to understand their evolution in time, and the origin of spatial variability, of water temperature and geochemistry. We also have biological samples from a year period. In addition to differences between individual springs, we also see seasonal variations in the biological communities at a given spring.

A second site was chosen which we believe may be more analogous to Martian springs during periods of high discharge because the springs originate is largely unweathered basalt. They may also represent a possible terrestrial analog for Fe-based microbial ecosystems on Mars. This site (Box Canyon, Idaho) has been the subject of geomorphological and hydrological research by our NAI team (see subproject 1). We have focused on enumeration, enrichment, and isolation of lithoautotrophic Fe(II)-oxidizing and dissimilatory Fe(III)-reducing microorganisms from this circumneutral pH groundwater seep environment. At present we have several highly-purified enrichment cultures, and are preparing to isolate organisms in pure culture. The phylogenetic position of the pure culture isolates will be compared to in situ microbial community composition at the two sites as determined by 16S rRNA gene clone libraries (currently under construction) in order to assess whether the cultures are representative of dominant Fe redox-metabolism organisms in situ.

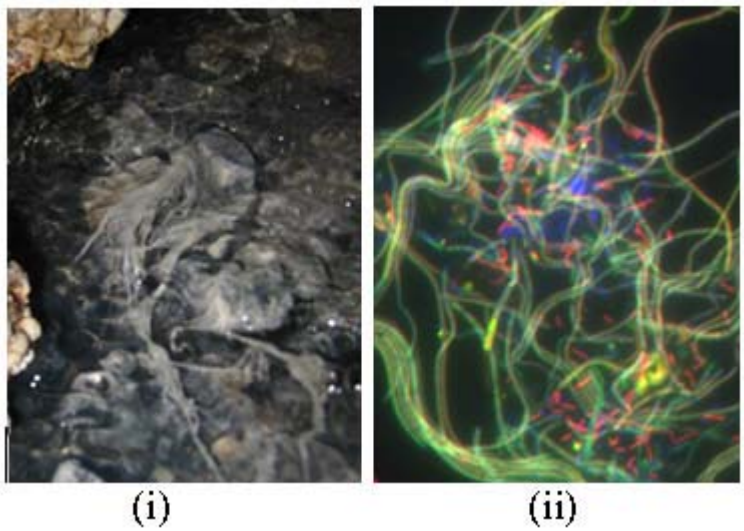


Figure (i) Biofilm present on the surface of spring water; (ii) Flourescent in situ hybridization of the biofilm - blue indicates presence of nucleic acids, red and green indicate Epsilon- and Gammaproteobacteria, respectively.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 2.1:** Mars exploration
- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Field Expeditions

Field Trip Name: Prince William County iron seeps
Start Date: Dec 2004 **End Date:**
Continent: **Country:** USA
State/Province: **Nearest City/Town:**
Latitude: **Longitude:**
Name of site(cave, mine, e.g.): **Keywords:**
Description of Work: Sample freshwater Fe mats for lab studies; perform in situ Fe(II) measurements of mats
Members Involved:

Field Trip Name: Box Canyon
Start Date: Nov 6, 2004 **End Date:** Nov 9, 2004
Continent: **Country:** USA
State/Province: **Nearest City/Town:**
Latitude: **Longitude:**
Name of site(cave, mine, e.g.): **Keywords:**
Description of Work: Examine possibility of groundwater sapping in bedrock as an analog for Martian channel development; collect samples for cultivating Fe-oxidizing bacteria; test robots in complex and difficult terrain.
Members Involved:

Field Trip Name: Alum Rock Spring
Start Date: Jan 2003 **End Date:** continuing
Continent: **Country:** USA
State/Province: **Nearest City/Town:**
Latitude: **Longitude:**
Name of site(cave, mine, e.g.): **Keywords:**
Description of Work: This project involves approximately monthly site visits. Sample spring water for stable isotope measurements, geochemistry, discharge, temperature; sample bacterial mats for analysis and culture; sample carbonate mounds for preserved bacteria.
Members Involved:

Cross Team Collaborations

Manga and Dietrich have talked with Nimmo (UCLA) about water-ice-spring interactions.

The History of Evolution of the Martian Surface and Water on Mars

Project Investigators: Janice Bishop, Kristie Boering, Donald DePaolo, William Dietrich, Michael Manga

Project Progress

This project focuses on the early evolution of the Martian atmosphere, the interaction of geodynamic and hydrologic processes, and the possible role of seepage in channel development (with implications for subsurface water available to support life). Our research indicates that organic aerosols may have had a large influence on the climate of early Mars and hence habitability of the planet. Particle formation can occur at considerably lower CH_4-to-CO_2 ratios than predicted by photochemical models. Geophysical modeling of polar wander and internal dynamic processes of Mars has shown that features mapped as potential shorelines, which currently exhibit relief of up to 2 km, could indeed be paleoshorelines from large, vanished oceans. Modeling also suggests that some (or even many) of the Martian outburst floods may have been triggered by large impacts and that the resulting liquefaction provides a source of water and may form the chaotic terrain. In contrast, analysis of some of the landslide features in Valles Marineris indicates that these features were dry fall, rather than associated with water. We conducted field investigations in the Colorado Plateau and Hawaii at sites often cited as examples of seepage driven channel formation. Unexpectedly, we have concluded the case for seepage erosion of bedrock is unpersuasive. Detailed field research at a new site in which a spring headed channel has carved into the basalts of the Snake River Plain has shown subtle evidence that at least one major flood down the plain may be responsible for carving the canyon, rather sapping at the channel head. Key data at this site are exposure age dating of boulders to test whether the channel advanced progressively over 10's of thousands of years or was essentially in an instant. Our findings here have important implications for the common assumptions about the role of seepage in cutting channels across the Martian surface.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 2.1:** Mars exploration
- **Objective No. 4.1:** Earth's early biosphere

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
0	MastCam	

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Field Expeditions

Field Trip Name: Box Canyon, Idaho
Start Date: November 6, 2004 **End Date:** November 8, 2004
Continent: **Country:**
State/Province: Idaho **Nearest City/Town:** Hagerman
Latitude: **Longitude:**
Name of site(cave, mine, e.g.): Box Canyon **Keywords:**

Description of Work: Researched the possible role of groundwater

sapping in Martian channel development and collected samples for cultivation of Fe-oxidizing bacteria. The site provided an example of the types of terrain that robots may need to traverse and the opportunity to observe scientists obtaining samples providing input for future development criteria for robot technology.

Members Involved:

EPO Reports: University of California, Berkeley

BioMARS - E/PO

IMPROVING SCIENCE LITERACY IN UNDERSERVED COMMUNITIES - BioMARS E/PO Efforts During 2005
Kevin E. Cuff and Herbert D. Thier, E/PO Co-Directors

INTRODUCTION BioMARS E/PO efforts aim to increase participants' science, technology, engineering, and mathematics (STEM) literacy. To accomplish this, our main objective is to increase understanding of and stimulate interest in STEM subject areas by providing participants in both formal and informal education settings with opportunities to engage in investigation and analysis of data collected on Mars and in model systems on Earth. Given their emphasis on helping participants understand how to design an investigation to find out something they want to know, BioMARS' E/PO materials foster the realization of how the application of the evidence-based approach of science to their personal decision - making can enrich their lives.

INSTRUCTIONAL MATERIALS CURRENTLY UNDER DEVELOPMENT Over the past year we have developed a science education module consisting of a set of hands-on explorations of standards-based concepts for use with after school groups, middle and high school classes. The current module consists of inquiry-based investigations that provide participants with opportunities to evaluate information the way scientists do. They are project-based in nature, and as such their themes engage participants in age appropriate, investigative activities whose focus is related to the efforts of the BioMARS scientific team. Thus, participants work in teams investigating geochemical processes associated with iron processing organisms, analyzing evidence of past and present fluid distribution and flow on Mars, evidence related to the evolution of Mars' atmosphere and hydrosphere, and evidence of Martian surface feature development throughout its history. They relate this evidence and that derived from their investigations to the search for and understanding of possible Martian habitats, and use accumulated understandings to make decisions on where future sampling on Mars should occur. Overall, the module is multidisciplinary in nature, and emphasizes guided learning leading to inquiry as its instructional approach. Topics selected and the approaches used emphasize specific concepts and understandings highlighted in the National Science Education Standards. Specific topics covered in the current module include: A) Detectors and detection; B) Tools that extend our senses; C) Investigation design and variables D) Energy transfer; E) Atoms, elements, compounds; F) Properties of metals; and G) Iron oxidation and reduction.

SERVING DIVERSE STUDENT POPULATIONS Another important goal of BioMARS E/PO efforts is to develop instructional materials that can be used in both formal and informal education settings, which contribute to an overall improvement in STEM subject literacy among members of urban communities with large disadvantaged, underserved and underrepresented populations. As such, we have developed and begun field-testing materials in schools and community centers in northern California communities that contain large African American and Latino, and Asian/Pacific Islander populations, including Berkeley, Oakland, and Richmond. These communities contain consistently low performing schools in fiscally troubled school districts, and we have begun assessing the impact that BioMARS materials have in terms of helping to improve academic achievement amongst its youth population. For example, from February to June 2005 these materials were presented during the science portion of a science and mathematics academy hosted on Saturdays by Berkeley Youth Alternatives, a community center in Berkeley that serves populations mentioned above. Additionally, in the fall of 2005 we will begin field-testing materials at other northern California community centers to assess their efficacy in a variety of socio-economic settings.

During June and July 2005 we presented our materials to a self selected group of entering 7th graders in the Orinda, California Summer Enrichment Program. Each of the participants expressed strong interest in science as a school subject and self reported their school grades as "A" & "B." Several of the students were in the gifted and other academically talented programs in this school district that ranks near the top in standardized testing in California. Our goal was to see whether our evolving instructional materials appealed to and challenged high performing and gifted students in this socio-economically favored community. High student interest, statistically significant attitude change, and the district?s desire to work the program into their school year offerings provided further strong evidence that the materials under development can provoke interest in and challenged students from a broad spectrum of educational interests and accomplishments. We will continue to test and refine our instructional materials so that they appeal to as broad a spectrum of students as possible while meeting our special goal of building interest and accomplishment in STEM focused materials for disadvantaged students in urban communities.

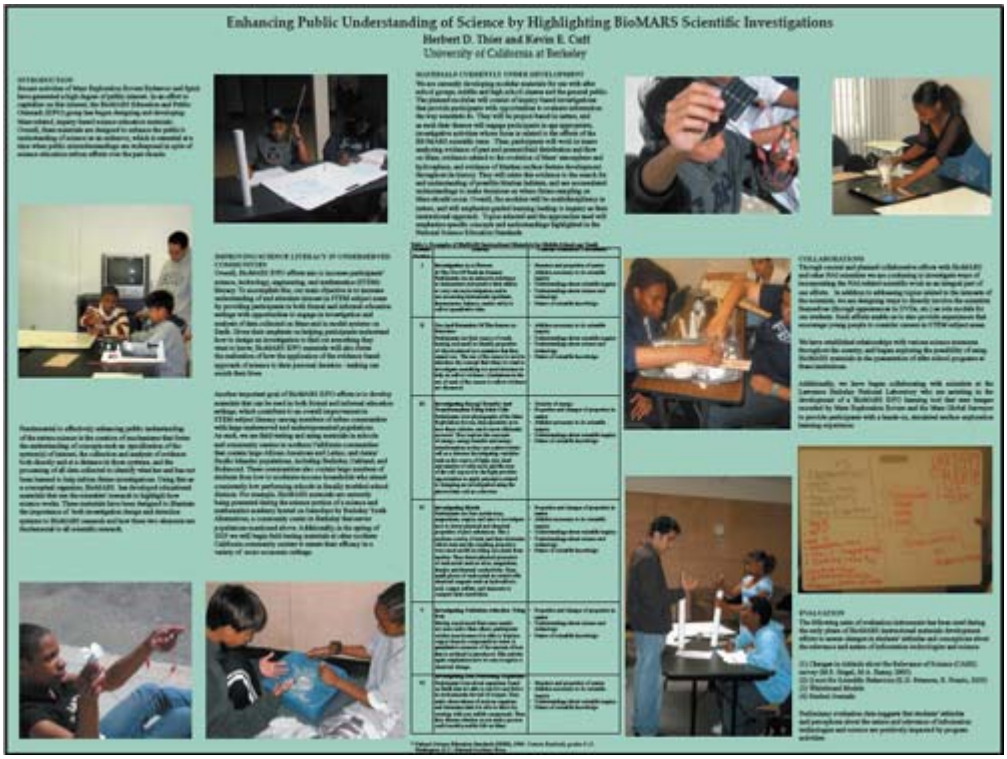
STAFF DEVELOPMENT The finest instructional materials are relatively useless in the hands of a relatively incompetent instructional leader. Therefore at the same time we are developing and testing the instructional materials we are beginning to test out adaptations of our materials intended to help teachers and other instructional leaders better understand our approach to directed instruction leading to guided inquiry while using our materials and other STEM focused materials. The first field test of these ideas took place by invitation in July 2005 in a special summer institute for teachers in the San Jose California Schools.

FUTURE EFFORTS Through current and planned collaborative efforts with BioMARS and other NAI scientists we are continuing to investigate ways of incorporating NAI-related scientific work as an integral part of our efforts. In addition to addressing topics related to the interests of the scientists, we plan to continue designing ways to directly involve the scientists themselves as role models for students. In this regard we plan to create a DVD in the near future that includes the participation of graduate students and scientists involved in research associated with the BioMARS project, as well as other NAI-sponsored projects. Such efforts enable us to also provide experiences that encourage young people to consider careers in STEM subject areas. We have also established relationships with various science museums and other NAI-sponsored projects throughout the country, such as the Indiana-Princeton-Tennessee Astrobiology Initiative (IPTAI), and begun exploring the possibility of using BioMARS materials in the presentation of after school programs in association with these institutions.

Additionally, we have begun collaborating with scientists at the Lawrence Berkeley National Laboratory who are assisting in the development of a BioMARS E/PO learning tool that uses high resolution images recorded by Mars Exploration Rovers and the Mars Global Surveyor to provide participants with a hands-on, simulated surface exploration learning experience.

EVALUATION We have employed the following suite of evaluation instruments to assess changes in students' attitudes and conceptions about the relevance and nature of science that result from using BioMARS instructional materials. (1) Changes in Attitude about the Relevance of Science (CARS) survey (M.S. Siegel, M.A. Raney, 2003) (2) Q-sort for Scientific Behaviors (K.D. Peterson, R. Ponzio, 2003) (3) Whiteboard Models (4) Student Journals

Though preliminary in nature, evaluation data collected thus far indicates that students' attitudes and perceptions about the nature and relevance of science are positively impacted by activities that comprise the current set of BioMARS materials.



Publications: University of California, Berkeley

There are **23** publication entries for the University of California, Berkeley

Baker, B.J., Lutz, M.A., Dawson, S.C., Bond, P.L. & Banfield, J.F. (2004). Metabolically active eukaryotes in extremely acidic mine drainage. *Appl. Environ. Microbiol.*, 70:6264-6271.

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Team Members: University of California, Berkeley

38 members found.

Name:Sarah Aciego
Project Role: Doctoral Student
Institution: University of California, Berkeley
Projects | Publications | Update Profile

Name:William Anderson
Project Role: Masters Student
Institution:
Projects | Publications | Update Profile

Name:Brett Baker
Project Role: Research Staff
Institution: University of California, Berkeley
Projects | Publications | Update Profile

Name:Jill Banfield
Project Role:
Institution: University of California, Berkeley
Website: http://eps.berkeley.edu/cgi-bin/faculty.cgi?name=banfield§ion=Home
Projects | Publications | Update Profile

Name:Janice Bishop
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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

Executive Summary: University of California, Los Angeles

Executive Summary: University of California, Los Angeles
Principal Investigator: Edward Young
Reporting Period: 2005 (7/04-6/05)

Introduction

The UCLA astrobiology research program comprises four broad themes. These are: 1) extrasolar planetary systems and the origins of organic molecules; 2) habitability of planets and their satellites; 3) Earth's early environment and life; and 4) evolution of biological complexity. Milestones achieved this year include demonstration that water was extant on Earth within 200 million years of the formation of the solar system, detection of organic molecules in debris disk surrounding a nearby star, detection of an extrasolar analogue to our own Kuiper belt, direct imaging of extrasolar planets, establishment of a time scale for rock formation in our solar system, elucidation of the causes of transition metal isotope fractionation that might be used as a biomarker, and a significant revision to our view of Earth's "tree of life." The projects reported on in this annual report can be grouped according to the four themes described above. Some of the results of these studies are summarized below.

Extrasolar planetary systems

As part of a French/American team, UCLA astronomers reported discovery of two young planets. The targets of the study were among the list of stars identified previously by the UCLA lead team as most likely to harbor warm, young planets that could emit enough infrared light for detection from Earth-based telescopes. The two new planets were imaged in the infrared wavelengths using adaptive optics techniques at the "Very Large Telescope" in northern Chile . These objects are the first planets to be directly imaged outside of our solar system. Detection of planets by gathering their emitted light, rather than relying on their indirect gravitational influences on their star, represents a substantial step forward in the planet hunting field. One of the planets orbits a star, the other orbits a brown dwarf (a star-like object lacking sufficient mass to ignite as a true star). The planet that orbits the brown dwarf has a mass about 5 times that of Jupiter. This is the first time a planet has been detected in orbit around a brown dwarf by any observing technique, direct or indirect.

Several of the UCLA lead team astronomers are reporting this year discovery of a uniquely dusty sun-like star (BD+20 307). Previously, NASA's IRAS satellite had been used to pinpoint hundreds of main sequence stars that are orbited by particulate matter located in regions analogous to the Kuiper-Belt of our solar system. The Kuiper belt , located out beyond the orbit of Neptune , is populated by Pluto-like, asteroidal-size objects composed of ices and rock. Collisions among the icy-rocky bodies there produce dust. IRAS found very few extrasolar analogs of the asteroid belt and zodiacal light regions that are vestiges of planet formation present in our solar system within a few Earth-Sun distances (astronomical units, AU) from the Sun. From mid-infrared measurements at the Keck and Gemini telescopes at Mauna Kea Observatory, the UCLA group found that BD+20 307 is orbited by dust somewhat analogous to the Sun's zodiacal dust but with a million times greater amounts of dust than the zodiacal dust, and the BD+20 307 particle sizes are typically much smaller than the size of the zodiacal dust particles. The group interprets the BD+20 307 phenomenon as evidence of recent massive and violent collisions of asteroidal-size objects.

Work on projecting the future orbital evolution of objects in the solar system continues. This is an effort to understand the possible connections between orbital dynamics and the evolution of rocky planets in our own solar system, with an eye towards relating such forcing of planetary evolution to the evolution of life. Members of the UCLA team carried out a detailed analysis of numerical simulations of our solar system. They found that chaos in the inner solar system has two sources. While the chaotic interaction between Earth and Mars is the main source of, there is smaller component in the interaction of Venus and Mercury. They note that the system is presently in a transition to a more chaotic state (Figure 1).

Members of the UCLA team completed two studies pertaining to the details of the processes that gave rise to rocks in our solar system. Such studies are useful in the context of astrobiology as the afford comparisons with astronomical observations of nascent solar systems forming around other stars. For example, our team found that the time scale for high-temperature processing of protoplanetary dust was

likely to have been on the order of 300,000 years. This span of time can be compared with the lifetime of protoplanetary disks elsewhere in the galaxy (e.g., the Orion nebula). Similarly, members of the team showed this year that photochemistry of the sort that is known to occur in the interstellar medium might also explain the anomalous distribution of the isotopes of oxygen that comprises a first-order characteristic of solar system materials. It may be possible to use these results to constrain the astrophysical environment in which our solar system formed, and thus to make inferences about where other Earth's might be forming today.

Habitability of planets and their satellites

Detection of small amounts of methane in the Martian atmosphere has been reported now by three different groups. Our team has been engaged in evaluating the likelihood that such a detection is a sign of life on Mars.

Since organisms referred to as methanogens are a primary producer of methane on Earth, the mere presence of methane on Mars begs the question as to whether or not Martian methane might also be biogenic. The logic is that the methane (CH_4) molecule can not survive in the thin Martian atmosphere due to the high flux of penetrating ultraviolet light from the Sun, and yet part per billion levels (10 ppb) of the gas are present. One is forced to conclude that the CH_4 is being produced at the present time. However, the methane flux implied by the new measurements is only one-millionth the terrestrial methane flux. This means that the many abiogenic sources of methane on Earth would be sufficient to explain the presence of CH_4 on Mars today.

The UCLA lead team considered the viability of reactions between hydrothermal fluids and rocks deeper in the crust of Mars as potential abiogenic sources of CH_4. Previous work on the shergottite Martian meteorites demonstrated that the partial pressure of oxygen in the Martian crust was such that carbon dioxide (CO_2) in a water-dominated hydrothermal fluid will be converted to CH_4 at temperatures of about 400 °C and less. Phase separation of supercritical water and methane results in methane vapor, which can then diffuse through the crust and reach the atmosphere. The UCLA workers showed that a very small igneous intrusion (~1 km wide x 10 km long) at a depth of 10 km could easily explain a 10 ppb methane fraction in the Martian atmosphere. The implication is that the presence of methane in the Martian atmosphere is most likely a result of the normal physical chemistry associated with reactions between water and rock and can not be taken as evidence for the presence of methanogens, at least not yet.

Earth's early environment

Our lead team was involved in a study that shows that water was extant very early in Earth history. The work is the latest outcome of an on-going project aimed at reconstructing Earth's history predating the oldest terrestrial rocks (but not the oldest mineral grains). The workers used the concept of a "geothermometer" (Figure 1) to show that the most ancient mineral grains on Earth, ca. 4.0 to 4.3 billion year old zircons from the Jack Hills of Western Australia , crystallized from granites. The formation of granites of this type requires partial melting of rock in the presence of water. Without the water, the rocks could not form at such low temperatures. The team concludes that the formation of the low-temperature granites during the Hadeon Eon of Earth history (4.5 to 4.0 billion years ago) means that there was a cycle of water-driven weathering and crust formation that resembled that of today. This is an important conclusion in that it implies that conditions during Hadeon time were not so inhospitable to life as previously thought. Is it possible that life on Earth began much sooner than is commonly supposed?

Studies of the nature of the Cretaceous-Tertiary boundary (Tasman Sea) and the Triassic Jurassic boundary (Nova Scotia) continued this past year at UCLA. In the latter case the team finds evidence of a small iridium (Ir) anomaly that might be from terrestrial volcanism rather than impact of an asteroid. This is important as there is a long-standing debate as to whether or not unusual levels of volcanic activity or asteroid/comet impacts are responsible for mass extinctions. It would seem both impacts and volcanism might play a role. Work continued on the Permian-Triassic boundary where previous claims of shocked quartz are now disproved, and on impacts in the late Eocene that were caused by bolides from the inner asteroid belt. In October 2004, members of our team organized a field trip to sample the Permian Triassic Boundary at Meishan , China in collaboration with workers at the Nanjing Institute of Paleontology. Samples from this collection will be distributed to an international consortium of research labs to test

whether these samples contain evidence of asteroid or comet impact.

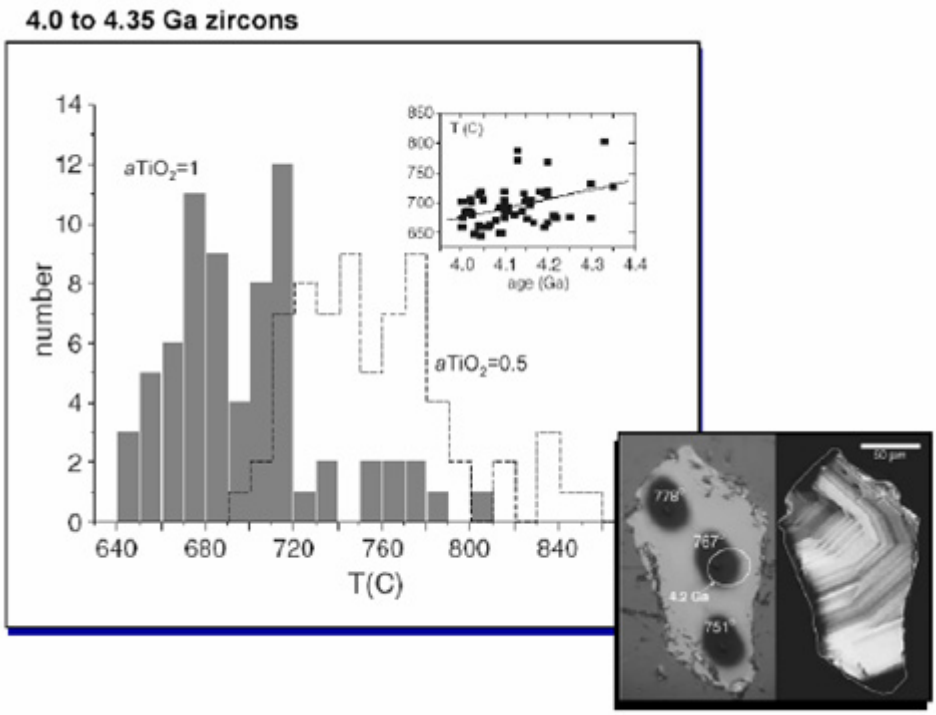

Figure 1. Histogram of crystallization temperatures for Hadean zircons derived from measured Ti contents. Gray bars assumed unit activity of titania while the white bars assume an activity of 0.5. Inset shows reflected light (left) and cathodoluminescence (right) images of Hadean zircon fragment used in the study. Dark spots are ion microprobe Ti analysis points and the white circle shows the spot where the U-Pb age data were obtained (after Watson and Harrison, 2005, Science v. 308, p. 841).

Research continued into the evidence for ancient life on Earth. Throughout biologic history, microbial life has been ubiquitous, abundant, metabolically diverse, and for the earliest (Precambrian) seven-eighths of geological time, such microorganisms dominatged. Understanding of this earliest stage of biologic development has progressed markedly in past decades, but problems in identifying fossilized ancient life remain. Arguably, foremost among them is the difficulty of unambiguously distinguishing true microbial biologic remnants from non-biologic look-alikes. This problem was the subject of new work at UCLA this year aimed at correlating "biological morphology" with "biological chemistry", albeit the geochemically altered. The newly installed imaging laboratory at UCLA has now developed two non-destructive, non-intrusive techniques, both new to paleobiology/astrobiology, that can be used toward this end. The techniques are confocal laser optical microsopy and laser Raman spectroscopic imagery. Confocal laser optical microscopy provides means to image in three dimensions at micron-scale the visible characteristics of organic-walled microscopic fossils *in situ* . Laser-Raman spectroscopic imagery provides means to map *in situ* and in three dimensions (at micron-scale) (Figure 2) the distribution of the carbonaceous matter that comprises suspected fossils, a technique that also provides salient information regarding the geochemical maturity of such carbonaceous (kerogenous) material. These new techniques are available for collaborative studies and should be applicable not only to Precambrian specimens, but also to samples returned from elsewhere in the solar system.

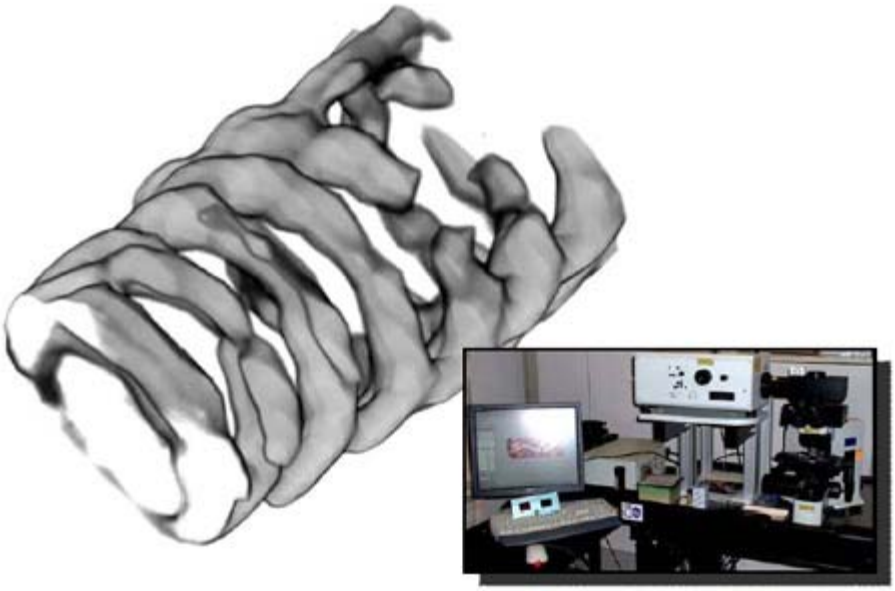

Figure 2. . 3-D Raman chemical image of a permineralized Precambrian microfossil obtained in the UCLA imaging facility. Inset shows the Raman imaging laboratory.

Research into the nature of early Earth by the UCLA team this past year included completion of a detailed oxygen and carbon isotopic stratigraphic section of carbonate rocks of marine origin comprising the Precambrian-Cambrian boundary in Siberia. The Siberian platform is one of the few places in the world where the Cambrian section is exceptionally complete and well preserved. This unique section spans one of the most geologically and biologically significant boundaries in Earth's history, spanning the transition from unfossiliferous to fossil-rich strata; the transition marks the first "radiation" of animal fauna. The isotopic signals, represented by over 2000 carbon and oxygen isotope ratios obtained at the UCLA stable isotope laboratory, reveal well-defined cycles of increasing and decreasing 13 C/ 12 C coincident with the earliest stages of the Cambrian "explosion" of life. Such swings in the isotopic composition of carbon in marine sediments are clear signs of changes in climate and or changes in biological productivity. The pattern of isotopic variability is telling us something significant about the relationship between Earth's early climate and the evolution of animal life. The challenge remains to unravel what these pronounced signals mean.

Evolution of biological complexity

The UCLA team continues to make good progress towards understanding the evolution of life on Earth. An analyses of the whole genomes of eukaryotes (animals, plants, fungi, and other organisms that consist of large, nucleated cells) and of prokaryotes (single celled organisms lacking nuclei) provided suggests that the eukaryotic genome resulted from a fusion of two diverse prokaryotic genomes, linking at the deepest evolutionary levels prokaryotes and eukaryotes. Said another way, the UCLA team concludes that the tree of life is actually a *ring of life*.

Collaborators from the UCLA team, the Penn State team, and UC Santa Cruz have entered into an agreement with the Department of Energie's Joint Genome Institute to sequence five genomes of the genus *Pyrobaculum* and close relatives. These closely related organisms are extraordinarily diverse in their metabolic repertoire, including many sulfur-based metabolisms, making them an ideal group for the study of the mechanisms and evolution of basic energy metabolisms, including sulfate reduction. Sulfate reduction genes arose early in Earth history, making it more likely that microbial sulfate reduction was an important component of ancient Earth's geochemical cycles.

Collaboration between the UCLA and Penn State teams on whole genome comparisons and hierarchical classifications continued this year. These workers are preparing a new publication on a novel classification scheme based on measurements of conserved gene order. This broad analysis will address also correlations of nucleotide level versus gene order evolutionary changes across different lineages.

Education and public outreach

Members of the UCLA lead team were engaged in an active EPO program this past year. The Center for the Study of Evolution and the Origin of Life (CSEOL) at UCLA convened an all-campus, free-of-charge, open-to-the public symposium entitled “Astrobiology: Life Among the Stars” in May of this year. Our director of EPO co-hosted a session at the American Geophysical Union Fall Meeting devoted to the subject of diversity and equity in the Earth and space sciences, participated in the NAI – SETI astrobiology summer science experience for teachers, and participated, along with a graduate student, in the Science Study of Navajo Astronomy held on the Navajo Reservation, New Mexico . Our program also conducted a number of class presentations and tours for local K-12 school children dealing with the subject matter of astrobiology. Finally, we are now completing final plans for a lecture series on astrobiology in association with Griffith Observatory.

Project Reports: University of California, Los Angeles

From Stars to Genes: Addition to Extrasolar Planetary Systems

Project Investigator: Ferenc Varadi

Project Progress

Martian obliquity and climate history We have developed an efficient way to simulate the rotational dynamics of Mars, using the results of long-term orbital simulations as forcing. We can simulate 100 million years in a few minutes. We have coupled the dynamics to simple models of deformations and changes in volatile and dust distribution. Since the system is both chaotic and dissipative, its past evolution is difficult to constrain. We have found that realistic volatile loads can significantly change obliquity evolution. In particular, it is now much less certain whether Mars had periods of high obliquity in the past few hundred million years.

General rotational dynamics A great deal of effort was devoted to derive a new general theory for the rotational dynamics of planets and satellites which is capable to predict evolution due to tides. We are now able to tell whether tides can drive obliquity to extreme values.

Chaos in the inner solar system We carried out a detailed analysis of our numerical simulation results of our solar system. We have found that chaos in the inner solar system has two sources. While the chaotic interaction between Earth and Mars is the main source of chaos, there is smaller component in the interaction of Venus and Mercury. Surprisingly, the system is presently in a transition to a more chaotic state.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 2.1:** Mars exploration
- **Objective No. 2.2:** Outer Solar System exploration
- **Objective No. 4.2:** Foundations of complex life
- **Objective No. 4.3:** Effects of extraterrestrial events upon the biosphere
- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.2:** Co-evolution of microbial communities

Serpentinization - part of the Geobiology and Geochemistry of Early Earth Project

Project Investigator: Craig Manning

Project Progress

C. Manning initiated experimental studies of serpentinzation in early Earth analogue systems with Ph.D. student G. C. Lazar. As part of this project, Manning is engaged in a theoretical study of CH_4 generation on Mars. First results, in collaboration with Lyons (UCLA) and Nimmo (UCSC) demonstrated a significant capacity for abiogenic CH_4 production by in crustal magma-hydrothermal systems.

Manning is also collaborating with PI E. Young on a pilot study exploring the thermodynamics of gas-rock metasomatism in the solar nebula.

Experimental and Theoretical Analysis of Mass-independent sulfur isotope effects-part of the Geobiology and Geochemistry of Early Earth project

Project Investigators: James Lyons, Joe Francisco, Ian Williams

Project Progress

Understanding mass-independent fractionation in sulfur isotopes

Understanding sulfur isotope fractionation in the early Earth geochemical record is a key astrobiology goal and an important component of our proposed work. James Lyons is taking both experimental and theoretical approached to this problem. Collaborative experiments on SO_2 dissociation with J. Farquhar at the University of Maryland are still in progress. (This work will be submitted soon for publication.) Lyons is planning sulfur experiments here at UCLA in Fall 2005.

On the theoretical side, Lyons initiated collaboration with a quantum chemist (J. Francisco, Purdue University) to investigate various sulfur molecule structures and sulfur isotope exchange rate coefficients. Their first objective was to see how well *ab initio* models could reproduce recent measurements of S_3 structure. Thiozone, S_3, is of interest because S_3 formation occurs be a reaction isovalent to the O_3 formation reaction, $O + O_2 \ddagger O_3$. Since O_3 is well known to exhibit mass-independent fractionation during formation, it is reasonable to expect that S_3 will do the same. The *ab initio* calculations show that S_3 structure (bond length and angle, vibrational frequencies) is very well reproduced by a high-level coupled-cluster theory. Isotopic shift patterns were also computed (I. Williams, University of Bath) for the two different S_3 structures. The calculations also yield an accurate potential energy surface, which will be useful for future studies of mass-independent fractionation in S_3. This work has been accepted for publication in the *Journal of Chemical Physics.*

Roadmap Objectives

- **Objective No. 4.1:** Earth's early biosphere

Cross Team Collaborations

See Project Report - Cross sTeam collaborations section

Geochemical Production of Methane on Mars

Project Investigators: James Lyons, Craig Manning, Francis Nimmo

Project Progress

Production of Mars methane by fluid-rock interaction in the crust

This work was a collaborative effort, involving J. Lyons, C. Manning, and F. Nimmo (now at UC Santa Cruz), to understand possible sources for the methane recently discovered in the Martian atmosphere. Detection of methane was reported by three different groups (Mumma et al. 2003; Formisano et al. 2004; Krasnopolsky et al. 2004). The observed methane volume fraction varied from 10 ppb (parts per billion) to about 100 ppb methane, with substantial (and surprising) variations with longitude. Given that terrestrial methane is primarily a product of methanogens, it is natural to consider Mars methane to also be biogenic. However, the methane flux implied by 10 ppb methane is only about 10^7 moles per year, about one-millionth the terrestrial methane flux. Because many abiogenic sources of methane on Earth produce comparable flux levels, we chose to explore abiogenic geochemical sources on Mars.

An obvious possible methane source is serpentinization, in which Fe^{2+} in olivine is oxidized to Fe^{3+} during aqueous alteration. The redox couple is balanced by reduction of C in the fluid (e.g., as carbonate) to methane. Another possible methane source, and the one that we focused on, is thermochemical reactions in hydrothermal fluids. Previous work on the shergottite meteorites demonstrated that the oxygen fugacity in the Martian crust is no higher than that of a quartz-fayalite-magnetite (QFM) rock buffer, and may be as low as QFM-4 (in fO_2 log units). At these oxygen fugacities magamtic CO_2 in a water-dominated hydrothermal fluid will be converted to CH_4 at temperatures of about 400 °C and less, assuming thermochemical equilibrium. Phase separation of supercritical water and methane yields methane vapor, which can then diffuse through the crust and reach the atmosphere. We showed that a very small magmatic intrusion (~1 km wide x 10 km long) at a depth of 10 km could easily explain a 10 ppb methane fraction in the Mars atmosphere. This work has been accepted for publication in *Geophysical Research Letters*. (The thermochemistry and phase diagram calculations in this work were carried out primarily by C. Manning using methods he developed for abiogenic methane production on early Earth. Nimmo provided the geophysical context for the work. Lyons provided the atmospheric context and also initiated the project.)

Roadmap Objectives

- **Objective No. 2.1:** Mars exploration
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Genome Evolution and Innovation

Project Investigator: James Lake

Project Progress

Lake and his group continue to make good progress to understand the evolution of life on Earth. Recently we published information obtained from the analyses of the whole genomes of eukaryotes (animals, plants, fungi, and other organisms that consist of large, nucleated cells) and of prokaryotes (single celled organisms lacking nuclei). These studies provided information suggesting that the eukaryotic genome resulted from a fusion of two diverse prokaryotic genomes, and therefore at the deepest levels linking prokaryotes and eukaryotes, the tree of life is actually a ring of life. One fusion partner branches from deep within an ancient photosynthetic clade, and the other is related to the archael prokaryotes.

Roadmap Objectives

- **Objective No. 3.2:** Origins and evolution of functional biomolecules
- **Objective No. 3.3:** Origins of energy transduction
- **Objective No. 3.4:** Origins of cellularity and protobiological systems
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.2:** Foundations of complex life
- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
0	Concept	

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

See AProject Report

Geobiology and the Geochemistry of Early Earth

Project Investigator: T. Mark Harrison

Project Progress

Harrison, with colleague E. B. Watson (RPI), published a paper this year in which they show that ancient zircons from Western Australia's Jack Hills preserve a record of conditions that prevailed on Earth during the Hadeon Eon (4.5 to 4.0 billion years before present). They applied their newly-developed geothermometer based on the concentration of titanium in zircon and found that these most ancient of Earth minerals record temperatures of about 700°C (Figure 1). Such temperatures are low for igneous rocks and require that the host rocks in which the zircons grew formed by partial melting in the presence of water (so-called "wet minimum temperature melting"). The implication is that the Earth had settled into a pattern of crust formation, involving a water cycle, just 200 million years after the formation of the solar system.

Roadmap Objectives

- **Objective No. 4.3:** Effects of extraterrestrial events upon the biosphere

Characterization of Earth's Early Life

Project Investigator: J. William Schopf

Project Progress

Throughout biologic history, microbe-level life has been ubiquitous, abundant, metabolically diverse, and for the earliest (Precambrian) seven-eighths of geological time, biotically predominant. Understanding of this earliest stage of biologic development has progressed markedly in past decades, but problems of interpreting the preserved fossil record still remain. Perhaps foremost among such problems is the difficulty of unambiguously distinguishing true microbial biologic remnants from nonbiologic (e.g., mineralic) look-alikes. This problem can be addressed by demonstrating in objects claimed to be microscopic fossils a one-to-one correlation, in three dimensions and at a micron scale, of preservable "biological morphology" with geochemically altered "biological chemistry." We have now developed two non-destructive, non-intrusive techniques, both new to paleobiology/astrobiology, that meet this need:

1. **Confocal laser optical microscopy** provides means to image in three dimensions at micron-scale the visible characteristics of organic-walled microscopic fossils *in situ*; and
2. **Laser-Raman spectroscopic imagery** provides means to map, *in situ* and in three dimensions at micron-scale, the distribution of the carbonaceous matter that comprises such fossils, a technique that also provides salient information regarding the geochemical maturity of such carbonaceous (kerogenous) material.

Applicable to samples returned to Earth from other planets, the use of these new techniques can be expected to revolutionize studies of microbial Precambrian life.

Figure 1.

Genomic Approach to Understanding of the Evolution of Sulfur Metabolisms

Project Investigator: Sorel Fitz-Gibbon

Project Progress

Sorel Fitz-Gibbon and collaborators (listed below) have entered into an agreement with the DOE's Joint Genome Institute to sequence five genomes of the genus *Pyrobaculum* and close relatives. These closely related organisms are extraordinarily diverse in their metabolic repertoire, including many sulfur-based metabolisms, making them an ideal group for the study of the mechanisms and evolution of basic energy metabolisms. Additionally, it will be of great interest to see if the unexpected clustering of large numbers of sulfur metabolism genes seen in *P. aerophilum* is also seen in the other *Pyrobaculum* genes. This information will be important for studies of function and regulation and may also be important for directing future studies of environmental samples. *Caldivirga maquilingensis* is the outgroup genome of the group and is particularly important for studies of sulfur metabolisms as it is the only Crenarchaeota clearly reported to use sulfate reduction for energy gain. Analysis of the sulfate reduction genes of this organism may lend further support to the idea that sulfate reduction arose early in the Archaeal lineage, making it more likely that microbial sulfate reduction was an important component of ancient Earth%'s geochemical cycles.

http://www.cbse.ucsc.edu/news/newsarchive05.shtml#lowe

Sorel Fitz-Gibbon and Christopher House (Penn State Astrobiology) continued their collaboration on whole genome comparisons and hierarchical classifications. They are preparing a new publication on a novel classification scheme based on measurements of conserved gene order. This broad analysis will additionally report on correlations of nucleotide level versus gene order evolutionary changes across different lineages.

Sorel Fitz-Gibbon has made progress in the initial steps towards developing a genetic system for *Pyrobaculum*. Focusing on *Pyrobaculum calidifontis* she is currently working on plating conditions and growth in minimally supplemented basal salt media.

Cross Team Collaborations

Collaborators on the genome sequence proposal are Christopher House (Penn State Astrobiology), Todd Lowe (UC Santa Cruz Biomolecular Engineering), and Chad Saltikov (UC Santa Cruz Environmental Toxicology). A press report for this project can be found at:

The astrochemistry of Protoplanetary Systems and the meteorite rRecord - Part of the Extrasolar Planetary Systems Project

Project Investigator: Edward Young

Project Progress

Oxygen isotopes in the solar nebula

In work supported both by Astrobiology (Young –PI; Lyons-Co-I) and by the NASA Origins program (PI-Lyons), J. Lyons has completed astrochemical modeling calculations relevant to the outer solar nebula. The goal of the modeling is to understand the role of isotope-selective photodissociation of CO in producing the well-known oxygen isotope anomaly in meteorites, and its impact on water in the nebula. Lyons converted a one-dimensional atmospheric chemistry code into a solar nebula chemistry code, and computed the expected isotopic composition of water at the nebula midplane. The required ultraviolet radiation to get sufficient CO dissociation at 20 – 30 AU from the protosun is consistent with birth of the solar system in a cluster of about 200 stars. This is an important step forward in understanding the implications of Clayton's discovery over 30 years ago. This work was recently published in *Nature*.

E. Young has completed a fully-functional reaction network code that includes for the first time the mass-dependent oxygen isotope fractionation as well as photochemistry and parameterized radiative transfer. The code integrates the rates of 7063 relevant reactions among 546 chemical and isotopologue gas and solid species in the context of a circumstellar disk environment. It permits comparisons between the competing effects of mass-dependent fractionation and photolysis as a function of temperature, total gas pressures, cosmic ray photon flux, cosmic ray proton flux, stellar ultraviolet and x-ray fluxes, and 1-D advective transport. Results are just now being collated. Findings to date suggest regions of our own protoplanetary disk where the photodissociation of CO could have produced a reservoir of water ice with high $^{18}O/^{16}O \sim {}^{17}O/^{16}O$ ratios as indicated by the meteorite record. It also shows where such a reservoir could not have been made.

These results represent substantial steps towards integrating the fields of astrochemistry and cosmochemistry with the goal of placing the history of the early solar stystem on a firmer footing.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets

Electrochemical isotope effects with applications to stable isotope fractionation in transition metals

Project Investigator: Abby Kavner

Project Progress

We have successfully begun a research program examining how electrochemical processes (e.g. electroplating, corrosion, biological metabolism) act on stable isotopes of transition metals, starting with Fe. A first series of experiments showed that electroplated Fe becomes increasingly fractionated as the electrochemical driving force increases in an aqueous electroplating experiment. These results, together with a new theory based on classical statisticall mechanics of charge transfer processes, were published this year in Geochimica et Cosmochimica Acta.

The theory we developed provides a general explanation for both thermodynamic and kinetic behavior of stable isotopes in electron charge transfer systems. The theory makes a series of predictions about how electrochemical stable isotope fractionation is influenced by a variety of factors, including solution chemical speciation, solution concentration, equilibrium fractionation factors, and temperatures. Currently, we are systematically testing the predictions for Fe electroplating, and will continue to examine electrochemical processes in other stable isotope systems, such as Cr.

Our newest laboratory experiments suggest that as the concentration of the $FeCl_2$ plating solution is reduced, the slope of the fractionation vs. voltage plot becomes less strong, and ultimately changes sign, a result in concordance with our theory and predictions of equilibrium fractionation [*Schauble et al.*, 2001] (see Fig. 1). However, the results also suggest that mass transport may be playing a role in the observed fractionation, as well as the electrochemical effect.

This research program is helping to provide a tie between the electrochemical-based metabolism of (all?) biotic systems, and potential stable isotope geochemical observables.

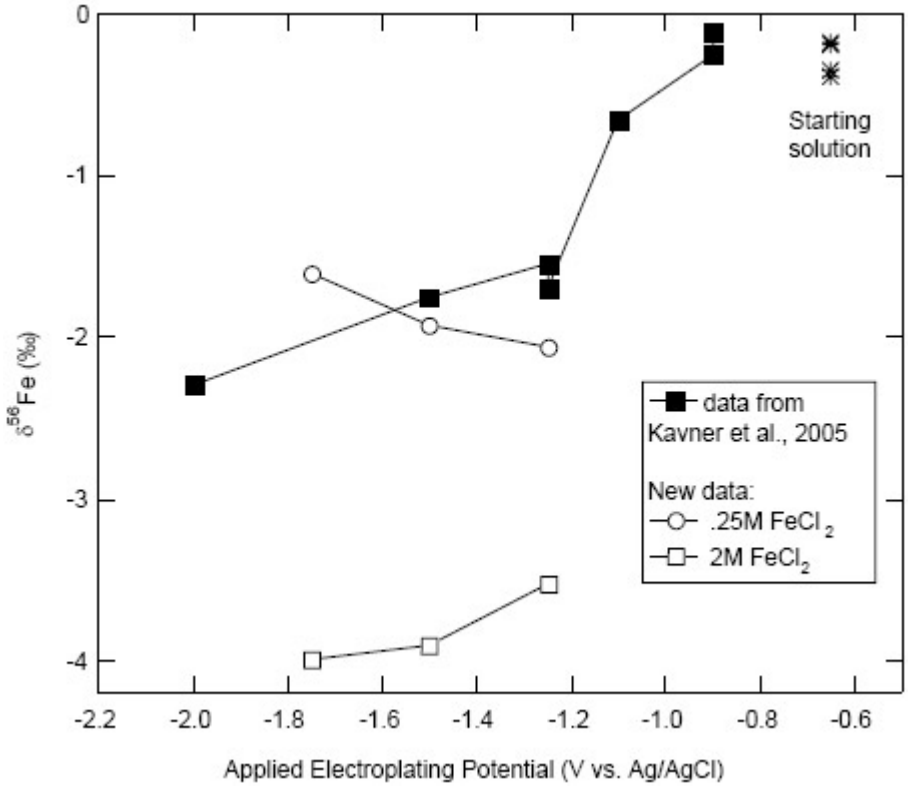

Figure 1.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 4.2:** Foundations of complex life
- **Objective No. 4.3:** Effects of extraterrestrial events upon the biosphere

Geochemical and Geochemistry of Early Earth - Isotope Stratigraphy

Project Investigator: Edward Young

Project Progress

C and O isotope analyses of carbonates from the Proterozoic/Phanerozoic transition of the Siberian Platform: proxy for early life evolution?

Ongoing research revolves around the carbon and oxygen isotope signals of carbonate rocks from across the Precambrian/Cambrian boundary and the Cambrian of the Siberian platform. The Siberian platform is one of the few places in the world where the Cambrian section is present in relatively continuously and unmodified succession, making Siberia unique among localities where major depositional hiata occur throughout this important evolutionary time period. This transition from unfossiliferous to fossil-rich strata has long been recognized as one of the most significant boundaries in geological and biological history. For reference, the first major radiation of metazoa occurred between Vendian (Precambrian) and Tommotian (Lower Cambrian) times. C-isotope stratigraphy has proven exceedingly useful not only in correlating those strata, but also in elucidating the evolution of life during the "Cambrian Explosion" of life. Marine $\delta^{13}C$ records are primarily controlled by changes in oceanic C concentrations and are thus useful proxies for paleoenvironments.

We are in the final stages of analyzing over 2000 samples from a profile spanning the uppermost Neoproterozoic (Vendian) to the Late Cambrian. To date we have two continuous profiles; one from the Vendian up to the lower Mayan (latest Middle Cambrian) covering the Precambrian/Cambrian transition, and one from the upper Mayan to the Upper Cambrian covering the SPICE anomaly (Steptoean Positive Carbon Isotope Excursion) (Figure 1). Stratigraphic correlation of the results is preliminary at this stage, and there is still a stratigraphic gap in sample coverage between the two profiles.

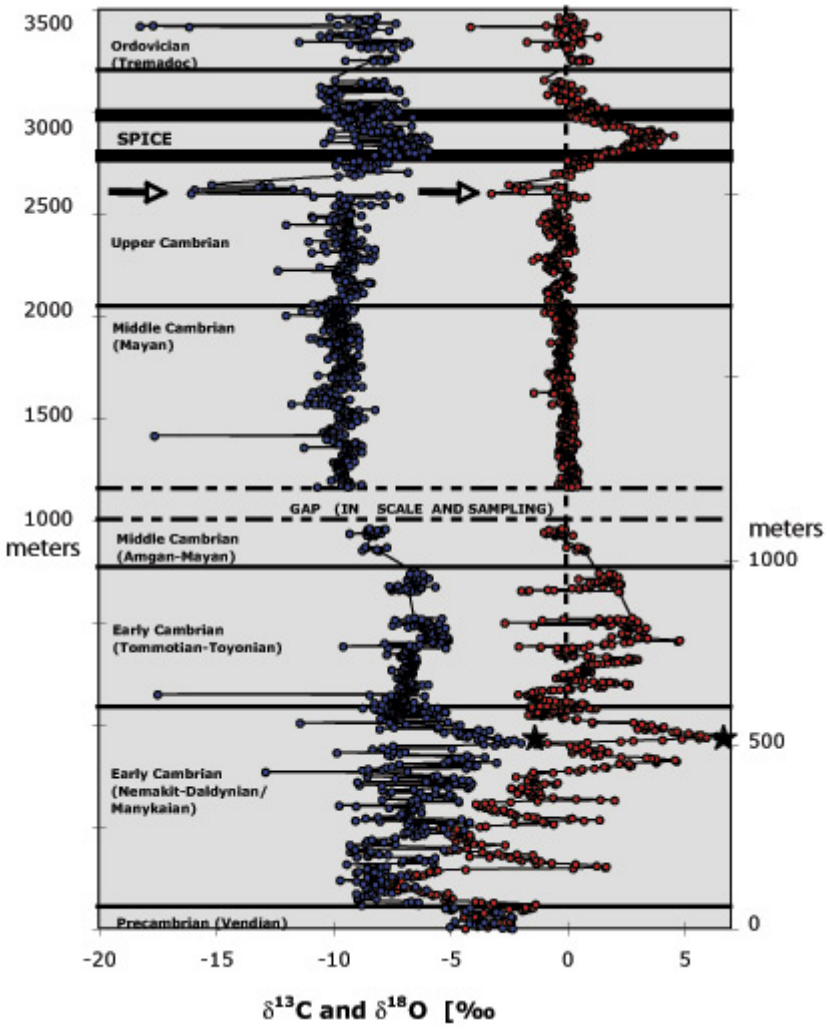

Figure 1.

The Precambrian/Cambrian transition is marked by a strong negative $\delta^{13}C$ excursion of about –7‰ relative to the $\delta^{13}C$ values in the uppermost Vendian. It is thought that mass extinction events are associated with negative $\delta^{13}C$ excursions in general, and the Precambrian Ediacara fauna (=Vendian) became extinct during this time frame.

Previous work shows that throughout the Nemakit-Daldynian Stage, $\delta^{13}C$ signals display a series of five major cycles with increasingly more positive peaks, reaching +6.4‰ towards the end of the Nemakit. Explosive diversification of marine invertebrates early in the Cambrian period may be correlated with the $\delta^{13}C$ cycles. Whereas similar cyclicity during this time frame has been observed before, our profile shows clearly resolvable, sharp cycles which we detected also at the earliest stages of the Cambrian explosion. Our results will facilitate detailed and qualitative interpretations and correlations with biological events during the earliest Cambrian

The upper portion of our section spans the top of the Middle Cambrian to the top of the Ordovician. The $\delta^{13}C$ signals are more stable than in the Lower Cambrian. We have detected a very brief and abrupt negative $\delta^{13}C$ excursion (-3.3‰, arrow in Figure) immediately preceding SPICE. Similarly negative $\delta^{13}C$ values have been observed in other profiles in different parts of the middle Cambrian (sequence boundaries?). We will test whether this excursion is a real signal of a pre-SPICE disturbance of the geochemical system that may be related to the mass extinction event or its underlying cause such as a change in ocean circulation, or whether diagenesis caused these signals.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 4.2:** Foundations of complex life

- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems

Extrasolar Planetary Systems and the Potential for Terrestrial Planets

Project Investigator: Eric Becklin

Project Progress

Dr. Becklin worked with Alycia Weinberger and Ben Zuckerman to detect organic material in a nearby debris disk and worked with Inseok Song, Alycia Weinberger, and Ben Zuckerman and discovered a debris disk around a solar like star with processed crystal silicates in the Earth region.

Dr. Becklin is also the Chief Scientist and Director Designate of the Stratospheric Observatory for Infrared Astronomy (SOFIA). SOFIA has the potential to be one of NASA's primary astronomical platforms to study organic material in space. Dr. Becklin has worked with the various NAI members and the SOFIA team to make this happen. This year's accomplishments include: 1) assured that UCLA's SOFIA instrument FLITECAM has spectrometer to observe the 3.3 micron C-H stretch band 2) worked with NASA NAI and SOFIA team to have spectroscopic capability in 5-30μm region including 6μm C-C feature.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
0	SOFIA	Project Scientist

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Eric Becklin is Chief Scientist on this mission

Earth's Early Environment and Life

Project Investigator: Gary Byerly

Project Progress

Field work was conducted in the 3.5-3.2 Ga Barberton greenstone belt, South Africa for three weeks, July 2004. Several meteorite impact spherule layers were examined in place, and samples collected for future analytical studies.

Materials from two of five possible meteorite impact layers were processed to examine heavy minerals looking for nickel spinels and separate zircons. Spinels found only had compositions consistent with terrestrial volcanic sources. Zircons were isolated, mounted and polished, and examined and photographed in transmitted light, backscatter, and CL in preparation for U-Pb isotopic microanalysis at the USGS-SHRIMP laboratory at Stanford. One sample yielded an age near 3225 Ma and likely represents a new impact layer in the Archean. The second sample contained mostly discordant zircons and the age obtained only allows us to confirm that the impact layer in this new terrain represents one of the three (now four?) large impacts at circa 3225-3255 Ma.

A paper on impact layer "S3" from the Barberton greenstone belt is in preparation.

Six impact samples previously collected are being processed for zircons. One is for the attempt to corroborate the 3225 Ma age of the youngest Barberton impact. The others are to confirm the ages of S2 and S3 across several regional faults.

Roadmap Objectives

- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.3:** Effects of extraterrestrial events upon the biosphere

Field Expeditions

Field Trip Name: Barberton greenstone belt	
Start Date: July 25, 2004	**End Date:** August 15, 2004
Continent: Africa	**Country:** Soputh Africa
State/Province:	**Nearest City/Town:** Barberton
Latitude:	**Longitude:**
Name of site(cave, mine, e.g.): Barberton green belt	**Keywords:**
Description of Work: See Project Progress	
Members Involved:	

Extrasolar Planetary Systems

Project Investigator: Michael Jura

Project Progress

Mike Jura has described a method to detect comets around young stars where planets are forming. The basic idea is that the water outgassing from comets is photodissociated into OH. This OH has absorption lines which can be detected from the ground with high spectral resolution near 310 nm. Comets may be an important source of water on terrestrial planets, and thus these potential observations may help us study the delivery of water to young terrestrial planets. Young solar-type stars with large amounts of dust that may be in the environmental phase described by this model have been identified in the Sco-Cen association by their infrared excess with Spitzer telescope data.

Roadmap Objectives

- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets

From Stars to Genes

Project Investigator: William Moore

Project Progress

1. Thermal evolution of Io: The thermal equilibrium of a silicate body subject to tidal heating has been studied and applied to the thermal state of Io. The results of this work demonstrate that heat transport in Io is accomplished predominantly by melt segregation and not by convection as previously assumed. This has a number of consequences for Io's thermal and rheological structure. Self-consistent models of heat production and melt segregation have been advanced from a simple analysis [Moore, 2001], to a calculation involving convection [Moore, 2003], and are being synthesized into a complete model of melt segregation, tidal heating, and convection in Io [Moore, 2005].

2. Thermal evolution of Europa's ice shell: Unlike the silicate case, a floating ice shell has only a single, stable equilibrium. Since the internal temperature of the shell is constrained by the melting point at its base, a unique solution for the equilibrium thickness of the shell can be found, given the rheological and physical properties of ice. One of the major advances has been the incorporation of laboratory derived composite flow-laws for ice, including temperature, pressure, stress, and grain-size dependence. Unfortunately, one of these properties, the grain size, is very poorly constrained, and thus a range of thicknesses is possible, depending on the grain size. The minimum thickness is about 15 km (at a grain size of about 1 mm and the current eccentricity), below which the shell is simply too efficient at transporting heat to balance what can be generated by tidal flexing. Obviously, this has strong implications for exploration of the subsurface ocean. At lower eccentricity, this minimum thickness is larger, becoming the thickness of the whole water layer for eccentricities below 0.003, about one third the present value. Eccentricity variations may thus lead to shell thickness variations which become amplified as the eccentricity decreases. This work is currently in press [Moore, 2005].

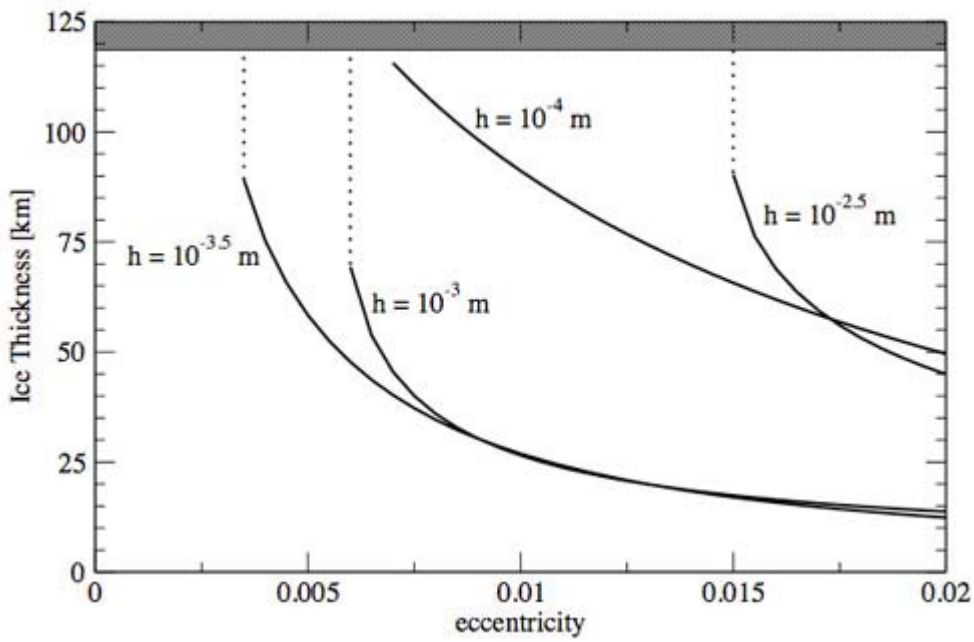

Figure 1. Equilibrium ice shell thickness on Europa vs. eccentricity, for rigidity 5×10^9 Pa and several different grain sizes. The grey band indicates the maximum shell thickness (119 km), and the dotted lines indicate that no equilibrium exists at eccentricities below this point.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 2.2:** Outer Solar System exploration

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
1	Cassini	Co-Investigator
3	Europa	Co-Investigator

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

1. Cassini. This work is quite general regarding the thermal evolution of tidally heated bodies and is applicable to bodies such as Enceladus or Titan which are currently being investigated by Cassini.

3. Europa Orbiter (in whatever configuration). The results of our thermal modeling provide predictions of the minimum ice shell thickness that must be penetrated if one desires to sample the ocean on Europa (remotely or otherwise).

EPO Reports: University of California, Los Angeles

Southeast Regional Clearinghouse 2K5 Funding opportunity

Barbara Laval, Director of Education and Public Outreach for the NAI UCLA Center for Astrobiology, was invited to participate as an EPO Peer Reviewer for the Southeast Regional Clearinghouse (SERCH) 2K5 Funding Opportunity.

Ms. Laval was a member of a team of four and designated the primary on three of the six proposals submitted and reviewed for scientific/educational content. Reviewers' were members from the following organizations: NASA Goddard Space Flight Center, NASA Ames, Space Telescope Science Institute and the University of California, Los Angeles.

SERCH Goals:

1) To develop a network of educators and researchers interested in space science. 2) To be an effective interface between researchers and educators in the area of space science. 3) To be a primary information and resource clearinghouse for space science data, information, and educational products. 4) To support SMD mission scientists in their educational outreach activities. 5) To facilitate the modification of SMD materials to meet the needs of diverse educational environments. 6) To be a leader in serving exceptional students and the general public. 7) To enhance minority involvement across NASA SMD programs.

Additional information regarding SERCH can be found at - http://serch.cofc.edu/

UCLA Astrobiology Course - ESS33

Professor William I. Newman, faculty Member of the NAI-UCLA Center for Astrobiology, teaches UCLA's Astrobiology course ESS33.

ESS33 continues to grow, with approximately 30 students. Substantially more biological material has been added to the course, including field trips to Long Beach's "Aquarium of the Pacific" (to better appreciate biological diversity and adaptation) and additional material related to nucleotide sequences and the significance of the human genome project.

ESS33 continues to have an essentially equal emphasis on the physical and life sciences characteristic of Astrobiology.

16th Annual CSEOL Symposium - Life Among the Stars

Professor William F. Schopf, Director of The Center for the Study of Evolution and the Origin of Life (CESOL) in UCLA's Institute of Geophysics and Planetary Physics and faculty member of the NASA Astrobiology Institute's (NAI), UCLA Center for Astrobiology, convened an all-campus, free-of-charge, open-to-the-public, all-day Symposium, May 13, 2005, entitled "Astrobiology: Life Among the Stars".

The ~2000 attendees enjoyed presentations by speakers that included:

1) David Stevenson, "What Makes Planets Habitable?" California Institute of Technology (CalTech), 2) Steve Squyres,"Spirit and Opportunity: Latest Results from the Mars Rovers" Cornell University, 3) Charles Elachi, "Roadmap for Exploration of Potentially Organic-rich Planetary Environments" Director, NASA Jet Propulsion Laboratory (JPL), 4) Lynne Hillenbrand, "Earth-based Search for Jupiter-sized Planets Beyond the Solar System" California Institute of Technology (CalTech), 5) Jon M. Jenkins, Space-based Search for Earth-sized Planets Beyond the Solar System" SETI Institute, 6) Dan Goldin, former NASA Administrator, "Discovery of Life on Other Worlds: What Will it Mean?"

Professor Edward L. Wright, Moderator, University of California, Los Angeles, Lead the Panel discussion on

"The Search for Life on Other Worlds".

http://www.igpp.ucla.edu/cseol/

Flier - May 13, 2005 CESOI Symposium - Astrobiology: Life Among the Stars

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The Licancabur Expedition

The Licancabur Expedition

Andrew Hock, member of the NASA Astrobiology Institute's UCLA Center for Astrobiology and distinguished UCLA graduate student continues his involvement with the Licancabur expedition. The Licancabur expedition is a joint venture with the following NASA organization: SETI (Search for Extraterrestrial Intelligence), NASA Astrobiology Institute (NAI), and NASA ARC. The Licancabur volcano (6,014 m) located at the boundary of Chile and Bolivia hosts a lake that is amongst the highest and the least explored lakes on Earth. The lake environment combines low-oxygen, low atmospheric pressure, and high-UV radiation. Sediments are formed in volcanic material. It is ice-covered most of the year and the bottom water temperature remains above freezing. These conditions make Licancabur a unique analog (comparison) to ancient Martian lakes.

Science classrooms everywhere are following and participating with the team as it explores extreme environments! We can watch as the classrooms conduct their own experiments related to the science at Licancabur and ask real questions of our team.

Classroom resources include: Lesson plans, additional links, books, questions & answers, classroom videos and classroom archives that provided students the opportunity to view simulated expeditions.

The Licancabur Expedition's new webpage is under construction.

Below is a link to the old webpage http://www.extremeenvironment.com/2003/expedition/index.htm

Offical Licancabur Collaborative Patch

Co-Convener - American Geophysical Union (AGU) 2004 Fall Session - Diversity and Equity in the Earth and Space Sciences: Building Effective Partnerships with Minority Serving Institutions

Barbara Laval, Director of Education and Public Outreach for the NAI-UCLA Center for Astrobiology, was invited to Co-Convene a session on Diversity at the 2004 Fall Meeting of the American Geophysical Union (AGU), December 13 -17, 2004. Session Title: Diversity and Equity in the Earth and Space Sciences: Model K-16 Education Programs and Lessons Learned

The session convened, 1340 - Thursday, December 16, 2004 Session ED43C - room MCC3020 at the San Francisco Moscone Conference Center.

Presiding: P Morris, University of Houston-Downtown; N Maynard, NASA Goddard Space Flight Center; E CoBabe-Amman, University of Colorado; B Laval, University of California, Los Angeles

Session details can be viewed at: http://www.agu.org/cgi-bin/sessionsfm04?meeting=fm04&sec=ED

One Earth-One Universe Workshop

Barbara Laval, Director of Education and Public Outreach for the NAI-UCLA Center for Astrobiology, was invited to attend and participate at the initial "One Earth-One Universe workshop", February 14-18 2005, Bishop Lodge, Santa Fe, New Mexico.

The One Earth One Universe workshop was carried out in time-honored Native American style where everyone was heard and respected. NASA educators and Native American scholars came together to learn and develop an enhanced appreciation of Native practices and science. The workshop will continue to focus on and explore ways of developing collaborative opportunities for Native Americans and NASA.

Participants will be invited to follow-up workshops to continue the learning process, work together for greater understanding and experience the richness and beauty of Native American customs, traditions, and knowledge.

http://www.oneearthoneuniverse.org/about.html

UCLA's Director of Education and Public Outreach Barbara Laval having a discussion with Rose Von Thater-Braan and Nancy Maryboy at the One Earth One Universe workshop- Santa Fe, New Mexico, February 14-18, 2005

One Earth Evening gathering

One Earth Group Picture

Informal Science Education Professional Development Workshop "Aliens Earths" - Lawrence Hall of Science - University of California, Berkeley

Barbara Laval, Director of Education and Public Outreach for the NAI-UCLA Center for Astrobiology, was invited to attend an Education and Public Outreach Professional Development Workshop on Informal Education, for NASA Astrobiology Institute Education & Public Outreach (EPO) Leaders.

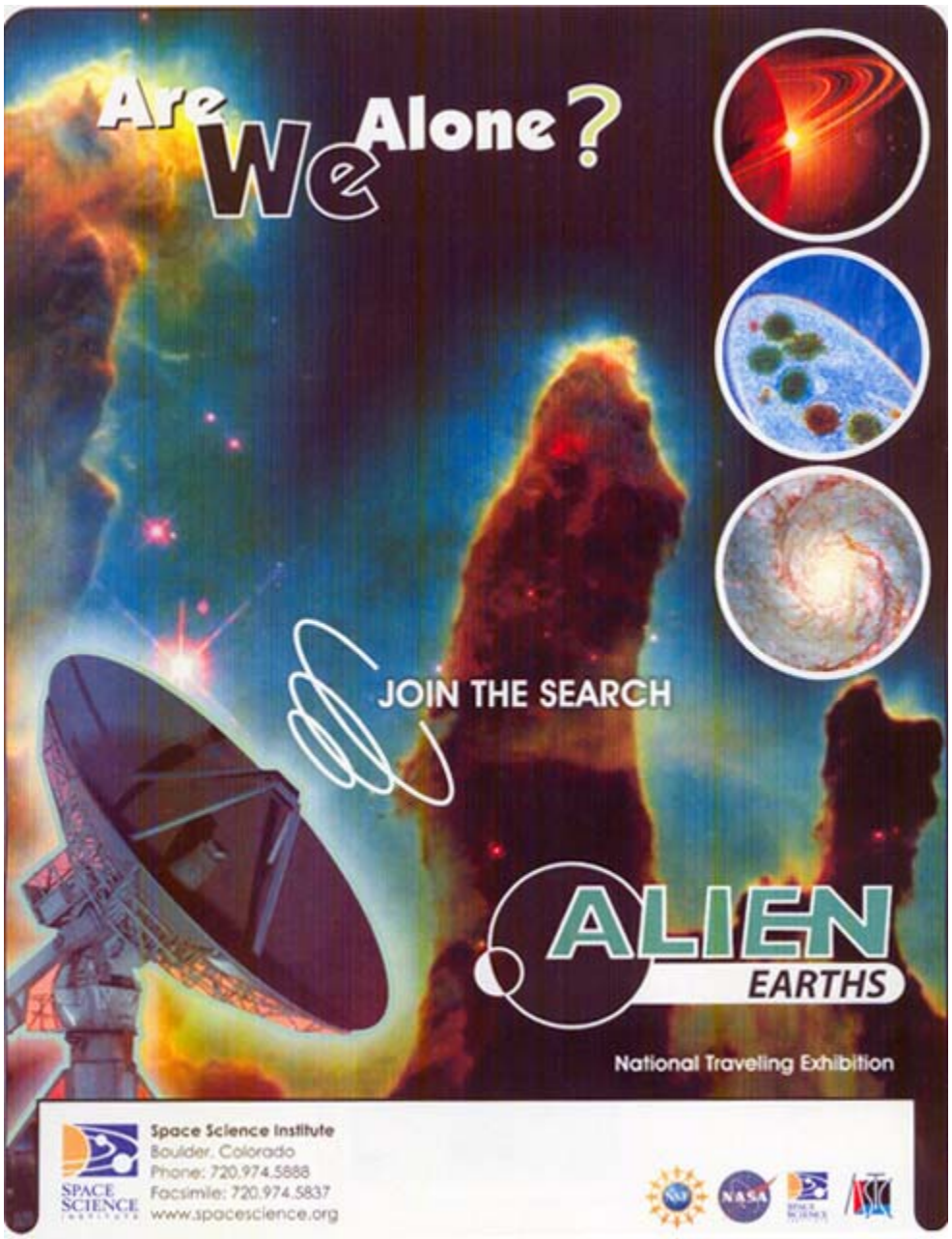
The workshop titled "Alien Earths" was held on March 7th and 8th, 2005 at the Lawrence Hall of Science, University of California, Berkeley. The Alien Earth's workshop invites visitors to join the search for distant, habitable worlds. The "Alien Earth's" exhibit is an interactive traveling museum exhibit.

The professional development workshop consisted of:

1. Introduction and overview of the exhibit and program 2. Interaction with the Alien Earths Exhibit. 3. Discussion of Basics of Facilitation 4. Facilitated experiences in the Exhibit

The EPO's evaluated the exhibit for thoroughness and durability, then separated into groups of three to evaluate how much was learned and introduced the exhibit to a pre-selected audience. UCLA requested follow-up information for the possibility of sharing the "Alien Earths" exhibit with students, teachers, and the general public in the Los Angeles area.

http://www.alienearths.org/



Picture of - "Alien Earth flyer" - courtesy of "Space Science Institute" - page one

Searching for Planets & Life Around Distant Stars

A National Traveling Exhibition

ALIEN EARTHS

Overview

Alien Earths invites visitors to join the search for distant, habitable worlds. How do we explore areas that we cannot reach with spacecraft? How do we find what we cannot see? What can we learn about a distant planet's habitability from just a few pixels of light? The answers will engage visitors with one of humanity's most fundamental questions: Are we alone?

Key Experiences

Interactive components and multi-media presentations allow visitors to:

- Compare the life cycle of our Sun to other stars
- Set planets in motion around a star and watch what happens
- Experiment with an infrared camera and ordinary objects
- Feel the difference in density between three known planets
- Explore the methods used to search for extrasolar planets
- Learn about the most abundant life form on Earth and possibly elsewhere–microbes
- Smell the difference between various microbial colonies
- Listen to sounds from space and find out what signals from intelligent beings might sound like

Rental Information

- Opens February 2005 at the Lawrence Hall of Science
- Rental fee (includes a set-up and take-down technician): $40,000 for ASTC members, $45,000 for non-members
- Inbound shipping (1 to 2 vans) paid by the host site
- 3,000 square feet of exhibit space needed
- Crates designed for easy handling
- 10-foot ceiling minimum, 12-foot or greater recommended
- Staffing and technical support required
- Available beginning June 2005

To book Alien Earths, contact:
Wendy Hancock, Manager, Exhibition Services
Association of Science-Technology Centers (ASTC)
202.783.7200, ext. 117, whancock@astc.org
www.astc.org

WWW.ALIENEARTHS.ORG

This stunning picture of a giant galactic nebula captures various images of the life cycle of stars. Courtesy NASA/STSci

An artist's conception of an extrasolar planet. Credit: Greg Bacon, STSci.

One influence on the search for life beyond Earth has been the discovery of life in extreme environments, such as these tube worms found in the hot, acidic waters near a deep-sea hydrothermal vent. Image courtesy NOAA/ Dept. of Commerce

For more information contact:

Lisa Curtis, Exhibit Manager
Space Science Institute
720.974.5821
curtis@spacescience.org

SPACE SCIENCE INSTITUTE

Picture of - "Alien Earths flyer" - courtesy of "Space Science Institute" - page two

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NASA Astrobiology Biennial Meeting EPO Poster Session - Boulder, Colorado - Astrobiology in a K-14 Diverse Multi-Cultural Society

Barbara Laval, Director of Education and Public Outreach for the NAI-UCLA Center for Astrobiology, submitted the following abstract and poster at the NASA Astrobiology Institute's Biennial Meeting, April 14-19, 2005, Boulder, Colorado.

Astrobiology in a K-14 Diverse Multi-Cultural Society

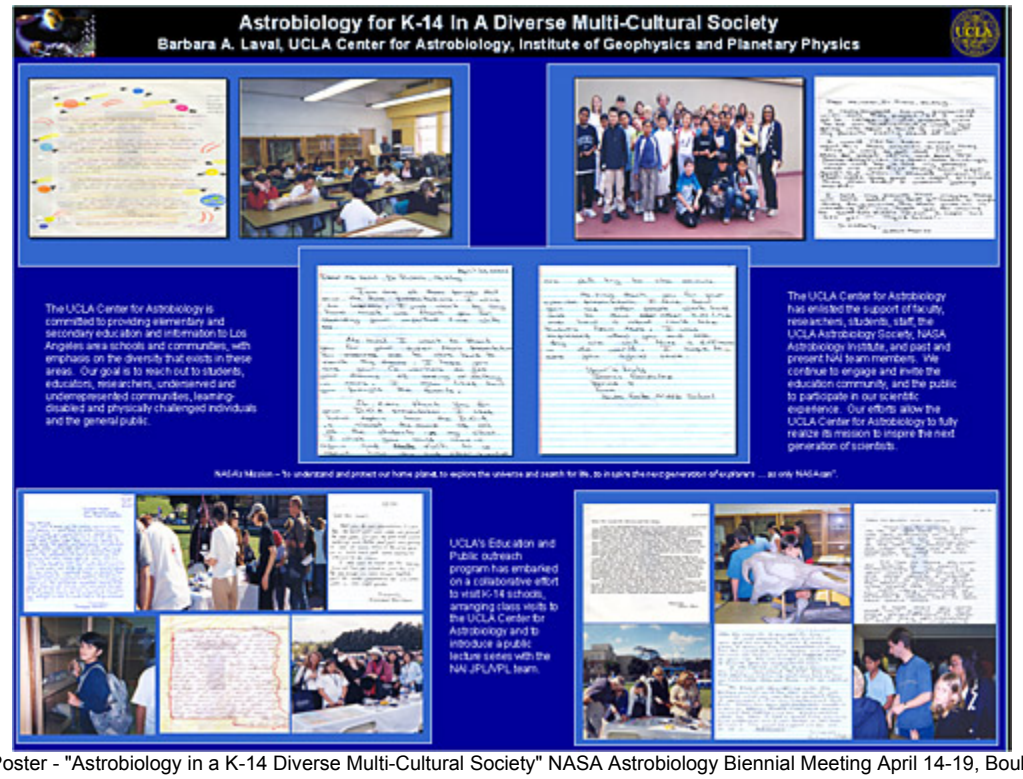
NASA's Mission -"to understand and protect our home planet, to explore the universe and search for life, to inspire the next generation of explorers....as only NASA can".

The UCLA Center for Astrobiology is committed to providing elementary and secondary education and information to the extensive Los Angeles area schools and communities, with emphases on the diversity that exists in these communities. Our goal is to reach out to students, educators, researchers, underrepresented and underserved communities, learning disabled and physically challenged individuals and the general public.

UCLA's Education and Public Outreach program is in the process of educating and inspiring the next

generation of explorers. We have embarked on a collaborative effort visiting K-14 schools, arranging class visits to the UCLA Center for Astrobiology and introducing a public lecture series with the NAI JPL/VPL team.

The UCLA Center for Astrobiology has enlisted the support of faculty, researchers, students, staff, the UCLA AstroBiology Society, NASA Astrobiology Institute staff, and past and recent NAI team members. We continue to engage and invite the educational community, students and the public to participate in our scientific experience. Our efforts allow the UCLA Center for Astrobiology to fully realize its mission to understand, explore, and inspire people from all walks of life.



UCLA's NAI Poster - "Astrobiology in a K-14 Diverse Multi-Cultural Society" NASA Astrobiology Biennial Meeting April 14-19, Boulder, Colorado

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Intel International Science and Engineering Fair - Phoenix, Arizona

Barbara Laval, Director of Education and Public Outreach for the NAI-UCLA Center for Astrobiology, was invited to judge at the International Science and Engineering Fair (ISEF), held in Phoenix, Arizona.

ISEF is now in its 50th year and is the only international science project competition for students in the 9th - 12th grades and is a means of encouraging pre-college students to conduct scientific research. Student finalists compete via a step by step process to qualify. Students begin at the local school and/or science fairs and participate in regional and/or state fairs as representatives of previously won fairs (city, regional, and state fairs), ultimately participating in the Intel ISEF. There were over 1300 student finalists representing 40 nations competing for over 3 million in scholarships and awards.

The Intel International Science and Engineering Fair is a non-profit corporation devoted to advancing the understanding and appreciation of science through publications and education programs.

www.intelisef2005.org

Judging guide from the ISEF Phoenix, Arizona

Astrobiology Summer Science Experience for Teachers (ASSET) - National Science Teachers Association NSTA

Barbara Laval, Director of Education and Public Outreach for the NAI-UCLA Center for Astrobiology, took part in the NASA Astrobiology Institute - SETI Astrobiology Summer Science Experience for Teachers (ASSET) 2004 Program.

As a follow-up to last years contributions, Ms. Laval was invited by SETI to attend the National Science Teachers Association conference (NSTA) in Dallas and supported the activities of their NASA booth and provided information pertaining to SETI's Voyages Through Time science curriculum.

In addition to providing information regarding the Voyages Through Time curriculum, Ms. Laval supported demonstrations of the Kepler Transit Demonstration, constructed with Lego Orrery parts and SETI's Infrared Astronomy exhibition.

UCLA's Director of Education and Public Outreach Barbara Laval Participating at the 2005 NSTA-SETI Booth - Dallas Texas

UCLA's Director of Education and Public Outreach Barbara Laval Demonstrating Infrared Technology

UCLA's Director of Education and Public Outreach Posing in Astronauts uniform at the 2005 National Science Teachers Conference - Dallas Texas

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The Science Study of Navajo Astronomy

Barbara Laval, Director of Education and Public Outreach for the NAI-UCLA Center for Astrobiology, was invited to participate and teach 5th grade students at The Science Study of Navajo Astronomy, an educational outreach program held on the Navajo Reservation in Navajo New, Mexico. Ms. Laval invited Dianne Taylor an Astrobiology Graduate Student to join her on this trip. The representatives from UCLA spent two (2) days with the 5th grade students at the Navajo Elementary School. Along with the two teachers, fifteen students took part in the UCLA two-day event. Students were given presentations on Astronomy and Astrobiology and participated in science discussions regarding the planets in our solar

system.

The 5th grade Navajo Elementary students:

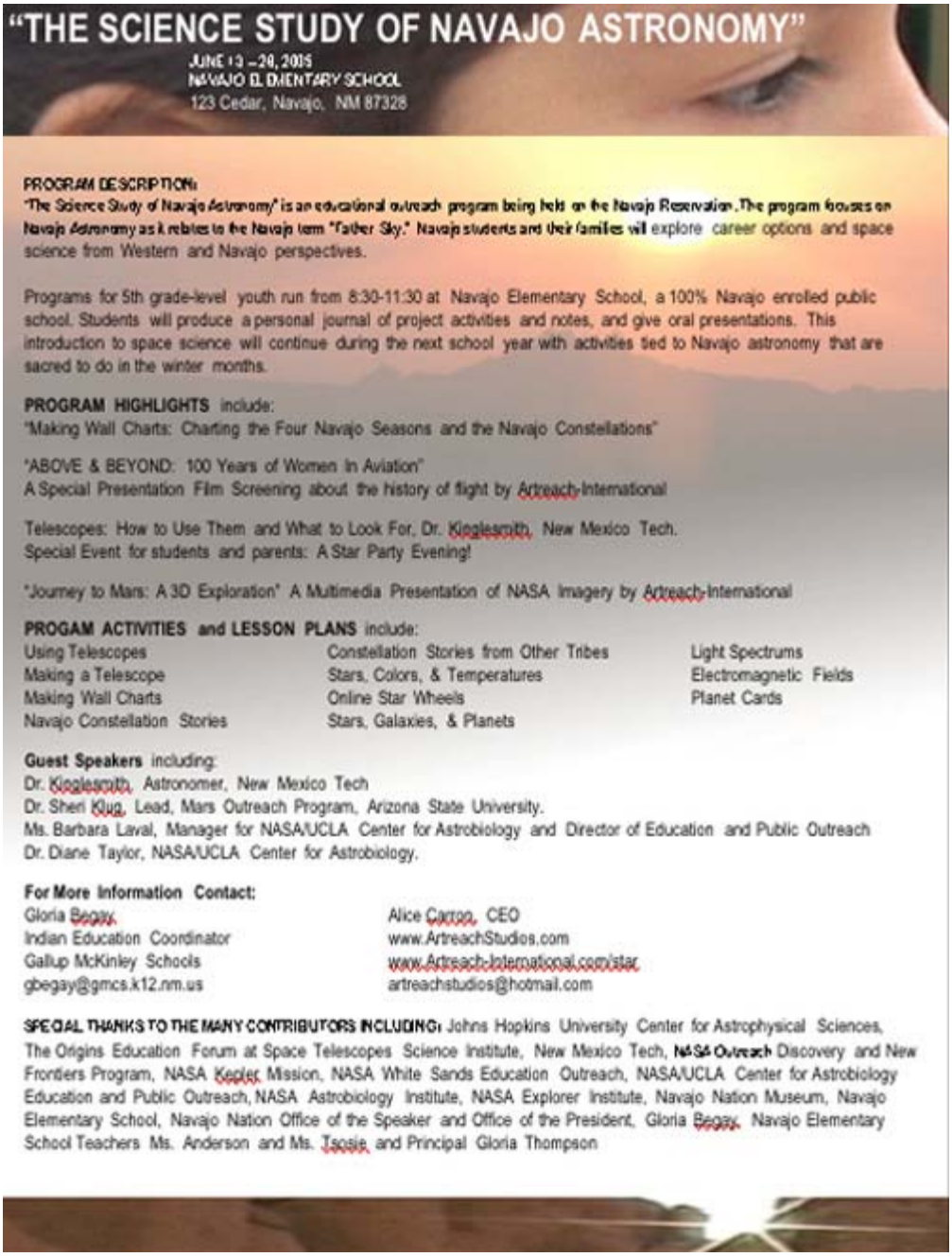
1) Learned the correlated History of Earth with emphases on the Mesozoic Era. 2) Viewed videos on (Opportunity and Spirit's Mars landing and SOFIA's future flights). 3) Were introduced to the NAI Astrobiology film "Aliens of the Deep". 4) Discussed their futures in the fields of science - (Astronomers (7), Astrobiologists (4), Astronauts (2), and Do it all (2). 5) Taught Navajo Astronomy to Ms. Laval and Ms. Taylor. 6) Reported back on homework assignment - (Discuss and teach the science they learned to a family member). 7) Learned about our star and the planets in our solar system. 8) Participated in two (2) activities (constructing their own comets and demonstrations on the Big Bang theory - meteor impacts and craters on earth). 9) Participated in a question/answer segments both days. 10) Were presented with a certificate as participants in the "New Horizons Missions," a compact disc with each student names will be included on the space craft.

Ms. Pamela Harman and Ms. Marita Beard of the NAI SETI Institute provided the following materials for the teachers and students in support of the UCLA visit to the Navajo Reservation Elementary School.

1. Sampler CD's (1 & 2) of Voyages Through Time Science Curriculum 2. Kepler Lithographs and stickers 3. SOFIA Lithographs and stickers 4. Posters 5. Bookmarks 6. Explorer Magazines

Navajo Flyer - Science Study of Navajo Astronomy

Thanks for coming!



"THE SCIENCE STUDY OF NAVAJO ASTRONOMY"

JUNE 13 – 20, 2015
NAVAJO ELEMENTARY SCHOOL
123 Cedar, Navajo, NM 87328

PROGRAM DESCRIPTION:
"The Science Study of Navajo Astronomy" is an educational outreach program being held on the Navajo Reservation. The program focuses on Navajo Astronomy as it relates to the Navajo term "Father Sky." Navajo students and their families will explore career options and space science from Western and Navajo perspectives.

Programs for 5th grade-level youth run from 8:30-11:30 at Navajo Elementary School, a 100% Navajo enrolled public school. Students will produce a personal journal of project activities and notes, and give oral presentations. This introduction to space science will continue during the next school year with activities tied to Navajo astronomy that are sacred to do in the winter months.

PROGRAM HIGHLIGHTS include:
"Making Wall Charts: Charting the Four Navajo Seasons and the Navajo Constellations"

"ABOVE & BEYOND: 100 Years of Women In Aviation"
A Special Presentation Film Screening about the history of flight by Artreach-International

Telescopes: How to Use Them and What to Look For, Dr. Kieglesmith, New Mexico Tech.
Special Event for students and parents: A Star Party Evening!

"Journey to Mars: A 3D Exploration" A Multimedia Presentation of NASA Imagery by Artreach-International

PROGAM ACTIVITIES and LESSON PLANS include:

Using Telescopes	Constellation Stories from Other Tribes	Light Spectrums
Making a Telescope	Stars, Colors, & Temperatures	Electromagnetic Fields
Making Wall Charts	Online Star Wheels	Planet Cards
Navajo Constellation Stories	Stars, Galaxies, & Planets	

Guest Speakers including:
Dr. Kieglesmith, Astronomer, New Mexico Tech
Dr. Sheri Klug, Lead, Mars Outreach Program, Arizona State University.
Ms. Barbara Laval, Manager for NASA/UCLA Center for Astrobiology and Director of Education and Public Outreach
Dr. Diane Taylor, NASA/UCLA Center for Astrobiology.

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SPECIAL THANKS TO THE MANY CONTRIBUTORS INCLUDING: Johns Hopkins University Center for Astrophysical Sciences, The Origins Education Forum at Space Telescopes Science Institute, New Mexico Tech, NASA Outreach Discovery and New Frontiers Program, NASA Kepler Mission, NASA White Sands Education Outreach, NASA/UCLA Center for Astrobiology Education and Public Outreach, NASA Astrobiology Institute, NASA Explorer Institute, Navajo Nation Museum, Navajo Elementary School, Navajo Nation Office of the Speaker and Office of the President, Gloria Begay, Navajo Elementary School Teachers Ms. Anderson and Ms. Tsosie and Principal Gloria Thompson

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NASA Astrobiology Biennial Meeting - Session 1 - Lead Talk -: Formation and Evolution of Planetary Systems - Lead Talk -Boulder, Colorado -

Professor T. Harrison, Faculty Member of the NAI UCLA Center for Astrobiology presented the following LEAD TALK hosted by the University of Colorado, Boulder, NASA Astrobiology Biennial Meeting.

FORMATION AND EVOLUTION OF HABITABLE WORLDS

While considerable progress has been made in the past 20 years in understanding the evolution of accretion disks surrounding sun-like stars at radii from 0.03-03 AU (dissipating on timescales of 1-10 MA0, as well as older debris disks from 30-300 AU (with ages of 1-10 Ma), we still lack answers to basic questions such as: 1) how long do gas-rich disks survive from 0.3-30 AU; 2) how do disks transition from primordial accretion to post-accretion debris; and 3) what is the range of typical disk properties as a function of radius and age and how do these properties compare to the inferred history of our own solar system. Answers to these questions constrain theories of gas-giant and terrestrial planet formation, both of which have an impact concerning the habitability of emergent planetary systems. We seek to understand, among the ensemble of terrestrial-like planets that may be out there, how common habitable (and inhabited) worlds are. This depends on how different extraterrestrial life could be from ours and the nature and range of environments

in which life could emerge. While little about this is known, there is consensus that research examining the conditions necessary to retain liquid water and create life in extreme environments is important. Key questions are: 1) how do terrestrial planers gain and maintain, or lose, water; 2) when did the Moon form and what is its role in the emergence of life; 3) what is the evidence for the oldest life on Earth and under what conditions did it arise; 4) how does a planet's impact history bear on early habitability; and 5) is atmosphere and biosphere co-evolution an inevitable consequence of life?

Publications: University of California, Los Angeles

There are **44** publication entries for the University of California, Los Angeles

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Unknown type: Generic (13)

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Executive Summary: University of Rhode Island

Executive Summary: University of Rhode Island
Principal Investigator: Steven D'Hondt
Reporting Period: 2005 (7/04-6/05)

The University of Rhode Island (URI) team of the NASA Astrobiology Institute (NAI) works to gain a fundamental understanding of Earth's subsurface life. Our principal research objectives are to understand (1) the subsurface microbial ecosystems of marine sediments, (2) their role in Earth's biogeochemical cycles, and (3) their relevance to the search for life on other planets. Our investigators are based at the University of Rhode Island (URI), the University of North Carolina at Chapel Hill (UNC), and Woods Hole Oceanographic Institution (WHOI). To effectively accomplish our objectives, URI team researchers collaborate with each other and with scientists at other institutions throughout the world (e.g., D'Hondt et al., 2004). Our current collaborators include members of the Marine Biological Laboratory (MBL), Pennsylvania State University (PSU) and Indiana/Princeton/Tennessee (IPTAI) NAI teams. Other collaborators include scientists at the University of Bremen (Germany), the Max Planck Institute for Marine Microbiology (Germany), the Japan Marine Science and Technology Center, the Massachusetts Institute of Technology, Roger Williams University, and a number of other institutions. To gain access to subsurface environments in Year 7, we participated in field expeditions to many regions, including the Arctic Ocean, the northeastern Pacific, the northeastern Atlantic (the Ireland Margin and the Lost City Hydrothermal Field), and subarctic Canada (Figure 1).

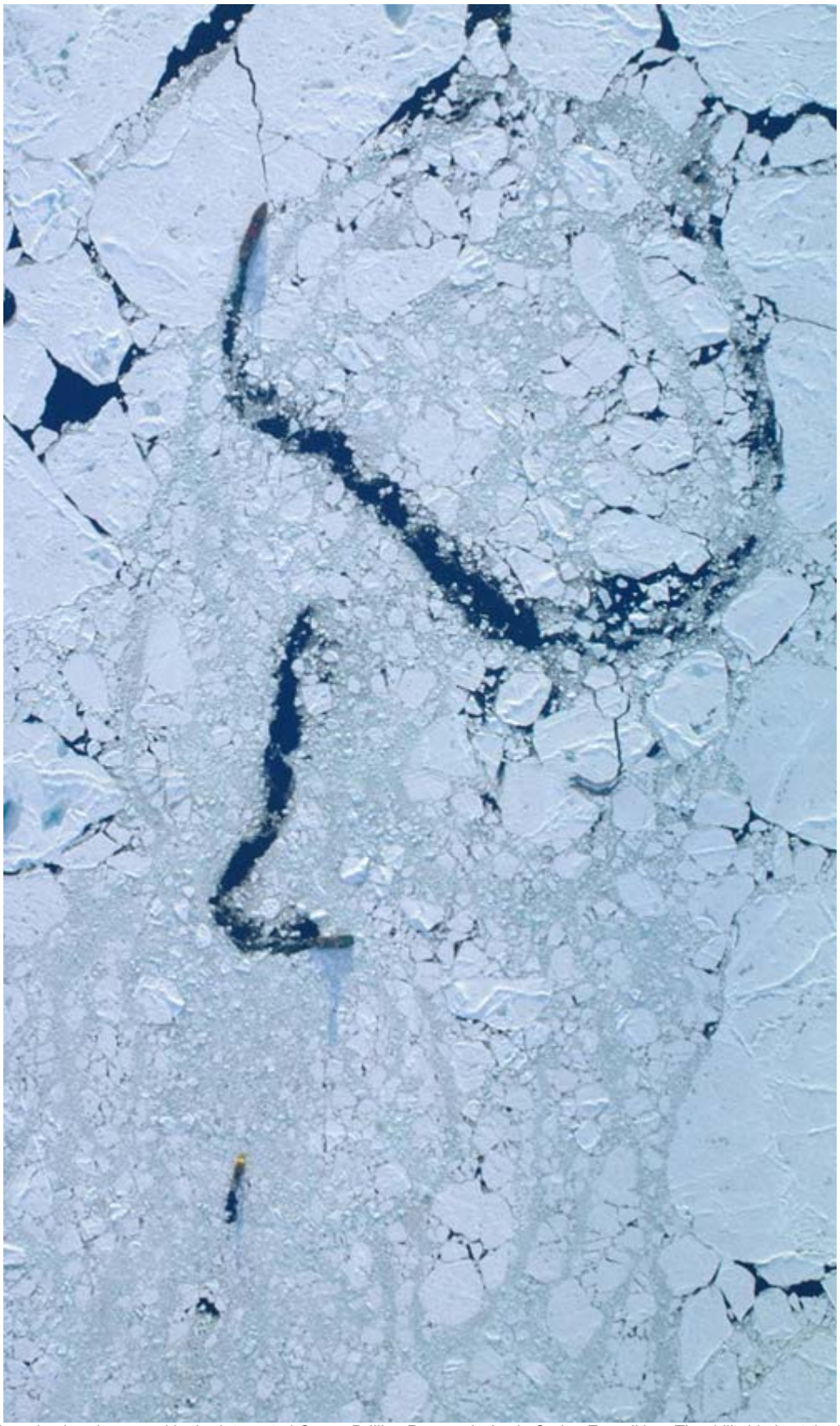

Figure 1. Arial view of the three ice-breakers used in the Integrated Ocean Drilling Program's Arctic Coring Expedition. The drill-ship is at the bottom. URI Team Member David C. Smith sailed on the expedition as the shipboard microbiologist.

Members of our team at UNC Chapel Hill focus on molecular studies of deep subsurface communities. In year 7, we published the first molecular community analyses (16S rRNA genes) of organic-poor deep marine subsurface sediments. In collaboration with MBL team members, we also undertook what may be the first rRNA analyses of deep subsurface communities. The latter analyses allow us to identify the active members of deep subsurface communities (in contrast to DNA-based assays that combine signatures of active, inactive and dead prokaryotes).

With our 16S rRNA gene studies, we finished and published the molecular community analysis for archaea in organic-poor deep subseafloor sediments of the Peru Basin (Sørensen et al. 2004) and the equatorial Pacific (Lauer et al. 2004). These environments are model systems for abyssal basins with very low sedimentation of organic matter. Such organic-poor sediments had not been studied by 16S rDNA sequencing before. Sequencing results for the equatorial Pacific site indicated an archaeal community that was similar to most other cold sediment communities. The Peru Basin site is marked by much lower activity and lower biomass than previously studied sites. Its archaeal community exhibits considerable overlap with hydrothermal vent communities, suggesting transport and dispersal of vent archaea either through surface or subsurface environments (Sørensen et al. 2004).

We are presently extracting, reverse-transcribing and PCR-amplifying rRNA from deep sediments at several Peru Margin sites (ODP Sites 1227, 1228, 1229, 1230). We are cloning and sequencing these samples in collaboration with members of the MBL team. Our goal is to identify the active microbial components of these deep subsurface sediments, and to differentiate them from potentially inactive or dead cells that harbor DNA, but no rRNA (Lever and Teske, 2005).

By 16S rDNA and Rubisco gene sequencing, w e also analyzed formation fluids from a sealed borehole (ODP Site 896A) (Harris and Teske, 2005). Our data indicate that the inorganic electron donors in the formation fluid provide energy for a diverse, partially chemolithotrophic bacterial community.

Team members at WHOI principally focus on organic biogeochemical and isotopic signatures of life in subsurface environments. During year 7, our WHOI investigators continued their research on (1) compound-specific analyses of intact polar lipids (IPLs) in deeply buried sediments of the Peru Margin, (2) the construction of a taxonomic database of IPL distributions in prokaryotes that encompasses now more than 100 cultures, (3) the study of biological formation of ethane and propane in subsurface sediments, (4) and peridotite-based hydrothermal ecosystems with abundant chemolithoautotrophic prokaryotes.

For our taxonomic database, we have systematically studied more than 100 cultures of biogeochemically and astrobiologically relevant prokaryotes from all major phyla of Archaea and Bacteria. Major distinctive features examined are structure and distribution of polar headgroups, bond type between alkyl chains and glycerol, and the lengths of and number of rings and/or bonds in alkyl chains. In combination, these structural features are distinctive on the mono-specific level and yield taxonomically valuable chemical fingerprints. Because environmental communities are typically complex, their lipid signatures represent ecosystem fingerprints, which are relevant to both environmental and life sciences. As a result of these studies, analysis of intact membrane lipids is now taxonomically far more specific than previously used lipid techniques.

From the distribution and isotopic systematics of methane, ethane and propane in marine sediments we have identified evidence that ethane and propane are produced biologically at low temperatures (Hinrichs et al., in review). To undertake these studies, we decreased the detection limit for isotopic analysis of acetate in marine pore waters by almost two orders of magnitude. To test our hypothesis of low-temperature microbial ethanogenesis and propanogenesis, we are currently searching for potential abiotic pathways of hydrocarbon formation that could be catalyzed by sedimentary components such as minerals. Ongoing experiments, in which we treat sediments with D_2O and NaOH, have so far not yielded D-labeled hydrocarbons. This is consistent with our proposed biological mechanism.

Members of our team at URI principally focus on studies of deep subsurface activities, ecosystem structure and biogeochemical fluxes. To further these studies, we continue to develop and apply techniques for quantification of deep subsurface activities and ecosystem structure.

A recent technical advance of our team is our development and utilization of an extremely sensitive tritium-based method for the detection of life based on the measurement of hydrogenase activity. This work has been co-funded by the NAI and the US National Science Foundation (NSF). We have submitted the protocol for publication (Soffientino et al., in review). We are currently refining this technique and applying it to samples from deep subseafloor sediments and (in collaboration with IPTAI team members) deep gold mines (Figure 2).

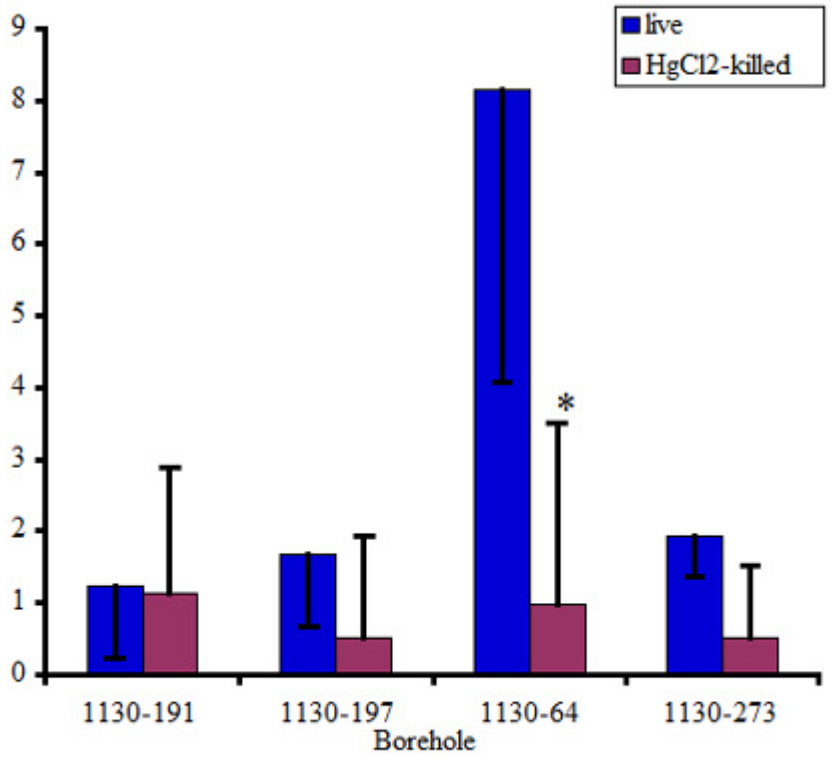

Figure 2. Hydrogenase activity of samples from 1130-m deep boreholes at Lupin gold mine (Canada). Microbes from sample 1130-64 exhibited significant activity (Error bars are 95% confidence intervals; asterisk denotes significant difference from killed control). The samples were taken by URI team member Bruno Soffientino on an expedition led by T.C. Onstott of the IPTAI team. Data and figure courtesy of B. Soffientino.

Another recent technical advance is a new method for determining *in situ* concentrations of hydrocarbons (e.g., methane, ethane, propane) from samples that depressurize during their recovery from great depth (Spivack et al., in review). Our method is based on direct gas chromatographic analysis of the methane/argon/nitrogen ratios of gas voids. It does not involve the expensive and time-consuming technology of existing methods. Another current technological focus is development of techniques for isolating intact cells from sediments. Future application of the latter techniques will greatly improve enumeration of subsurface cells, molecular studies of populational composition, and direct study of individual organisms.

In the last year, we also showed that a deep subseafloor ecosystem is a thermodynamic homeostat where sulfate reduction, iron reduction, methanogenesis and possibly methanotrophy are mutually dependent and produce biologically useful energy throughout a sediment column deposited over millions of years (Wang et al., 2005, in preparation).

In all settings, we are combining our microbiological and biogeochemical studies for a comprehensive picture of the microbial community and its interaction with its environment. For example, biogeochemical data are used to define ecological niches for each microbial community defined by our DNA and RNA results. The synthesis of these different lines of research is nicely illustrated by our studies of archaeal communities in deeply buried sulfate-methane transition zones, which URI team members at WHOI and UNC are undertaking with PSU team member C. House. Extractable archaeal 16S rRNA indicates that these communities are dominated by two novel lineages that are distinct from archaeal methanotrophs in surface sediments. We have reconstructed the carbon flow in the ecosystem from isotopic compositions of various sedimentary carbon pools, including live archaeal biomass (as whole cells and intact lipids). Our data indicate that the archaea are heterotrophic and, unlike near-surface methanotrophs, do not assimilate carbon from methane. Slow decomposition of fossil organic carbon on geological time scales is likely providing the organic compounds assimilated by the archaeal community. In short, sulfate-methane transition zones in deeply buried marine sediments are uniformly dominated by heterotrophic archaea that appear to ferment and assimilate fossil organic carbon. This collaborative work is currently being prepared for submission to a scientific journal with an appropriately broad readership (Biddle, Lipp et al., in preparation).

To help strengthen the infrastructure of the astrobiology community, members of the URI team sought and received significant support from the NSF and the University of Rhode Island for a containerized Subsurface Life field laboratory. We are now building the laboratory. It will be fully outfitted for: (1) microbiological and biogeochemical sampling of diverse subsurface environments, (2) on-site analyses of biologically significant transient properties, and (3) on-site analyses of chemical and physical properties that will be used to guide microbiological and biogeochemical sampling strategies. The proposed laboratory will be made internationally accessible to support studies of subsurface life by scientists from institutions throughout the world.

Graduate, undergraduate and post-doctoral education and research are integral parts of the URI team's mission. During the Year-7 report interval, our active research team included five post-doctoral scholars (Jens Kallmeyer, Antje Lauer, Ketil Sørensen, Bruno Soffientino and Sturt), four graduate students (Lever, Lloyd, Guizhi Wang and Carly Blair) and nine undergraduate students. To introduce astrobiology to young scientists with particularly strong potential, each year the URI team provides internationally competed summer research fellowships for upper-class (junior or senior) students to work with URI investigators on projects of astrobiological significance. All of these individuals played vital roles in our ongoing program.

To build a deeper institutional base of astrobiology awareness among undergraduate and graduate scientists and engineers, our team members continue to expand the academic programs of our home institutions by integrating astrobiological themes into existing courses, and by offering new astrobiology courses. In Year 7, we offered a Freshman Honors seminar at URI titled "Life in the Universe" (Spring, 2005). This course will be a regular course offering in future years. To introduce our work and the field of astrobiology to the broader public, URI team investigators gave public presentations and lectures at a variety of universities and other venues (including a lecture on subsurface life and planetary exploration by Steven D'Hondt at the Annual Meeting of the New England Association of Chemistry Teachers). To disseminate our work and its relevance more broadly, in the Year-7 interval the team continues to participate in collaborative outreach with Rhode Island Space Grant and with the Rhode Island GEMS-NET program. We also continue to maintain our website on URI astrobiology efforts in research and education (http://www.gso.uri.edu/astrobiology).

In short, research, education and outreach by the NAI URI Team and its collaborators continue to steadily advance knowledge and awareness of life deep beneath Earth's surface, its role in Earth's surface processes, and its relevance to the search for life on other planets.

Project Reports: University of Rhode Island

Subsurface Biospheres (project)

Project Investigator: Steven D'Hondt

Project Progress

Members of our team at UNC Chapel Hill focus on molecular studies of deep subsurface communities. In year 7, we published the first molecular community analyses (16S rRNA genes) of organic-poor deep marine subsurface sediments. In collaboration with MBL team members, we also undertook what may be the first rRNA analyses of deep subsurface communities. These analyses allow us to identify the active members of deep subsurface communities (in contrast to DNA-based assays that combine signatures of active, inactive and dead prokaryotes). Our DNA-based studies of formation fluid from a sealed borehole near Costa Rica indicate that the fluid helps to support a diverse, partially chemolithotrophic community.

The WHOI members of our team continued research on biomarkers and subseafloor processes. With PSU team member C. House, we showed that archaeal communities in deeply buried sulfate-methane transition zones are dominated by two novel lineages that are distinct from methanotrophs in surface sediments and, unlike near-surface methanotrophs, do not assimilate carbon from methane. To further test our Year 6 hypothesis of microbial ethanogenesis and propanogenesis in subseafloor sediments, we are searching for potential abiotic pathways of hydrocarbon formation. We also undertook molecular isotopic studies of peridotite-based hydrothermal ecosystems with abundant chemolithoautotrophs. To date, we have also systematically identified biomarkers that distinguish more than 100 cultures of prokaryotes that collectively cover all major phyla of Bacteria and Archaea.

Members of our team at URI continued to develop and apply techniques for quantification of deep subsurface activities and ecosystem structure. We showed that a deep subseafloor ecosystem is a thermodynamic homeostat where sulfate reduction, iron reduction, methanogenesis and possibly methanotrophy are mutually dependent and produce biologically useful energy throughout a sediment column deposited over millions of years. We are refining our extremely sensitive tritium-based method for detection of life and applying it to deep subseafloor sediments and (in collaboration with IPTAI team members) to deep gold mine samples. We developed and tested (1) a robust new method for determination of subsurface methane concentrations, and (2) techniques for isolation of intact cells from sediments. Future application of the latter techniques will greatly improve analyses of subsurface life.

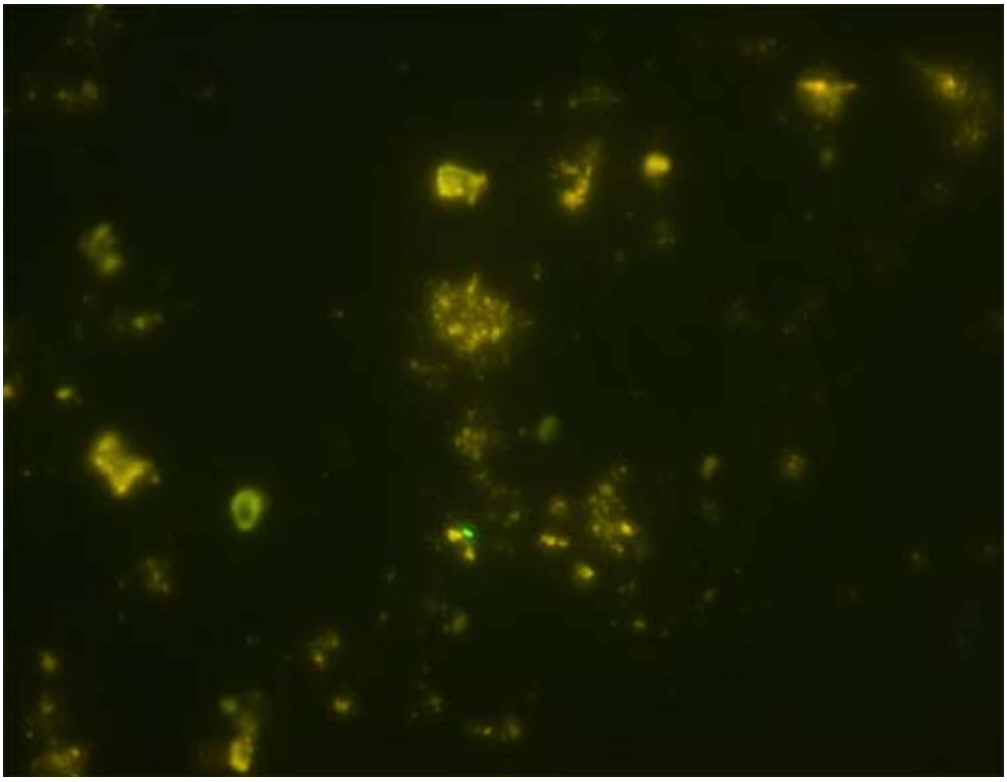

Figure 1. Epifluorescence micrograph of a SYBR-green stained microbial cell in a deep sediment sample collected from the Lomonosov Ridge, Arctic Ocean. Figure courtesy of David C. Smith.

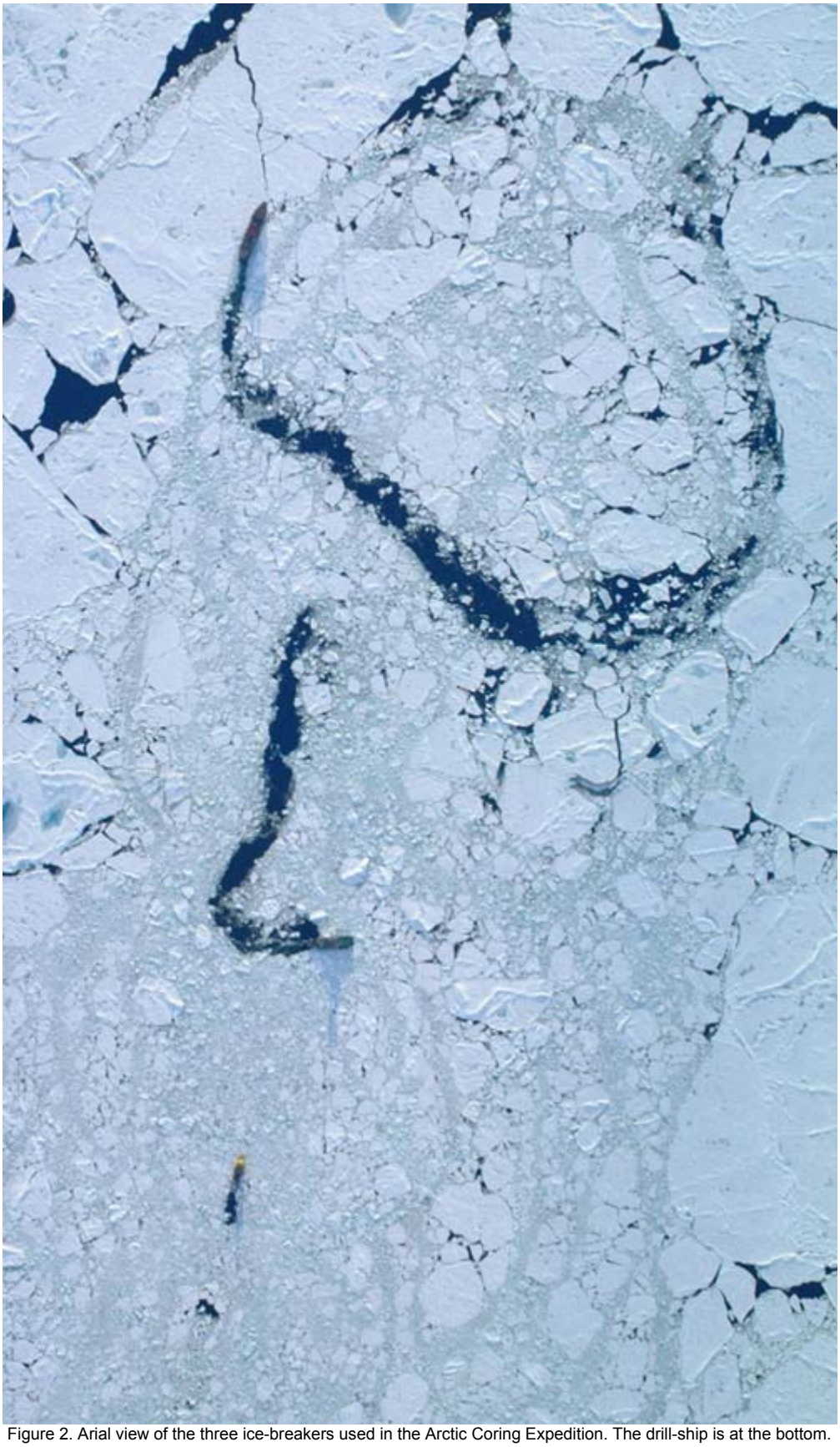

Figure 2. Arial view of the three ice-breakers used in the Arctic Coring Expedition. The drill-ship is at the bottom.

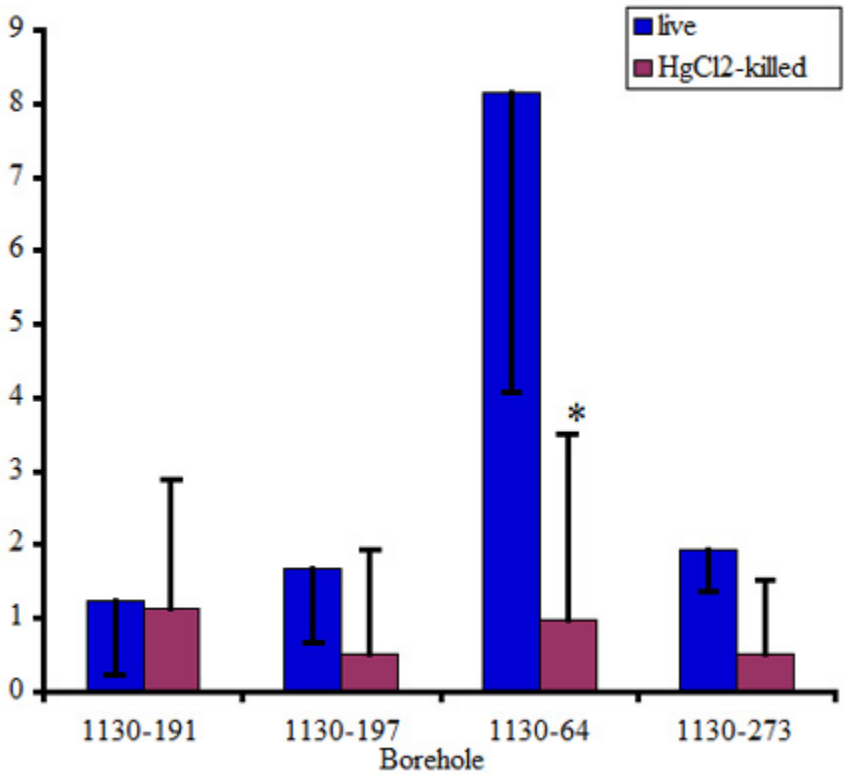

Figure 3. Microbes from an 1130-m deep borehole (1130-64) at Lupin gold mine (Canada), sampled during a 2005 expedition organized by the NAI IPTAI Team (stained with Cyber Green). In combination with isolation studies done by IPTAI investigators, the presence of different morphologies suggests a diverse microbial community. Figure courtesy of Bruno Soffientino.

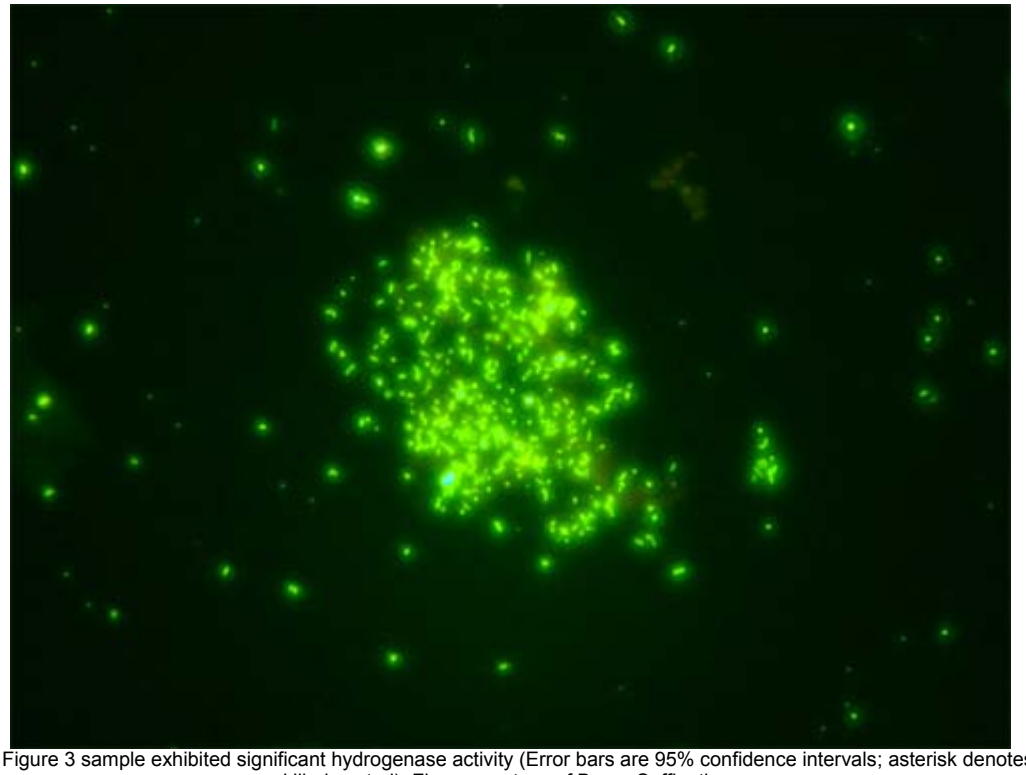

Figure 4. Microbes from the Figure 3 sample exhibited significant hydrogenase activity (Error bars are 95% confidence intervals; asterisk denotes significant difference from killed control). Figure courtesy of Bruno Soffientino.

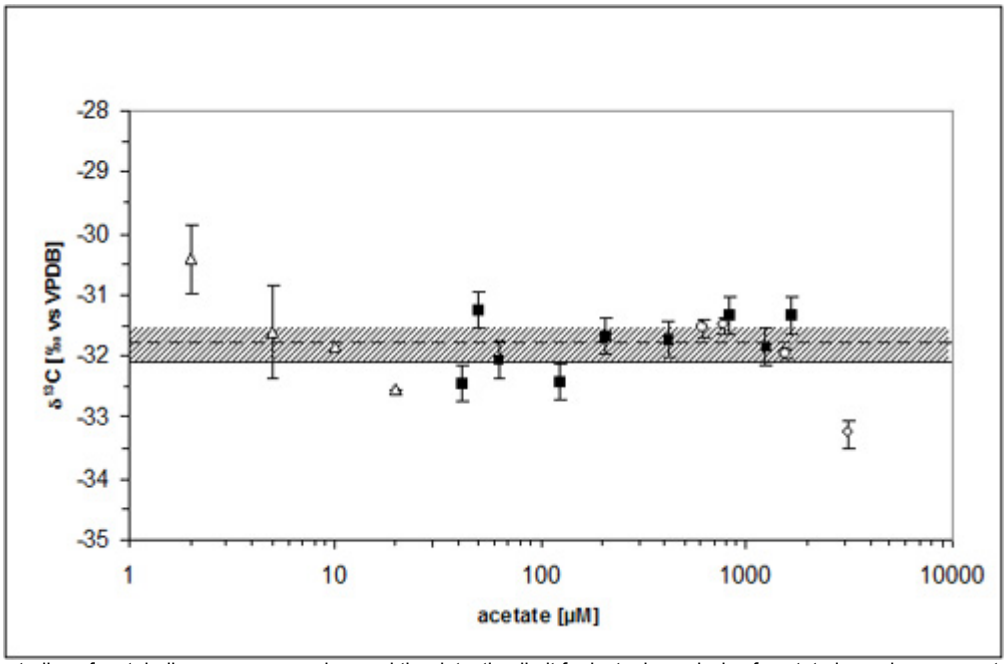

Figure 5. To undertake our studies of metabolic processes, we lowered the detection limit for isotopic analysis of acetate in marine pore waters by almost two orders of magnitude. Carbon isotopic analysis of acetate by irm-LC/MS yields a mean δ13C value of -31.8‰ (n = 31, dashed line) for 2 to 3125 µM aqueous solutions prepared from a pure Na-acetate salt. With the precision (95% confidence interval) of the analysis being ± 0.3‰ (n = 31, shaded area), irm-LC/MS results agree well with the δ13C value of -32.08 ± 0.08‰ (n = 3) determined for pure Na-acetate by irm-EA-MS (solid line). Open triangles represent 2-20 µM acetate solutions, analyzed after 12.5-fold pre-concentration. Solid squares symbolize 42 - 1667 µM standards. Open circles designate 625 - 3125 µM solutions obtained from 12.5-fold pre-concentration of 50-250 µM standards and document negligibility of isotopic fractionation. The analyzed concentration range is equivalent to 30 - 3750 ng of carbon delivered to the ion source (from Elvert et al., abstract, IMOG meeting 2005).

Roadmap Objectives

- **Objective No. 2.1:** Mars exploration
- **Objective No. 2.2:** Outer Solar System exploration
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.3:** Effects of extraterrestrial events upon the biosphere
- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
3	Concept: Deep subsurface life on inhospitable planets	Background Research
3	Concept: Biomarkers	Research or Analysis Techniques

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Planets that are characterized by inhospitable surface conditions (UV and cosmic radiation; thin or unsuitable atmosphere; temperature extremes, lack of liquid water) may still harbor life in their subsurface that is to some extent protected from these stress factors. On Earth, phylogenetically (and presumably physiologically) distinct bacterial and archaeal communities are present and active in the marine

sedimentary subsurface. These communities provide a model for possible subsurface communities on other planets and moons (e.g., Mars, Europa).

Several of our analytical techniques and results are appropriate to search for life on other bodies; these include our tritium-based assay for enzymatic activity, our isotopic analyses of biologically active molecules (e.g., methane ethane, acetate, complex organic compounds), and our demonstration that a subsurface community may be a thermodynamic homeostat with predictable energy yields.

Field Expeditions

Field Trip Name: Leg 308, Integrated Ocean Drilling Program
Start Date: April 29, 2005 **End Date:** May 30, 2005
Continent: North Atlantic **Country:** n.a.
State/Province: **Nearest City/Town:**
Latitude: ~ 48° N **Longitude:** 15° W
Name of site(cave, mine, e.g.): Porcupine Basin **Keywords:**
Description of Work: Shipboard geochemistry; postcruise radioassays for hydrogenase activity.
Members Involved:

Field Trip Name: Leg 309 Integrated Ocean Drilling Program
Start Date: May 31 **End Date:** July 7
Continent: Gulf of Mexico **Country:** n.a.
State/Province: **Nearest City/Town:**
Latitude: ~29° N **Longitude:** ~ 90° W
Name of site(cave, mine, e.g.): **Keywords:**
Description of Work: postcruise radioassays for hydrogenase activity
Members Involved:

Field Trip Name: Lupin Mine
Start Date: March 1, 2005 **End Date:** March 31, 2005
Continent: North America **Country:** Canada
State/Province: Nunavut **Nearest City/Town:** Yellowknife
Latitude: ~65° N **Longitude:** ~ 111° W
Name of site(cave, mine, e.g.): Lupin gold mine **Keywords:**
Description of Work: Collection of water from deep, subpermafrost aquifer(s). Post-expedition cell enumeration and radioassays for hydrogenase enzymatic activity.
Members Involved:

Field Trip Name: IODP Leg 301, Juan de Fuca ridge flanks
Start Date: June 21, 2004 **End Date:** August 29, 2004
Continent: North America, Pacific Northwest, offshore Oregon **Country:** USA
State/Province: Offshore Oregon and Washington **Nearest City/Town:** Portland, OR
Latitude: 47°45N to 47°54N **Longitude:** 127°10 N to 128°34N
Name of site(cave, mine, e.g.): Boreholes FR-1, SR-1, SR-2, DR-1, DR-2 **Keywords:** Juan de Fuca, ridge flanks, hydrothermal circulation
Description of Work: ---Shipboard microbiology --- DNA/RNA extraction, sequencing of key genes (mcrA) and reverse-transcribed 16S rRNA, to infer community structure and activity --- Modeling of key chemical gradients (methane, sulfate), to infer anaerobic process rates in the Leg 301 sediments (sulfate reduction, methanogensis, sulfate-dependent

methane oxidation) --- cultivation attempts for methanogens
Members Involved:

Field Trip Name: ACEX: Arctic Coring Expedition, Integrated Ocean Drilling Program Expedition 302

Start Date: August 7, 2004	**End Date:** September 14, 2004
Continent: NONE (Arctic Ocean)	**Country:** NONE (Arctic Ocean)
State/Province:	**Nearest City/Town:** Cape Fligeli (Franz Josef Land)
Latitude: 87.93	**Longitude:** 139.53
Name of site(cave, mine, e.g.): Lomonosov Ridge	**Keywords:** Arctic Ocean seafloor drilling

Description of Work: Retrieve ~400 m of marine sediments on the Lomonosov Ridge to study microorganisms inhabiting this extreme environment
Members Involved:

Cross Team Collaborations

We are collaborating with the MBL Team in our sequencing survey of reverse-transcribed rRNA from all Peru Margin sites (1227, 1228, 1229, 1230). This is the first time that active archaea have been detected by sequencing of rRNA; all other published PCR-based sequencing studies of deep-subsurface sediments were performed with genomic DNA. This distinction between rRNA and rDNA is crucial, because rRNA is characteristic of living, active cells, whereas rDNA can also be derived from inactive or dead cells. This collaborative sequencing project allows for the first time reliable identification of active archaeal subsurface microbiaota, cultured and uncultured. This project would be orders of magnitude more time-consuming and expensive with local sequencing resources in Chapel Hill. Individuals involved are A. Teske, K.B. Sorensen, K. Lloyd, M. Lever, L.Wehrmann and D. Kalhoefer (URI team members at UNC Chapel Hill), and, M. Sogin and L. Graham at MBL..

So far, Site 1227 rRNA has been sequenced from multiple sediment horizons, and a manuscript is in preparation (Soerensen and Teske 2005). Study of Site 1228 is in progress, and is being screened by two summer students (L. Wehrmann and D. Kalhoefer, Oldenburg University, Germany). Site 1229 is being processed by K. Lloyd, and Site 1230 by M. Lever. In all cases, archaeal clone libraries are dominated by members of several uncultured phyla (Miscellaneous Crenarchaeotal group, Marine Benthic Group B; SAGMEG-1, and a few others). Thus, active archaeal communities in deep marine sediments consist of representatives of only a few lineages.

Together with Penn State NAI team members C. House and J. Biddle, URI-NAI team members K.-U. Hinrichs and Teske have conducted a study of the archaeal communities in deeply buried sulfate-methane transition zones. Extractable archaeal 16S rRNA indicates that these communities are dominated by two novel lineages that are distinct from archaeal methanotrophs in surface sediments. The carbon flow in the ecosystem is reconstructed on the basis of isotopic compositions of various sedimentary carbon pools, including live archaeal biomass (as whole cells and intact lipids). The data indicate that the archaea are heterotrophic and do not assimilate methane carbon. Slow decomposition of fossil organic carbon on geological time scales is likely providing the organic compounds assimilated by the archaeal community. This collaborative work is currently being prepared for submission to Science (Biddle, Lipp et al.).

URI team member B. Soffientino participated in a field trip to Lupin Mine, Nunavut, Canada, as part of an expedition organized by the IPTAI team and led by IPTAI team member T.C. Onstott in March, 2005. Soffientino collected water samples for hydrogenase activity measurement, and for direct microbial counts. The samples were frozen to approximately -30°C and transported back to URI where the work was carried out. Significant activity was detected in water from one of the 8 boreholes sampled. This borehole, from 1130 meters below surface contained about 105 cells/ml and had a hydrogenase activity of 1.4 X 10-16 mol H2 exchanged/ml/min. As far as we know, these are the first direct (radiotracer) measurements of microbial activity ever made from such a deep subsurface environment.

EPO Reports: University of Rhode Island

There are no EPO Records for this reporting period. (2005 (7/04-6/05))

Publications: University of Rhode Island

There are **50** publication entries for the University of Rhode Island

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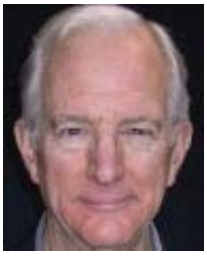

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Executive Summary: University of Washington

Executive Summary: University of Washington
Principal Investigator:
Reporting Period: 2005 (7/04-6/05)

In this, our fourth year, many of our group have come into full productivity. Our NAI sponsored research at the University of Washington has concentrated on the following important astrobiological questions:

1. What are the characteristics of planets that can evolve complex organisms?
2. Where might such planets occur?
3. How does biological complexity evolve on a planet, and how might it end?

4. What are the limits and permissible chemistries of life and how might they arise?

During the 2004-2005 period significant progress into these problems was made. Below, our results and progress is summarized based on specific research problems defined in our original proposal.

How often, where, and under which conditions do habitable planets form and persist? Even a decade ago we could not, with confidence, predict how many planets there might be beyond our own solar system. Now the rate of planet discovery is dizzying. But how many of these planets are habitable? While there was no indication that there was anything special about our own solar system and star that would make us unique in having planets, there was no real data to the contrary. Now there is definite evidence that planet formation is not only common, but might be ubiquitous to every region in our Milky Way Galaxy, and perhaps in most or all of the far flung galaxies making up the known Universe. We have gone from asking, “how many stars have planets”, to “how many planets have life?”

We define a habitable planet as a solid body capable of supporting life, as we know it. The study of extra-solar habitable planets involves a broad interdisciplinary approach that extends from understanding how planets are formed to understanding the conditions that allow such life to originate, survive, and evolve.

As one approach to understanding the evolution of habitability, Co-I Tom Quinn and his team have studied solar system formation with computer models. During the past year (2004-2005) Mejia and Quinn in collaboration with Mayer (Zurich) have continued performing simulations of giant planet formation by fragmentation of a gaseous disk. They are also investigating the dynamics of gas and dust interaction in protoplanetary disks. Dust may also move into the higher density regions of a fragmenting disk giving an alternative mechanism for forming giant planet cores.

Lufkin and Quinn performed simulations of giant planet migration and accretion in gaseous disks, while Barnes and Quinn in collaboration with Lissauer (Ames) continue their simulations of planetesimal accretion in the terrestrial region.

Barnes and Quinn continue to investigate the stability of extra-solar planetary systems as they are being discovered. They continue to find that most planetary systems, including our own, are on the edge of being unstable. This has implications for the efficiency of planet formation. Barnes and Raymond have also been investigating the formation of terrestrial planets within these known extra-solar systems.

Finally, Quinn and Kaib are starting to investigate the formation of cometary Clouds under various galactic contexts. They are also investigating the resulting impact history of comets on terrestrial planets. This latter area allows bridges to both the Impact group at the University of Washington, as well as the NAI Impact Focus Group.

What caused the delivery and retention of organics and volatiles through Earth History? What are the relative roles of large comet and asteroid fragments and interplanetary dust particles (IDPs) in bringing these materials to a planet? Co-I and project leader Don Brownlee and his post-Doc, G. Matrajt, have made a significant breakthrough: In collaboration with S. Taylor and S. Pizzarello, they discovered the first amino acids in extraterrestrial dust. The concentration of AIB in these 100µm samples is being used as a basis for estimating the total delivery rate of amino acids to the early Earth over the time period when dust

accretion by Earth was greatly enhanced by the early evolution of the asteroid belt and the comet belts. These samples will soon be augmented by comet samples to be returned by the Stardust mission. All of these materials are believed to be identical to the particles that carried extraterrestrial organic materials to Earth during Earth's prebiotic history.

Matrajt and Brownlee have also explored the survival of a variety of organics that are carried in small extraterrestrial particles. They built a special furnace that duplicates the ~5 second heat pulse and atmospheric environment that entering particles are exposed to. They have made10µm thin films of nano-porous alumina particles impregnated, in different runs, with lysine, coronene, and 2 pentadecanone (a ketone) and exposed them to the simulated atmospheric entry heating environment. By measuring pre and post-heating concentrations with GC/MS and electrospray/MS, they have been able to determine survival curves with temperature. Remarkably, all three of these relatively volatile compounds survive at the several percent level for the dynamic pulse heating to 600 C, a common maximum temperature during atmospheric entry. Lesser amounts survive even a >800C!

How do mass extinctions and impacts affect the evolution and survival of complex organisms, i.e., the long-term habitability of planets? Large impacts are the norm for all bodies, habitable or not. Project leader Ward and his team consisting of Ken Farley, Roger Buick, Joe Kirschvink and David Kring have been concentrating on impacts.

Impacts can have major effects on the evolution of macroscopic life (e.g., ocean sterilizing events, dinosaur extinctions). However, we don't understand the details of these effects and how they might affect in different ways various environments and types of organisms and survivability. If we are to seek existing or past life elsewhere, we should understand how those planets' history of impacts might have affected the evolution of those organisms. We also want to know what predictions can be made about fossil and current life at different time periods, environments, and locations on other habitable bodies. These areas were examined in the 2004-2005-time interval.

Abundant new data indicate that we need both a concerted new examination into the effects of large body impacts on habitable planets and moons, and a critical re-examination of what has happened on and to Earth because of its own impact history. Mass Extinctions (MEs) during the Phanerozoic have been major factors in determining the make up of metazoan life on Earth, and have been intensely studied for decades, but there is still controversy as to cause(s). Until recently, we had an agreed-upon cause only for the "End Cretaceous" event (formerly the K/Tertiary, now officially renamed K/P, i.e., K/Paleogene, which is the term we will use here) among the "Big Five" MEs (K/P, Ordovician, Devonian, Permian/ Triassic [P/T], and Triassic/Jurassic [T/J]). That cause is large body impact – specifically, environmental effects following the Chicxulub impact of 65 My BP. But new results from drilling work in the crater itself has led one group to ask if this impact is the same age as the K/P mass extinction. Cause(s) of the other four remain controversial: most commonly invoked are impact, climate change, atmospheric gas compositional change, or some combination of these. Both the P/T and T/J MEs have been linked to (a) extrinsic causes (large body impacts), and (b) competing hypotheses of intrinsic causes. The association of flood basalt volcanism with the P/T, T/J, and K/P extinctions has caused the community to reconsider whether the Chicxulub impact was the sole or even major contributor to the K/P extinction, especially in deeper marine communities. This year our mass extinction group published two major papers on the Permian mass extinction in *Science*, as well as others on the Triassic/Jurassic mass extinction in refereed journals. As yet we cannot find evidence that either of these events was caused by impact.

Laboratory work continues on samples from the Permian-Triassic boundary in Africa and Canada, and the Triassic-Jurassic boundary in the Queen Charlotte Islands, Nevada, Italy, and the Newark Basin. We made new collecting trips to the Queen Charlottes, Nevada, and are finishing lab work on samples collected in early 2004 from New Zealand. During the year we continued to analyze samples from previous fieldwork for evidence of shocked quartz, Helium3, Iridium, and carbon isotopes.

What can we learn from the geological and fossil record about the evolution of eukaryotes and metazoans? During the 2004-2005 interval co-I Buick concentrated on finishing the drilling of three deep diamond-drill cores in Australia for the NAI Astrobiology Drilling Program. This work took place during July-August 2004. These were completed through

1. the unconformity between the Coonterunah (3.52Ga) and Warrawoona (3.45Ga) Groups: 350 metres;
2. the lower Hamersley Group (2.65-2.47Ga): 1000 metres;

3. the Tumbiana Formation of the Fortescue Group (2.72Ga): 250 metres.

Notable intersections were: 1) a thickened basal sandstone unit to the Strelley Pool Chert in the Warrawoona Group; 2) two meteorite impact spherule horizons in the Wittenoom Formation; 3) ooid grainstones and evaporitic horizons in the Tumbiana Formation Uncontaminated samples for organic geochemical investigation were collected immediately upon surfacing, which yielded confirmation that indigenous biomarkers compatible with host-rock thermal maturity are indeed preserved.

Other fieldwork was conducted in the 3.52Ga Coonterunah Group, collecting samples for carbon isotope studies of metamorphosed early Archean sediments for comparison with older and more metamorphosed rocks from Greenland (Harnmeijer & Buick, 2005).

Ongoing Studies included organic geochemistry of Paleoproterozoic oil-bearing fluid inclusions, to confirm the syngenetic origin of biomarkers, and organic geochemistry of mid-Archean shales, to extend the temporal biomarker record.

What can the study of life in ice tell us about the potential for life beyond the Earth? During 2004-2005 post Doc Joe Marx of the Deming group studied the role of exopolymers in facilitating bacterial activity, including specific enzyme activity, and survival under extreme conditions. During this year he showed that exopolymer production by a cold-adapted bacterium, *Colwellia psychrerythraea* strain 34H, goes up whenever the cells are stressed either by suboptimal growth temperatures, hydrostatic pressures, and available nutrient supply. These experiments will complement earlier work by Deming student Karen Junge, addressing what it takes for a bacterium to survive in deeply frozen ice formations rather than be active.

Another area of research this year was in looking at the role and biology of viruses in cold environments. Deming student Llyd Well has one paper in press (discovery of elevated concentrations of Archaea in cold Arctic waters), another submitted (viral lysis of bacteria and bacterial growth at -12°C in winter sea-ice brines – novel, with implications for lateral gene transfer in the cold), a third under review (lytic and lysogenic viruses in Arctic winter waters), and a fourth, the complete description of the novel virus he has obtained that lyses our model *Colwellia* bacterium in the cold, in preparation.

Finally, Deming worked with colleagues at The Institute for Genomic Research to complete the annotation and analysis of the cold-adapted *Colwellia* genome, which will soon appear in a paper in PNAS. Unusual findings include the presence of Archaeal genes (possible evidence for cross-Domain lateral gene transfer) and a record number of genes encoding for proteins and other compounds destined for export from the cytoplasm.

During this past year co-I Steve Warren began discussions with the Deming group about future collaboration. Warren has been studying models that pertain to the ancient “Snowball Earth” events of the PreCambrian. These intervals of time when the Earth may have gotten cold enough to freeze all, or some portion of the oceans remains controversial. The connection of the Warren research to the studies of cold life is a first step in understanding the effect that such events may have had on Earth’s biology during cold intervals.

Evolutionary pathways by which microbes and their communities evolve, and by which complex organisms originate. Three separate groups carried out our team’s investigations into specific microbes and microbial communities that are not in ice: the Staley lab, the Leigh lab, and the Stahl lab.

During the past year co-I Staley and his group have shifted focus toward anaerobic communities in the Black Sea, as well as continuing work on tubulin and the origin of eukaryotes and the cytoskeleton.

With regard to the anaerobic microbes of the Black Sea, the Staley lab has begun investigations of a novel

reaction, the anammox (anaerobic ammonia oxidation) reaction in which ammonia is oxidized anaerobically as an energy source and nitrite is the electron acceptor. Importantly, the anammox reaction is carried out by a group within the Planctomycetes phylum. They are also looking at denitrification (Oakley et al, in preparation), thiodenitrification and nitrogen fixation. These results also reveal novel clades within the Planctomycetes whose function is not yet understood. The goal is to determine what the activities are of each of the novel clades and also determine which organisms are responsible for denitrification, thiodenitrification and nitrogen fixation.

The Staley lab has also worked on cold life. This year the Staley lab discovered that *Psychromonas ingrahami* grows at –12°C, the lowest temperature reported for a bacterium with an authenticated growth curve. Staley is now comparing this organism with its south polar counterpart, which is a member of this same species.

The John Leigh lab is also looking at anaerobic microbes, in their case methanogens. This past year, Leigh and his colleagues studied the response of *M. maripaludis* to hydrogen limitation, as well as studying electron flow in the process of methanogenesis. To do this, Leigh made mutations in genes involved in the various steps in methanogenesis to determine the roles of these enzymes.

The third co-I in this project is Dave Stahl. The primary research objective of Stahl's lab is to better understand the origins and adaptive radiation of an ancient and biogeochemically significant assemblage of microorganisms, the sulfate-reducing prokaryotes (SRP). Research activities addressing this objective included field studies of SRP in habitats possibly similar to those that existed on early Earth (microbial mats and hot springs) and comparative sequence analysis of genes encoding the pathway for sulfate respiration.

Perhaps the most important finding of the Stahl group during the 2004-2005 reporting period concerns the importance and mechanisms lateral gene transfer (LGT) in the evolution and adaptive radiation of sulfate-reducing prokaryotes. A more complete understanding of LGT was obtained by conducting a census of SRP in diverse environments using a combination of molecular and cultivation dependent methodologies. Molecular analyses focused on the direct inspection of the genes (*dsrAB*) encoding a key enzyme (dissimilatory sulfite reductase) in the pathway for sulfate respiration. This work was aided by collaboration with Dr. Michael Wagner's laboratory (University of Vienna), utilizing complete analysis (examining 16 new reference cultures) of lateral gene transfer among cultured species of sulfate-reducing microorganisms. These studies have more clearly resolved the multiple lateral transfers of dissimilatory (bi)sulfite reductase genes (*dsrAB*) between major lineages. A major result of this more comprehensive analysis was the first discovery of a possible donor lineage among extant sulfate-reducing microorganisms.

Field work during the study period was undertaken at two hot springs in Yellowstone National Park, (Obsidian Pool and Black Sediment Pool), the Shoshone Geyser Basin, and at Guerro Negro in Baja California. Sediments collected from OP and BSP were used to inoculate enrichments in defined synthetic medium containing sulfate (~25 mM) and a variety of organic electron donors or hydrogen. Enrichment cultures were incubated at 60˚C or 80˚C. At 60˚C, sulfide production and growth were observed after 3-10 days with acetate, lactate, pyruvate, propionate, hydrogen, and a complex mixture of short chain fatty acids and yeast extract when inoculated with sediment from both OP and BSP. No sulfide was detected when ethanol, benzoate or a casamino acid mixture were added. Stahl found that there is greater metabolic diversity, defined by the pattern of electron donor usage in enrichment cultures, at 60˚C than at 80˚C. The preferred utilization of hydrogen as electron donor at 80˚C by SRP enrichments from both OP and BSP supports the proposed importance of H2-based lithotrophic metabolism at higher temperatures in Yellowstone hot springs.

Sediments and mats from seven springs in the Shoshone Geyser Basin were examined for endogenous sulfate reduction rates (SRR). It was found that this system appears to be related to sequences previously recovered from a geothermal feature near Bath Lake Vista in Mammoth Hot Springs.

At the Guerrero Negro Microbial Mat Community (Baja Sur, Mexico), it was observed that photosynthesis drives highly predictable diel fluctuations of chemical structure in microbial mat communities, most notably as manifested by periodic extremes of oxygen and sulfide at the near surface. A combined molecular and chemical fine-structure mapping of a hypersaline microbial mat in Guerrero Negro (Baja Sur, Mexico) related diel variation in depth and regional community structure to changing chemical structure.

Finally, progress was made in isolating and culturing the microbe *Ammonifex degensii*. These isolates comprise a closely related assemblage (~98% 16S rRNA sequence similarity) loosely affiliated with described *Ammonifex* (ca. ~90% 16S rRNA sequence similarity) and likely represent a new genus of sulfate-reducing bacteria.

The variety of life The University of Washington team added Stephen Benner to its group in 2003-2004. Benner and his colleagues have been investigating alternatives to “life as we know it”, as well as studying chemical pathways to the formation of RNA and other biological molecules and materials. During 2004-2005, Benner and his team made progress in synthesizing DNA with 6 and 8 nucleotide “letters”. Benner has also collected with Chris McKay in an effort to identify various kinds of organics in the natural world.

The role of plate tectonics Co-I Solomatov has been studying the role of plate tectonics in Astrobiology. Plate tectonics play an important role in the evolution of global planetary climate and life. Yet, there is very little consensus on when and how plate tectonics began on Earth. In 2004-2005 Solomatov made progress in modeling the initiation of plate tectonics be deriving a 3-D scaling relationship for spherical shells that stand in for a planet’s density layers. This is a conceptual improvement over previous models.

Project Reports: University of Washington

Delivery of organic materials to planets

Project Investigator: Thomas Quinn

Project Progress

In collaboration with Jonathan Lunine, Quinn and Raymond have performed integrations of planetary embryos as they form the terrestrial planets. They have explored the dependence of the chemical composition of the resulting terrestrial planets on the properties of the planet formation scenario. They have extended this work to look at scenarios in planetary systems with "Hot Jupiters". They have found that planets with compositions suitable for habitability can form in these situations. They have also performed higher resolution simulations of the volatile delivery process, and have discovered that with more lower mass protoplanets planets are formed that have lower eccentricities and a less stochastic distribution of volatile elements.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
1	Kepler	Background Research
2	TPF	Science Team Member
1	SIM	Background Research

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

In the case of TPF, estimates of the amount and kind of volatiles that terrestial planets can have will make a significant difference in the mission design in order insure the success of the mission.

For the other missions, Fundamental theoretical research on planet formation is need both for mission planning, particularly in the case of TPF, and in interpreting mission results.

Plate tectonics on the terrestrial planets

Project Investigator: Viatcheslav Solomatov

Project Progress

Plate tectonics plays an important role in the evolution of global planetary climate and life. Yet, there is very little consensus on when and how plate tectonics began on Earth. Various scenarios have been proposed ranging from initiation of plate tectonics as early as after crystallization of magma ocean to a relatively late start of plate tectonics, in the Late Archean. The most difficult aspect of plate tectonics is initiation of subduction. Although initiation of subduction has been extensively studied, the focus has been on the present-day Earth where plate tectonics is already occurring. The major difference between initiation of subduction on the present-day Earth and the early Earth is that in the absence of plate tectonics forces associated with plate tectonics are absent and cannot participate in subduction initiation. We have been working on the hypothesis that sublithospheric small-scale convection might be the mechanism of initiating plate tectonics. Sublithospheric small-scale convection was proposed as an explanation for the bathimetry, the heat flow, and the geoid in the old oceanic region and for the heat flow and seismic velocity anomalies in the continental regions. Sublithospheric small-scale convection was proposed to be the major convective mode on other terrestrial planets. In the past we developed constraints for this mechanism with the help of systematic finite element simulations in two dimensions. Two-dimensional studies showed that small-scale convection generates stresses comparable with the stresses required for initiation of subduction on the present-day Earth and can indeed be a trigger mechanism for plate tectonics. During the last year we extended this work to three dimensions (Reese et al., 2005a). We obtained scaling relationships for realistic spherical shell geometry. The derived scaling relationships provide a theoretical basis for predicting initiation of plate tectonics – via this particular mechanism - on a silicate planet with arbitrary parameters (Reese et al, 2005b).

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 2.1:** Mars exploration

First-Stage Biofilm Formation Under Extreme Conditions in Ice

Project Investigator: Jody Deming

Project Progress

We continue to study life in saline ice formations, taking a multi-facetd approach that includes work on Bacteria, Archaea, viruses, exopolymers (EPS) and extracellular enzymes. Attachment or sorption to surfaces (first-stage biofilm formation) under extreme conditions provides an important focal point. Accomplishments this year stem from work with our model cold-adapted bacterium, *Colwellia psychrerythraea* strain 34H, and with field samples collected last year. A comparative whole-genomic and proteomic analysis of our *Colwellia* strain was completed and published (Methé et al., 2005); highlights include clear distinction of the psychrophilic proteome from proteomes of other thermal classes, an apparent record number of encoded proteins and other compounds destined for export from the cytoplasm, and potential evidence of lateral gene transfer (presence of Archaeal genes and two apparently complete viral genomes). Former post-doc Junge obtained evidence for EPS-enhanced leucine incorporation into protein by *Colwellia* cells down to –20°C (and for activity at sub-eutectic temperatures, originally expected to yield negative controls). New post-doc Marx verified *Colwellia* over-production of EPS under conditions of temperature, pressure , and salinity stress, with design of planned sub-eutectic experiments improved by co-I Eicken. These studies reinforce the importance of EPS to microbial survival in extreme habitats and possibly as biosignatures on icy planets and moons. From fieldwork in the Arctic (winter 2004), the PI obtained evidence for protease activity in saline ice at new temperature lows (down to –18°C; Deming, 2004), while graduate student Collins amplified Archaeal genes from winter ice (not known from warmer ice) and doctoral candidate Wells demonstrated viral lysis of bacteria, as well as bacterial growth, in ice brines at –12°C (Wells and Deming, submitted). Wells also completed work on the source and distribution of Archaea in subzero Arctic waters during autumn (Wells et al., submitted) and on characterization of a novel cold-active virus (the most heat-labile known) from this environment that lyses our *Colwellia* strain. The presence of Archaea in autumn waters and winter sea ice, detection of a dynamic microbial-viral community in winter ice, and availability of a model viral-bacterial host system (where the host contains Archaeal genes and other viruses) lead to hypothesis development regarding microbial evolution and gene exchange in saline ice formations, environments threatened with extinction on Earth (especially in the Arctic) due to climate warming and recently reported on Mars.

Highlights

- The salt-requiring and psychrophilic bacterium, *Colwellia psychrerythraea* strain 34H (genome sequence now published), over-produced extracellular polymeric substances (EPS) in response to temperature and pressure extremes, implying that first-stage biofilm formation (attachment via EPS) is a generic survival response under environmental stress.

  Viral lysis of bacteria and bacterial growth were detected in Arctic winter sea-ice brines at –12°C, demonstrating that such extreme environments support a dynamic bacterial/viral community.

Roadmap Objectives

- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
	far-future Mars or Europa, biomarkers,	

0 life detection

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Our work on strategies for microbial (including viral) success in extremely cold saline ice formations, particularly as it reveals possible compounds (exopolymers) signifying successful colonization, is relevant to developing far-future plans to sample saline ice formations on Mars and Europa.

Field Expeditions

Field Trip Name:
Start Date: **End Date:**
Continent: **Country:**
State / Province: **Nearest City / Town:**
Latitude: **Longitude:**
Name of site(cave, mine, e.g.): **Keywords:**
Description of Work: See last year's report for details (no new fieldwork this year).
Members Involved:

Cross Team Collaborations

Deming and Michael Thomashow (Michigan State) began informational exchanges on ABI-supported research accomplishments related to microbial life in the cold with a goal towards collaboration. She and James Tiedje (also at Michigan State) are serving together on the science organizing committee for an international conference on Low Temperature Microbiology (to be held in Innsbruck, Austria, March 2006), with the outcome that astrobiology-related research will be featured there. Eicken and Deming continued to interact with Giles Marion (Arizona State) on the subject of geochemical and microbial reactions at low temperatures, high salt concentrations and high pressures, with the outcome that new research plans were developed to experiment with more extreme conditions in vitrified saline ice than we have tested previously. Deming served on the Visiting Committee to the Carnegie Geophysical Laboratory, which examined (among other facets) the Laboratory's astrobiology efforts. Deming and doctoral candidate Wells continued as members of the NAI Virus Focus Group; Deming and Eicken, as members of the NAI Europa Focus Group.

Mass Extinction Events, The longest Snowball Earth Event, the evolution of Oxygenic Photosynthesis, and TPW Induced Perturbations of the Carbon Cycle.

Project Investigators: Roger Buick, Ken Farley, Geoff Garrison, Peter Ward

Project Progress

One of the major goals of Astrobiology is to understand how biological and geological processes operating on life-bearing, terrestrial planets interact with each other. Examples of this interaction include the mass extinction events that have punctuated the evolution of life on Earth, as well as understanding the geological, biological, geophysical, and geochemical triggers for major evolutionary events in the history of the biosphere, like the origin of atmospheric oxygen and the Cambrian Explosion. Research over the past decade has shown that such events are marked by large turnovers in faunal composition and major perturbations in the planetary carbon, sulfur, and oxygen cycles. Increasing our knowledge of the timing, paleogeography, and tectonic events associated with global-scale biological events will help lead to testable hypotheses about their causes, *e.g.*, impacts, large volcanic eruptions, or rapid polar wander.

In collaboration with the Ward NAI node at the University of Washington, the Kirschvink group at Caltech has been using paleomagnetic techniques to constrain the timing of mass extinction events at the Permian/Triassic, Triassic/Jurassic, and Cretaceous/Tertiary boundaries at critical locations in Africa, Canada, and China. We have also used magnetic tools along with geological reasoning to resolve a major correlation problem between Canada and South Africa, which in turn places tight constraints on the origin of oxygenic photosynthesis and the triggering of what may be the largest Snowball Earth event in Earth history. Following up our earlier work on Inertial-Interchange True Polar Wander (IITPW) and the Cambrian Explosion, we now have data that suggests that the emplacement of large igneous provinces (plume-head style eruptions) may be the driving mechanism for these events, and can perhaps explain both the large carbon isotope anomalies and kilometer-scale rapid sea-level drawdowns associated with them. We have also continued, at a lesser pace, collaborative work on the biological precipitation of magnetite as a possible analogue for the origin of fine-grained crystals in carbonate blebs from Martian meteorite ALH84001.

Research Results:

Permian/Triassic Boundary:

Our major study on the stratigraphy and biological extinctions of land vertebrates was published early this year (Ward et al., 2005); we were able to resolve a primary, two-polarity magnetic reversal pattern in many of the sequences studied that allowed us to refine global correlations from the latest Permian through to the Greisbachian/Dienarian boundary. We were able to show that the P/T boundary in the Karoo Desert of South Africa is near the beginning of a distinctively long Normal magnetic polarity chron, similar to that from elsewhere in the world. Two weeks of additional field work are planned for September 2005, during which we will use a small, portable Winke drilling system to collect ~20-100 m of continuous core materials across the Permian/Triassic boundary in the Karoo sediments at the Carlton Flat locality, north of Middleberg, South Africa. The target sequence will cross the P/T “Event Beds” located by Peter Ward and Roger Smith in their earlier work in the area. In addition to the paleomagnetic work, these samples should also provide pristine materials for geochemical and micropaleontological analyses.

At the suggestion of Greg Retallack (of the University of Oregon), we collected a series of oriented samples for magnetostratigraphy and carbon isotope analyses at a locality near Heit Marina on Lake Powell, Utah. This locality contains a series of paleosols that he correlates to the Permian/Triassic boundary beds in Texas and South Africa; our samples should be able to test these correlations.

One of our Caltech students (R. Kopp) was able to attend the Triassic Chronostratigraphy and Biotic Recovery Conference in Chaohu, China, last May, and visited the now-classical Permian/Triassic exposures of the Grand Bank of Guizhou. Our intent was to collect a preliminary suite of samples for magnetostratigraphy and magnetofossil analyses, but we discovered that Paul Montgomery (formerly a student at the University of Kansas, now at Chevron/Texaco, and collaborating with the paleomag group at

the Berkeley Geochronology Center) had already sampled extensively in the area and had preliminary results from some of the sections. However, a large number of his samples were sitting in the long paleomagnetics queue at the Berkeley Geochronology Center, with no prospects of completion. We are now formally collaborating with this group, and processing these materials at the Caltech paleomagnetics laboratory.

Triassic/Jurassic Boundary:

We are presently demagnetizing a suite of paleomagnetic samples collected from the Triassic/Jurassic boundary sediments at Kennecott Point in the Queen Charlotte Islands of Western Canada, collected on a field trip in July 2004 run by the UW NAI group. This section is being intensively studied for paleontological and isotopic analyses, in addition to the paleomagnetics. These samples are divided into three groups (not including the Karmutsen Basalts), 1KP, 2KP, and FI. The 1KP batch has been heated to 320˚C and the samples are dead or close to dead, strongly suggesting pyrrhotite as primary remanence carrier – rock magnetic analyses now underway should identify the magnetic phases properly. The 2KP samples are starting thermal demagnetization, and the FI samples are halfway to completion (if their demagnetization behavior parallels that of the 1KP samples). Visual inspection of the demagnetization data from all three sample groups suggest a dual-polarity, high inclination component. All three sample groups have magnetic moments between 10^{-9} and 10^{-11} Am^2.

Cretaceous/Tertiary Boundary:

Although magnetic polarity patterns across the K/T boundary played a critical role in testing the hypothesis that these extinctions were synchronous (which is a major implication of the impact hypothesis), no reliable magnetostratigraphy has yet been obtained from the international stratotype section (GSSP) in Tunisia. Kirschvink and Ward visited the sections about 5 years ago with Francis Robaszynski, collecting at El Kef and several adjacent localities that span the K/T boundary interval. NAI funds have been used to process the materials over the past year or so.

With over 4,000 demagnetization experiments so far, it is clear that they are not anywhere near as bad as the Austin Chalk of Texas, they all seem to be rather weakly magnetized, with moments typically of a few 10^{-11} Am^2 after the 200° C step,. Magnetic reversals are present, in what may be a coherent pattern. We are continuing the demagnetization experiments in small increments under pure N_2 gas to minimize the problem of the oxidation of the magnetic minerals.

Constraints on the Great Oxygenation Event:

The adaptation of life to the presence of free molecular oxygen in the environment was one of the major evolutionary events in the history of life on this planet and a prerequisite for the evolution of complex multicellular organisms. Using a combination of paleomagnetic, geochemical, and geological techniques, we have been able to constrain the correlation between the Transvaal Supergroup of South Africa and the Huronian Supergroup of Canada, two of the best-preserved stratigraphic sequences in the early Paleoproterozoic, the critical time interval that contains the first traces of the planetary oxygenation event.

We found that rocks from just above the final glacial unit failed a paleomagnetic fold test from just above the final Huronian glacial unit (Hilburn et al., 2005), which indicated that the Huronian glaciations were not necessarily low latitude and therefore removed the temptation to correlate any of them with the low-latitude Makganyene glaciation of South Africa. This result, coupled with newly published age constraints from the Hekpoort and Ongulek lavas in South Africa from the Beukes group at the University of Johannesberg, made clear that all three of the glacial units in the Huronian must pre-date the low-latitude Makganyene glaciation of South Africa. Critical re-evaluation of all of the published data on the geological constraints for the first appearance of oxygen indicate that significant environmental levels of O_2 likely first occurred in the time interval between the last of the Huronian glaciations (the Gowganda) and the Makganyene glaciation.

Kopp et al. (2005) develop the idea that this oxygen burst was due to the rather sudden evolution of oxygenic photosynthesis, which would have rapidly led to the destruction of a methane greenhouse and thereby triggered the Makganyene Snowball Earth event, which may have lasted for up to 100 million years

(2.32 – 2.22 Ga). Kopp et al. argue that, driven by glacial weathering, the phosphate flux into the ocean during glacial intervals would have been high enough to remove nutrient limitations on any populations of oxygenic photosynthetic bacteria. Thus, the failure of pre-Makganyene glaciations (the three Huronian events and the ~2.9 Ga Pongola glaciation) to precipitate a greenhouse collapse constrains the timing of the evolution of oxygenic photosynthesis. We hypothesize that a singular evolutionary event (the deveolopment of oxygenic photosynthesis) triggered a global climate catastrophe, a Snowball Earth event that lasted tens of millions of years.

A related and long-standing problem in evolutionary biology concerns how any organism could evolve the ability to produce molecular oxygen without killing itself in the process – a hurdle that the cyanobacteria must have overcome before the final assembly of their photosynthetic apparatus. An inorganic source of strong oxidants must have been present somewhere in the environment to promote the evolution of oxygen-mediating enzymes like superoxide dismutase and catalase. Working in conjunction with Caltech professor Yuk Yung and his graduate student Danie Liang, we realized that, during a glacial event on an oxygen-poor planet, ultraviolet light acting on water vapor near the ice surface will produce H_2O_2 and H_2 gas; the peroxide will freeze out and be incorporated into the ice, while the hydrogen will diffuse away and either be utilized by the biosphere or (if present in high enough concentrations) escape into space. At the melting ice front the peroxide is released and decomposes into water and O_2. This process would have been active during both the Pongola and Huronian glacial episodes and might have driven the evolution of oxygen-mediating enzymes.

Inertial Interchange True Polar Wander and the Cambrian Explosion.

Eruption of a plume head is one possible geophysical mechanism that can perturb Earth's moment of inertia tensor and possibly lead to inertial interchange events. For this reason we have focused an interdisciplinary study on the Sept-Iles mafic intrusive suite in Quebec, Canada, for which a previous paleomagnetic study suggested that both low and high-latitude magnetic directions were recorded during its emplacement. Our paleomagnetic re-study of this suite confirms these results, but in conjunction with new, high-resolution U/Pb data from zircons associated with the paleomagnetic sites our paleomagnetic data demonstrate that the TPW motions may have been exceedingly rapid, with equatorial to high latitude displacement on the order of only 1 My (Kirschvink et al., 2005c, h). It has not escaped our attention that such rapid motions, if real, could produce the km-scale regional sea-level variations deduced from incised canyons in both Australia and California. Sea-level drawdown would produce large perturbations in the global carbon cycle from the exposure and oxidation of organic-rich sediments exposed on the continental shelves and the pressure-destabilization of previously submerged methane clathrates. Thus, the mid-Ediacaran 'Shuram' carbon isotope anomaly should be of the same age as the Sept-Iles intrusive suite, a testable prediction.

Biosynthesis of ribose and the origin of Terrestrial life on Mars:

Kirschvink & Weiss (2005) note that evaporite-rich environments capable of producing Ca-B minerals needed to stabolize 5-carbon sugars like ribose are more likely to be present on Early Mars, rather than on Early Earth.

Roadmap Objectives

- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 3.3:** Origins of energy transduction
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.3:** Effects of extraterrestrial events upon the biosphere
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems

Field Expeditions

Field Trip Name: Triasic Biotic Recovery
Start Date: May, 2005 **End Date:** May, 2005

Continent: Asia
Country: China
State/Province: Guizhou
Nearest City/Town: Guizhou
Latitude:
Longitude:
Name of site(cave, mine, e.g.): Grand Bank of Guizhou
Keywords: Permian Triassic Extinction

Description of Work: One of our Caltech students (R. Kopp) was able to attend the Triassic Chronostratigraphy and Biotic Recovery Conference in Chaohu, China, last May, and visited the now-classical Permian/Triassic exposures of the Grand Bank of Guizhou. Our intent was to collect a preliminary suite of samples for magnetostratigraphy and magnetofossil analyses, but we discovered that Paul Montgomery (formerly a student at the University of Kansas, now at Chevron/Texaco, and collaborating with the paleomag group at the Berkeley Geochronology Center) had already sampled extensively in the area and had preliminary results from some of the sections. However, a large number of his samples were sitting in the long paleomagnetics queue at the Berkeley Geochronology Center, with no prospects of completion. We are now formally collaborating with this group, and processing these materials at the Caltech paleomagnetics laboratory.

Members Involved:

Causes of mass extinctions: testing impact models

Project Investigator: Roger Buick

Project Progress

Most fieldwork was directed towards drilling 3 deep diamond-drill cores in Australia for the NAI Astrobiology Drilling Program. These were completed through

1. the unconformity between the Coonterunah (3.52Ga) and Warrawoona (3.45Ga) Groups: 350 metres;
2. the lower Hamersley Group (2.65-2.47Ga): 1000 metres;

3. the Tumbiana Formation of the Fortescue Group (2.72Ga): 250 metres.

Notable intersections were: 1) a thickened basal sandstone unit to the Strelley Pool Chert in the Warrawoona Group; 2) two meteorite impact spherule horizons in the Wittenoom Formation; 3) ooid grainstones and evaporitic horizons in the Tumbiana Formation (Buick et al., 2004). Uncontaminated samples for organic geochemical investigation were collected immediately upon surfacing, which yielded confirmation that indigenous biomarkers compatible with host-rock thermal maturity are indeed preserved (Waldbauer et al., 2004).

Other fieldwork was conducted in the 3.52Ga Coonterunah Group, collecting samples for carbon isotope studies of metamorphosed early Archean sediments for comparison with older and more metamorphosed rocks from Greenland (Harnmeijer & Buick, 2005).

Studies completed during the year included:

1. a review of the Archean sulfur cycle and its constraints upon sulfur isotopic fractionation, confirming the existence of microbial sulfate reduction in ~3.5Ga oceans and showing that peripherally-branching bacterial phyla had already evolved (Shen & Buick, 2004);

2. a detailed geochronological transect through the ~2.7Ga Fortescue Group coupled to a paleomagnetic profile, which showed that apparent polar wander rates were periodically enhanced ten-fold over current maximum values. This implies that sea-floor spreading rates were much faster early in Earth's history and, when contrasted with the intervening intervals of little apparent polar wander, suggests that tectonic plates were also smaller than at present.

Studies continuing included:

1. organic geochemistry of Paleoproterozoic oil-bearing fluid inclusions, to confirm the syngenetic origin of biomarkers;

2. organic geochemistry of mid-Archean shales, to extend the temporal biomarker record.

Roadmap Objectives

- **Objective No. 4.3:** Effects of extraterrestrial events upon the biosphere
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems

Evolution of biocomplexity from an ancient autotrophic lineage

Project Investigator: John Leigh

Project Progress

Hydrogenotrophic methanogenesis occurs in a variety of anaerobic habitats, may have played an important role on early earth, and could be a dominant metabolism on other planetary bodies. In the past year we published our genome sequence of *Methanoccoccus maripaludis*, a model species of hydrogenotrophic methanogen. We also published on an advance in genetic methodology for *M. maripaludis*, and on a study of lateral gene transfer that gave rise to the unusual ability this species to use alanine as a nitrogen source for growth. We have made considerable progress in the post-genomics of *M. maripaludis*. Thus, we have used chemostat-grown cultures and expression arrays to learn how *M. maripaludis* responds to conditions in which growth is limited by the supply of hydrogen, an important electron donor in methanogenesis. We will continue these studies in the coming year and submit a paper for publication. We have also made progress in using genetics to understand the mechanism of methanogenesis. We have made mutants that are deficient in enzymes that catalyze steps in methanogenesis. We plan to make additional mutations that will allow us to elucidate the roles of certain enzymes in electron flow and in methanogenesis from the alternative substrate, formate. These metabolic studies will add to our understanding of a pathway that produces methane and that could have played fundamental roles in early life on earth. Finally, we have collaborated with D. Stahl to generate preliminary data regarding the patterns of gene expression in *M. maripaludis* and in *Desulfovibrio* sp. that result from the co-culture of the two species. We have formulated plans with the Stahl lab to generate additional samples of *M. maripaludis* monocultures grown in a chemostat for use in the gene expression analysis. The continuation of this project will take place in the coming year.

Roadmap Objectives

- **Objective No. 3.2:** Origins and evolution of functional biomolecules
- **Objective No. 3.3:** Origins of energy transduction
- **Objective No. 4.2:** Foundations of complex life
- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 5.3:** Biochemical adaptation to extreme environments

Bacterial tubulin and the evolution of the Eukaryotic cell; Sea ice bacteria

Project Investigator: James Staley

Project Progress

During this past year we have continued our studies on the bacteria that contain homologs for alpha- and beta-tubulin. Our most recent paper is a comparative genomic study. The genomes of the tubulinate bacterium, *Prosthecobacter dejongeii* of the phylum Verrucomicrobia and a member of the related phylum, Planctomyetes, named *Gemmata* Wa-1 were compared to the Eucarya. Since both of these organisms have been implicated as evolutionary progenitors of the Eucarya, a blast search was made against a group of 347 eukaryotic signature proteins (Staley et al., 2005). The results of that investigation cast doubt on these two phyla as being ancestors of the Eucarya. We have also found that the Planctomycetes contain six homologs for C-1 genes that encode enzymes involved in the oxidation of formaldehyde. Previously these genes were reported only in the methanogens of the Archaea and the methane-oxidizing members of the Bacteria that are in the phylum, Proteobacteria. The phylogeny of these six deduced proteins indicates that the Planctomycetes occupy an intermediate position between these two other phyla suggesting they may have played a role in their inter-Domain horizontal gene transfer (Chistoserdova, 2004).

In continuation of our low temperature work, we reported that “Psychromonas ingrahamii” grows at –12°C, the lowest temperature reported for for a bacterium with an authenticated growth curve (Breezee et al., 2004). We are now comparing this organism with its south polar counterpart which is a member of this same species (Staley et al., in preparation).

Our research has recently become focused on the Black Sea as a model for the early evolution of life and metabolism. Inasmuch as the Black Sea is the largest anoxic basin on Earth, its redox profile serves as an excellent place to study the evolution of metabolism and microbial life. We have begun our investigations by looking at a novel reaction, the anammox (anaerobic ammonia oxidation) reaction in which ammonia is oxidized anaerobically as an energy source and nitrite is the electron acceptor. Importantly, the anammox reaction is carried out by a group within the Planctomycetes phylum. We are also looking at denitrification (Oakley et al, in prepartion), thiodenitrification and nitrogen fixation. Using PCR with primers for the Planctomycetes-specific 16S rDNA, we have constructed a profile of this phylum across the suboxic zone of the Black Sea and identified the redox zone of the anammox bacteria (Oakley et al., submitted; Kirkpatrick et al., in prepartion). These results also reveal novel clades within the Planctomycetes whose function is not yet understood. Our goal is to determine what the activities are of each of the novel clades and also determine which organisms are responsible for dentrification, thiodenitrification and nitrogen fixation.

Roadmap Objectives

- **Objective No. 3.2:** Origins and evolution of functional biomolecules
- **Objective No. 3.4:** Origins of cellularity and protobiological systems
- **Objective No. 4.2:** Foundations of complex life
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems

Microbial Mat Communities

Project Investigator: Jesse Dillon

Project Progress

Our primary research objective is to better understand the origins and adaptive radiation of an ancient and biogeochemically significant assemblage of microorganisms, the sulfate-reducing prokaryotes (SRP). In overview, we have:

- Refined understanding of the contribution of lateral gene transfer to the adaptive radiation of sulfate reducing bacteria
- Identified energy sources sustaining SRP in geothermal habitats
- Explored the diversity and distribution of SRP in habitats possibly similar to those that existed on early earth (microbial mats and hot springs).

Lateral Gene Transfer. In collaboration with Dr. Michael Wagner's laboratory (University of Vienna) we identified a lineage of bacteria that was the likely source of genes in the pathway for sulfate respiration inherited by a distantly related clade via lateral gene transfer (Zverlov, Klein et al. 2005).

Energy Sources. Studies of two geothermal sites in Yellowstone National Park (Obsidian Pool and Black Sediment Pool) confirmed that H_2 was an important energy source for sulfate respiration. Enrichment on a H_2-based medium resulted in the isolation of organisms related to *Ammonifex degensii*, most likely representing a new genus of autotrophic sulfate-reducing bacteria. Endogenous rates of sulfate reduction were measured at additional geothermal sites in the Shoshone Geyser Basin, identifying three new springs of appreciable activity. DNA recovered from one site revealed a novel, and likely early diverging, lineage of sulfate reducing bacteria (Köenneke, de la Torre et al. 2004).

Microbial Mat Community. Photosynthesis drives highly predictable diel fluctuations of chemical structure in microbial mat communities, most notably as manifested by periodic extremes of oxygen and sulfide at the near surface. A fine-structure mapping of a geothermal mat in Yellowstone National Park and a hypersaline microbial mat in Guerrero Negro (Baja Sur, Mexico) associated diel variation in regional community structure with changing chemistry (Dillon, Fishbain et al. In preparation; Dillon, Miller et al. Prepared for submission). These studies revealed two major forms of adaptive response, populations that periodically migrate and those that are relatively sessile (Dillon, Miller et al. Prepared for submission).

Clone libraries of *dsrAB* and 16S rRNA gene sequences now being analyzed for both the Yellowstone and GN Microbial Mat systems have revealed additional novel sulfate reducers (Dillon, Miller et al. In preparation).

Roadmap Objectives

- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.2:** Foundations of complex life
- **Objective No. 5.1:** Environment-dependent, molecular evolution in microorganisms
- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems

Field Expeditions

Field Trip Name: Yellowstone 2004
Start Date: July 17, 2004 **End Date:** July 21, 2004

Continent: North America	**Country:** USA
State/Province: Wyoming	**Nearest City/Town:** West Yellowstone
Latitude:	**Longitude:**
Name of site(cave, mine, e.g.):	**Keywords:**
Description of Work: Geothermal spring microbial activity measurments and collection of samples for microbiological cutlure	
Members Involved:	

Cross Team Collaborations

Mitchell Sogin, Marine Biological Laboratory. Collaboration on comparative sequencing of genes encoding enzymes in the pathway for the dissimilatory reduction of sulfate.

Causes of mass extinctions: testing impact models_Kring

Project Investigator: David Kring

Project Progress

We published a study (in Earth and Planetary Science Letters by Ward, Garrison, Haggart, Kring, and Beattie) outlining the carbon isotope record, sedimentation, and biostratigraphy at the Triassic-Jurassic mass extinction boundary preserved in the Queen Charlotte Islands, Canada.

We published a study (in Journal of Geophysical Research by Kring and Durda) that determined the ignition threshold for impact-generated fires.

We published a study (in Palaios by Bailey, Cohen, and Kring) of the effects of impact-generated acid rain produced by the Chicxulub impact event at the Cretaceous-Tertiary mass extinction boundary.

We published a study (in Meteoritics and Planetary Science by Cohen, Swindle, and Kring) that investigated the impact bombardment of the Earth-Moon system ~3.9 billion years ago, which may have affected the origin and early evolution of life on Earth.

We published a study (in Origins: Genesis, Evolution and Diversity of Life by Campins, Swindle, and Kring) that discusses the origin of Earth's water, a critical ingredient for life on Earth.

We have a paper in press (in Palaeogeography, Palaeoclimatology, and Palaeoecology by Ward, Garrison, Kring, and Goodwin) that desribes the biologic, isotopic, and sedimentological changes that occur at the Triassic-Jurassic mass extinction boundary exposed in Muller Canyon, Nevada.

We have a paper in press (by Strom, Malhotra, Ito, Yoshida, and Kring) that confirms an earlier result (in Journal of Geosphysical Research by Kring and Cohen) that indicates the Earth-Moon system was severely bombarded by asteroids (not comets) approximately 3.9 billion years ago, which may have affected the origin and early evolution of life on Earth.

We submitted an invited review (to Palaeogeography, Palaeoclimatology, and Palaeoecology by Kring) of the Cretaceous-Tertiary mass extinction event.

We submitted a paper (Patzer, Kring, Goodwin, Ward, and Haggart) with a petrologic analysis of sediments deposited at the Triassic-Jurassic mass extinction boundary, Queen Charlotte Islands, Canada. We argued that the basin represented by the rocks was relatively shallow (albeit it with euxinic bottom waters) and adjacent to a magmatic arc. We did not detect any shocked quartz and suggested that mechanisms other than impact should be explored as the cause of the mass extinction.

We are preparing a paper with a complete summary of our analyses of the Triassic-Jurassic mass extinction event in the Queen Charlotte Islands, Canada.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.3:** Effects of extraterrestrial events upon the biosphere

Impacts and extinction

Project Investigator: Peter Ward

Project Progress

The project being reported on here deals with various aspects of asteroid or comet impact on the Earth, and the Astrobiological consequences (including extinction).

During Year 4 our group undertook several field trips for sample acquisition, continued with profitable laboratory research, and began to see an increasing stream of publications. This project is now running smoothly after a long start-up period.

Field trips (Ward): In June of 2004, Ward, accompanied by NAI NRC post doc Geoff Garrison, UW Astrobiology grad student Ken Williford, an undergraduate field assistant from Cal Tech, and SUNY bivalve specialist Chris McRoberts, and Geological Survey of Canada researcher Jim Haggart (an ex-Ward student) spent a week at the Triassic/Jurassic boundary site in the Queen Charlotte Islands, British Columbia. This is the same site that yielded the first recognizable carbon isotope signature across the T/J boundary (Ward et al, 2001). On this trip we sampled both higher and stratigraphically lower than on previous trips, and also sampled extensively for paleomagnetism with oriented cores.

In April of 2005 Ward, Williford, McRoberts, and Garrison returned to the classic Triassic/Jurassic site at Muller Canyon, Nevada, and sampled both higher and lower in the sections, as well as at other nearby sections.

Laboratory analysis, stable carbon isotopes (Ward). During year 4 we continued analyzing samples obtained this and in previous years for both organic and inorganic carbon isotope ratios. The sections analyzed included the Queen Charlotte Islands (T/J), Muller Canyon (T/J), New Zealand (T/J), Italy (T/J), Opal Creek, Alberta (Permian/Triassic), and the Karoo of South Africa (Permian and Triassic). Fossils from several of these sites were also prepared and photographed. Williford performed micro fossil extraction as well.

We obtained highly significant results from several of our T/J sections, all of which show a self similar pattern of isotopes across the Triassic/Jurassic.

Laboratory analysis (Farley): Helium as an Indicator of Extraterrestrial Impacts Over the last few years helium concentrations and isotopic compositions of sedimentary rocks have been used to detect important solar system events including catastrophic bolide impacts with Earth at several different extinction horizons. One advantage of using ^{3}He as an impact tracer is that elevated levels associated with major solar system events can last for a few million years making detection far easier than the location of a single ejecta layer in a long stratigraphic sequence. In 2003-2004 we completed detailed helium isotopic investigations of two possibly impact-induced extinction boundaries: the Permian-Triassic and the Triassic-Jurassic.

1. Permian-Triassic Boundary

Helium concentration and isotopic composition were measured in a suite of 33 cherts, siltstones and shales across the PT boundary at Opal Creek, Canada (Henderson, 1997). No extraterrestrial ^{3}He was detected, implying that neither fullerene hosted nor IDP hosted He is present at or near the boundary. This observation is consistent with similar studies of other PT sections, but contrasts sharply with reports from a single group of both fullerene and IDP hosted extraterrestrial ^{3}He at some other PT sections. If extraterrestrial ^{3}He is present at the PT boundary, it must be very heterogeneously distributed. As such, we conclude that the ^{3}He-based evidence for impact at PT time is uncompelling.

While no extraterrestrial ^{3}He was detected, there is a sharp increase in nucleogenic ^{3}He very close to or at the PT boundary. This presumably arises from the major lithologic change at this time, from cherts in the

Permian to shales and siltstones in the Triassic. Increased nucleogenic ^{3}He is associated with increases in both lithium and organic carbon content into the Triassic. Either the production rate or the retention of this ^{3}He is higher in the shales and silstones than in the cherts. One important conclusion of this new work is that care must be taken to eliminate such artifacts before interpreting changes in ^{3}He concentration in terms of fluctuations in the delivery of ^{3}He from space. A manuscript has been completed on this work and should be submitted shortly.

2. Triassic-Jurassic Boundary

To assess whether ^{3}He provides any insight to the cause of this extinction we analyzed thirty silty limestones spanning 40 meters centered on the TJ boundary, from Muller Canyon, Nevada (Hallam and Wignall, 2000).

The preliminary results are shown in Figure 1. Just as at the PT boundary, these data provide no support for extraterrestrial ^{3}He at or near the boundary - no evidence for either fullerene-hosted ^{3}He or enhanced interplanetary dust flux. This conclusion is consistent with work undertaken at several other TJ sections in eastern North America (Farley and Olson, unpublished). Further work is required to conclusively establish the origin of the ^{3}He in this section, but it is probably nucleogenic.

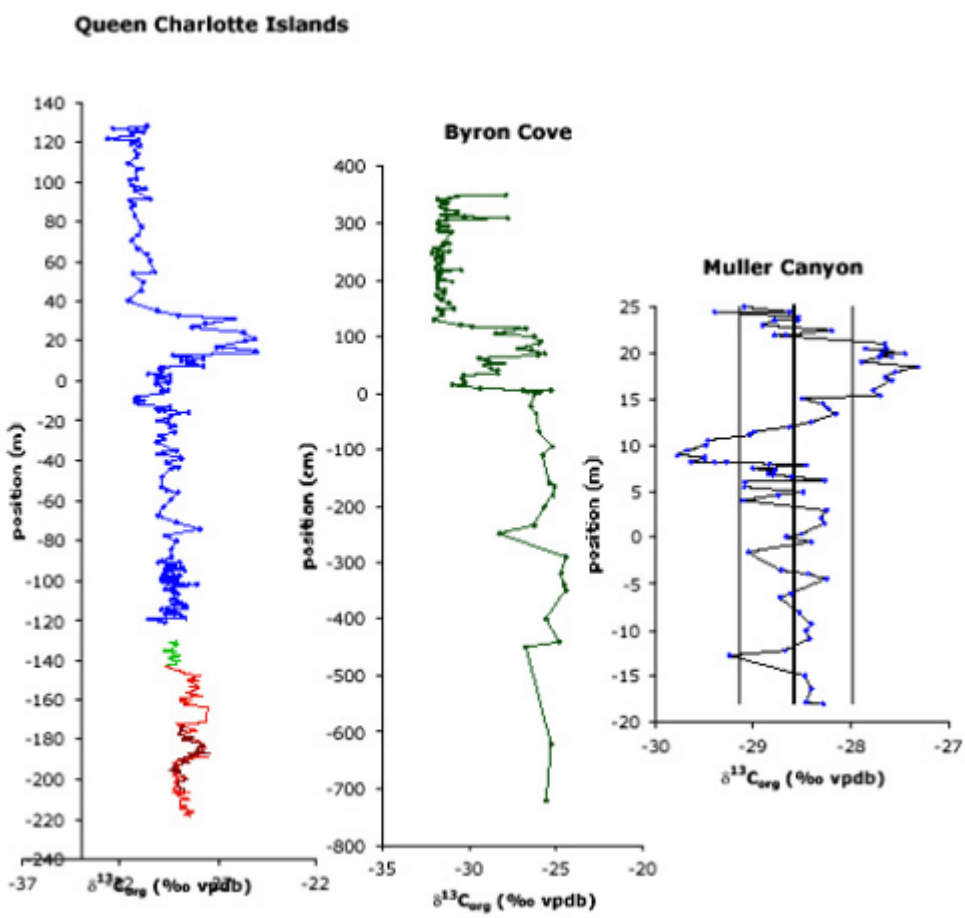

Figure 1. Carbon isotope analyses across Triassic/Jurassic interval from three target sections: Queen Charlottes, Byron Cove Italy, Muller Canyon. The Triassic /Jurassic mass extinction occurs simultaneous with the first major negative anomaly.

Kring- Shocked minerals

Co-I Kring continued examination for shocked quartz from two of our Triassic/Jurassic target sections: Muller Canyon, Nevada and the Kennecott Point section in the Queen Charlotte Islands. This involved making numerous thin sections and then examining individual grains for shock potential shock lamellae. No evidence of impact was found at either site, which is consistent with the negative results of Farley, and the faunal and isotopic patterns observed by Ward.

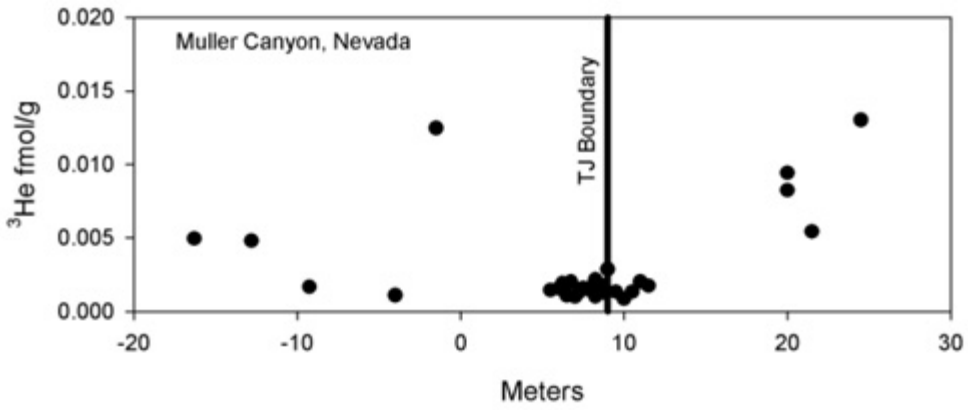

Figure 2. ^{3}He concentration in samples spanning boundary from Muller Canyon, Nevada. There is no evidence for enhanced extraterrestrial ^{3}He at or near the boundary

Roadmap Objectives

- **Objective No. 4.2:** Foundations of complex life
- **Objective No. 4.3:** Effects of extraterrestrial events upon the biosphere

Field Expeditions

Field Trip Name: Muller Canyon Nevada
Start Date: 4/4/05 **End Date:** 4/12/05
Continent: North America **Country:** USA
State / Province: Nevada **Nearest City / Town:** Hhawhorne
Latitude: **Longitude:**
Name of site(cave, mine, e.g.): Muller Can yon **Keywords:**
Description of Work: Collected samples and fossils accross a Triassic/Jurassic boundary site
Members Involved:

Field Trip Name: Kennecott Point, Queen Charlotte Islands
Start Date: 7/1/04 **End Date:** 7/10/04
Continent: North America **Country:** Canada
State / Province: B.C. **Nearest City / Town:** none
Latitude: **Longitude:**
Name of site(cave, mine, e.g.): **Keywords:**
Description of Work: Collected samples and fossils accross a Triassic/Jurassic boundary site
Members Involved:

Cross Team Collaborations

Lee Kump, Penn State- worked together on isotopic investigation Blair Hedges, Penn State - wrote proposal together Jay Melosh, Arizona - wrote proposal together

Brownlee and Matrajt

Project Investigators: Donald Brownlee, Matrajt Graciela

Project Progress

Brownlee and Matrajt have continued their investigation of the organic materials delivered to Earth by the 40,000 tons of asteroid and comet dust that is annually accreted from space. This laboratory study on extraterrestrial samples includes both work on nanogram particles collected from the both the stratosphere and microgram particles collected from Antarctic ice. These samples will soon be suplimented by comet samples to be returned by the Stardust mission. All of these materials are believed to be identical to the partilces that carried extraterrestrial organic materials to Earth during Earth's prebiotic history.

In collaboration with S. Taylor and S. Pizzarello, they discovered the first amino acids in extraterrestrial dust. The concenration of AIB in these 100µm samples is being used as a basis for estimating the total delivery rate of amino acids to the early Earth over the time period when dust accretion by Earth was greatly enhanced by the early evolution of the asteroid belt and the comet belts.

A major issue of organics delivery by small extraterrestrial partices is modification by high speed entry into the atmosphere. Matrajt and Brownlee have expored the survival of a variety of organics that are carried in small extraterrestrial particles. They built a special furnace that duplicates the ~5 second heat pulse and atmosperic environment that entering particles are exposed to. They have made10µm thin films of nano-porous alumina particles impregnated, in different runs, with lysine, coronene, and 2 pentadecanone (a ketone) and exposed them to the simulated atmospheric entry heating environment. By measuring pre and post-heating concentrations with GC/MS and electrospray/MS, they have been able to determine survival curves with temperature. Remarkably, all three of these relatively volatile compounds survive at the several percent level for the dynamic pulse heating to 600 C, a common maximum temperature during atmospheric entry. Lesser amounts survive even a >800C! The survival of these compounds in pulse-heated is enhanced by the poor thermal conductivity of their porous inorganic host and the effects of ablative cooling. This work will be used to estimate the fraction of volatile organics that that survive atmospheric entry and arrive at the Earth's surface.

In complimentary work, Brownlee and Kress are working with G. Cody in experiments to determine the nature of compounds that escape from pulse heated partilces, the ones that directly enter the atmosphere.

Related work in the 2004-2005 time period has invovled electron energy loss spectroscopy in a field emission transmission electron microscope to determine the nature of carbon in small extraterrestrial partilces. This work has invovled developing special techniques for mictotoming et particles in a way that leaves no residual carbon from mounting media. This has worked quite with a special acrylic media that can be removed after mircotomy.

Roadmap Objectives

- **Objective No. 3.1:** Sources of prebiotic materials and catalysts

Ocean Surfaces on Snowball Earth

Project Investigator: Stephen Warren

Project Progress

Oceanic processes on Snowball Earth: Laboratory experiments.

During a Neoproterozoic “Snowball Earth” event, the ocean surface conditions would determine both the surface climate and the locations for survival of surface life. A process that may be important in the tropical zones (where evaporation exceeds precipitation), as sea ice sublimates, is accumulation of a crust of sea-salt on the ice surface. This can happen only on ice below the eutectic temperature of NaCl brine, -22.9 °C, but such temperatures are expected on Snowball Earth, even at the equator. No modern surrogate is known to exist in nature now, but we can investigate these processes in our cold-room laboratories. The salt that would accumulate is not NaCl but rather $NaCl._2H_2O$, “hydrohalite,” which has not received much investigation. Dr. Bonnie Light is collaborating with Warren on this project.

In Year 4, Dr. Light invented a procedure to grow large single crystals (5 mm) of hydrohalite in isolation (i.e., not embedded in ice), so as to be able to study their inherent properties. She refined the procedure to make it reliably repeatable. She also began experiments on sublimation of sea ice to develop salt crusts. Often the solutions do not precipitate when they reach saturation; this supersaturation phenomenon is probably significant in nature.

Radiation modeling of ice on the Snowball Ocean

Richard Brandt worked with Warren to develop parameterizations for computing absorption and transmission of solar radiation by ice, for use in climate models of Snowball Earth.

The albedo and transmission of bubbly ice floating on water was calculated using a Discrete-Ordinates model for ice thicknesses ranging from 1 mm to 1 km containing uniform air bubbles of 0.1 mm radius and densities ranging from 0.01 to 100 per cubic mm. Spectrally averaged albedo and transmission were calculated for the entire solar spectrum, and also for two wavelength bands commonly used in climate models: visible (<700 nm) and near-infrared (near-IR, >700 nm).

Parameterizations for albedo in the three spectral bands, over the modeled ranges of bubble concentration and ice thickness, were developed. For each spectral band, an eleven-term parameterization fits the modeled albedo for ice thicker than 50 cm with maximum errors of 0.01 in the allwave and near-IR bands and 0.03 for the visible band. For ice thicknesses 0.1-50 cm, maximum albedo errors for near-IR, allwave and visible bands are 0.02, 0.04 and 0.06 respectively.

Currently we are developing the parameterizations for transmission.

A paper is in preparation: "Ocean surfaces on Snowball Earth: implications for survival of surface life". This paper identifies 13 different surface types that would occur at different times and latitudes during a snowball event, and recommends their albedos for use in climate modeling.

Radiative processes in Martian climate

Gary Hansen, a former Ph.D. student of Warren, has completed the analysis of his laboratory measurements of the absorption spectrum of carbon-dioxide ice for visible and ultraviolet radiation. This information is needed for computing radiation fluxes in Martian clouds and polar caps, to study the climate of Mars. He has written a paper, based on these measurements he did as a graduate student: "The ultraviolet to near-infrared absorption spectrum of carbon dioxide ice from 0.174 to 1.8 micrometers", submitted to J. Geophys. Res. (Planets), July 2005.

Roadmap Objectives

- **Objective No. 4.2:** Foundations of complex life

Darwinian Chemistry

Project Investigator: Steven Benner

Project Progress

The Benner laboratory has defined much of the chemistry that would allow sugars and other components of RNA to arise on a prebiotic Earth. This chemistry provides suggestions for the design of future Mars missions, and a critique of past Mars missions.

The Benner laboratory has made further progress in establishing synthetic biology as a field, developing tools to replicate and sequence DNA with 6 and 8 nucleotide letters. By converting questions of "origins", from biomacromolecules to enzymes to pathways to regulation to cells, into an experimental science assisted by deliberate design, this will contribute to our understanding of life in ways previously unavailable.

The Benner laboratory has collaborated with McKay in exploring the possibility of organics in extreme environments, where "extreme" here means "extreme on Earth".

The Benner laboratory has defined chemistries that might support "Weird" life in truly extreme environments, including in the hydrocarbon phase on Titan, above Venus, and in crysolvents like liquid dinitrogen.

The Benner laboratory has continued work in experimental paleobiochemistry, a field invented in the Benner laboratory, to understand the emergence of complex ecosystems. This year, the focus was the evolution of fungi and plants on Earth near the end of the Age of Dinosaurs.

This work is supported by only a very small ($35,000 direct) subcontract from the NAI node at the University of Washington (Peter Ward, Principal Investigator). The principal funding for this activity comes from the NASA Exobiology program, and from the National Science Foundation.

Roadmap Objectives

- **Objective No. 2.1:** Mars exploration
- **Objective No. 2.2:** Outer Solar System exploration
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 3.2:** Origins and evolution of functional biomolecules
- **Objective No. 3.3:** Origins of energy transduction
- **Objective No. 3.4:** Origins of cellularity and protobiological systems
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.2:** Foundations of complex life
- **Objective No. 4.3:** Effects of extraterrestrial events upon the biosphere
- **Objective No. 5.2:** Co-evolution of microbial communities
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials

Cross Team Collaborations

Jack Szostak has been a collaborator in developing synthetic biology. Chris McKay has been a collaborator on carbon-targeted life detection in hostile environments. Jonathan Lunine has been a collaborator on Titan chemistry. John Baross has been a collaborator in developing chemistry for "weird life" Gaucher, E. A., Graddy, L. G., Simmen, R. C. M., Simmen, F. A., Kowalski, A. A., Schreiber, D. R., Liberles, D. A., Janis, C. M., Benner, S. A. (2004) The planetary biology of cyochrome P450 aromatase from swine. BMC Evolutionary

Biol. 2, doi:10.1186/1741-7007-2-19 Bradley, M. E., Benner, S. A. (2005) Phylogenomic approaches to common problems encountered in the analysis of low copy repeats: The sulfotransferase 1A gene family example. BMC Evolutionary Biology 5, Art. No. 22. Thomson, J. M., Gaucher, E. A., Burgan, M. F., Aris, J. P., Benner, S. A. (2005) Resurrecting extinct proteins from ancient yeast at the origin of fermentation. Nature Genetics 37, 630-635. Benner, S. A., Ricardo, A., Carrigan, M. A. (2004) Is there a common chemical model for life in the universe? Curr. Opinion Chem. Biol. 8, 672-689 Sismour, A. M., Lutz, S., Park, J.-H., Lutz, M. J., Boyer, P. L., Hughes, S. H., Benner, S. A. (2004) PCR Amplification of DNA containing non-standard base pairs by variants of reverse transcriptase from human immunodeficiency virus-1. Nucl. Acids. Res.32, 728-735 von Krosigk, U., Benner, S. A. (2004) Expanding the genetic alphabet: Pyrazine nucleosides that support a donor-donor-acceptor hydrogen bonding pattern. Helv. Chim. Acta 87,1299-1324 Hendrickson, C., Devine, K., Benner, S. A. (2004) Probing the necessity of minor groove interactions with three DNA polymerase families using 3-deaza-2?-deoxyadenosine 5?-triphosphate. Nucl. Acids Res. 32, 2241-2250 Martinot, T. A., Benner, S. A. (2004) Expanding the genetic alphabet: 7-Deaza-isoguanosine favors the 1N-H keto form by 103-to-1 over the enol. J. Org. Chem. 69, 3972-3975

Dynamics of comets, asteroids, and planets

Project Investigator: Thomas Quinn

Project Progress

Mejia and Quinn in collaboration with Mayer (Zurich) have continued performing simulations of giant planet formation by fragmentation of a gaseous disk. They are extending previous work by considering models with radiative transfer. They are collaborating with other investigators to verify the accuracy of their calculations and to resolve discrepant results within the simulation community.

Mejia and Quinn are investigating the dynamics of gas and dust interaction in protoplanetary disks. There are two issues they are studying. The settling of dust into a thin layer in the midplane is a crucial aspect of building up the solids into large objects eventually leading to terrestrial planets. Dust may also move into the higher density regions of a fragmenting disk giving an alternative mechanism for forming giant planet cores.

Lufkin and Quinn performed simulations of giant planet migration and accretion in gaseous disks. These simulations confirm a puzzle that has been known from linear theory: that rapid migration should cause stars to swallow giant planets soon after they form, yet observational evidence shows that planet formation is robust.

Barnes and Quinn in collaboration with Lissauer (Ames) continue their simulations of planetesimal accretion in the terrestrial region. In a paper in preparation, they point out that runaway growth starts very soon after the first planetesimals form.

Barnes and Quinn continue to investigate the stability of extra-solar planetary systems as they are being discovered. They continue to find that most planetary systems, including our own, are on the edge of being unstable. This has implications for the efficiency of planet formation. Barnes and Raymond have also been investigating the formation of terrestrial planets within these known extra-solar systems.

Quinn and Kaib are starting to investigate the formation of cometary clouds under various galactic contexts. They are also investigating the resulting impact history of comets on terrestrial planets.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 2.2:** Outer Solar System exploration

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
1	Kepler	Background Research
2	TPF	Background Research

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Fundamental theoretical research on planet formation is need both for mission planning, particularly in the case of TPF, and in interpreting mission results.

Cross Team Collaborations

The research on terrestrial planet formation involves collaboration with Jack Lissauer, a member of the Ames Lead Team. The expertise of the Ames planetary scientists is helping to formulate the best computational experiments to perform.

EPO Reports: University of Washington

Project AstroBio: Year-Long Program of Science/Teacher Partnerships in Puget Sound

Project AstroBio has expanded on the success of Project ASTRO/Seattle, a science education and public outreach program administered by the UW Department of Astronomy since 1997. Project ASTRO/AstroBio created over 170 partnerships (and has sustained 53 of those) between teachers of grades 3 - 12 and professional and amateur astronomer and Earth and space scientists in the Puget Sound region of Washington. This year is our fourth as Project AstroBio and we continue to train new partnerships. The partnerships work together in the classroom, providing resource expertise and hands-on science activities as an adjunct to the regular teaching schedule. In each Project AstroBio partnership, students are guided through inquiry-based, hands-on activities in topics relevant to Astrobiology. Project AstroBio activities are rigorously designed to meet national and state education standards. In 2004-2005 astrobiology researchers and graduate students John Leigh, Billy Brazelton, and John Kirkpatrick continued with Project AstroBio as new science partners. For the 2005 ? 2006 school year, graduate students Linda Sauter, Michele Cash, and Ken Williford have joined the program. Director Woody Sullivan continues to visit an elementary school classroom, having begun as an astronomer partner with the original Project ASTRO in 1997. They each visited their classroom between five and seven times, thus having a direct impact on the science education of nearly 200 K-12 students.

Project AstroBio: Annual Training Workshop for Teachers and Science Partners

Project AstroBio workshop: This two day mandatory training session brings the new Project AstroBio partners together for the first time. Partners work together to learn strategies for effective communication between scientists and teachers, and between scientists and students, as well as take part in actual hands-on activities of the sort that they will be conducting with students. Each member of the partnership receives two volumes of activities in astronomy and related sciences, in addition to custom-made and classroom-tested activities in astrobiology. Various additional materials for classroom activities are also supplied.

In August 2005, astrobiology graduate students Linda Sauter, Michele Cash, and Ken Williford joined Project AstroBio as new science partners

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Astrobiology Public Lecture Series at UW

The goal of the lecture series is to present current astrobiological research results to the broader community. The lectures are presented by participating faculty and distinguished visitors, carefully chosen for their ability to communicate well with the public. The lectures, which typically occur each autumn and spring academic quarter, cover the many aspects of Astrobiology and address both the general public and a student audience (each in excess of 200). Our winter and spring 2005 quarters were unusual, in that we hosted three prominent researchers for public and school talks: January 2005, David Grinspoon discussed the Mars Rover and Cassini-Huygens missions; April 2005 Cassini mission specialist, Carolyn Porco presented details of that successful encounter with the Saturn system; June 2005 Mars Rover expert Jim Bell recounted the excitement and success of Spirit and Opportunity on Mars. As the lecture series is also intended to interest middle and high school students, we announce the series to Puget Sound science teachers and our Project AstroBio teacher partners.

Center for Astrobiology & Early Evolution Newsletter

The Center for Astrobiology and Early Evolution newsletter, titled Planets and Life is published each autumn and spring academic quarter, and disseminated to an interested public via mailing lists, lectures, workshops, and among our astrobiology community on campus. Each issue (seven to date) includes astrobiology research news and news of the UW astrobiology community. Newsletters will soon be available online via our web site. Articles submitted by the UW Astrobiology team over the past year include:

Issue # 8, December 2004 NASA?s Astrobiology Institute, Woody Sullivan (professor, Astronomy) An Exciting Encounter with a Cold Dark Mysterious Body from the Edge of the Solar System, Don Brownlee (professor, Astronomy)

Issue # 9, April 2005 A New Way to Make Planets, Annie C. Mejia (post doc, Astronomy)

Developing an Astrobiology Curriculum

The UW Astrobiology Graduate Program continues to be a world leader in the quality of its students, its innovative curriculum, and other aspects such as annual workshops, research rotation quarters, etc. Two students received the Certificate in Astrobiology during the past year.

During autumn quarter 2004, Professor Roger Buick coordinated and supervised the ASTBIO 501 course, ?Astrobiology Disciplines?. The annual Astrobiology Program was done in March 2005 at Kitt Peak Observatory, Tucson, where we were hosted by the U. of Arizona NAI node for 3 nights of learning the basics of observing (including stints on a radio telescope and on the McMath solar telescope). In October 2005 UW will reciprocate by hosting a Workshop at its Friday Harbor Marine Biology Lab. In Winter Quarter 2005 a seminar course on engineering aspects of life detection was held for astrobiology grad students.

In addition to working directly with students and teachers, UW astrobiologists are developing curricular and curriculum materials, and UW Astrobiology graduate students are assisting with these courses as Teaching Assistants (TA?s). For example, an introductory course for non-science majors, ASTBIO 115, is taught annually.

Weekly Astrobiology seminars throughout the year, featuring both outside and UW speakers were coordinated by Profs. Woody Sullivan and Don Brownlee. These seminars are advertised to a large mailing list both on- and off-campus, and members of the scientific public frequently attend.

In Spring of 2005, UW oceanographer Jody Deming worked with co-I Woody Sullivan (UW Astronomy) to lay the groundwork for a joint Astrobiology program between UW and the International University of Bremen, Germany, one that is expected to foster significant exchanges and educational/research opportunities for graduate students from around the world.

Astronomer Woody Sullivan and oceanographer John Baross are completing work on their graduate-level textbook on Astrobiology titled, "Planets and Life " (Cambridge University Press) with chapters contributed by both UW and non-UW NAI researchers. The book will appear in mid-2006. Co-I David Kring (LPL, U of A) taught an astrobiology course called PtyS209, ?Exploration and Discovery in the Solar System?. For a finale, students designed and flew simulated missions to Titan, where they tried to answer astrobiologically-relevant questions.

Public Access: Astrobiology Lectures and Presentations

Public presentations and lectures are an important component of UW's astrobiology education/public outreach efforts, and many investigators have been active in a variety of communities.

Graduate student Linda Sauter gave a lecture at the Ingleside Presbyterian Retirement Community in Washington, DC, titled ?The Search for Life on Other Planets?, a general talk about Astrobiology that focused on the Mars Exploration Rovers, Europa, Life in Extreme Environments, and the (then upcoming) Cassini mission to Titan. At the National Science Teachers Conference in downtown Seattle she was part of a workshop giving a general overview of Astrobiology with a focus on the Mars Rovers and Cassini. She then worked with an NAI EPO team to present activities for teachers, including one that modeled the detection of microscopic life.

The Astrobiology Program participated in annual Open Houses (for the public) held by the Astronomy Dept,

and the School of Oceanoraphy.

Astronomy Co-I Sullivan and Oceanography Co-I Baross were members of the faculty (along with 3 others form the U. of Arizona node) for the June 2005 Vatican Observatory Summer School, held at Castel Gondolfo, Italy. The topic of ?Astrobiology? was unprecedented for this previously all-astronomy venue, and was hugely successful for the 25 students attending for 4 weeks from around the world.

In October of 2004, oceanographer Deming was featured in a CBC Discovery Channel film for her role as chief scientist aboard the Canadian icebreaker Amundsen during an international overwintering expedition (2003-2004) in the Canadian Arctic (go to http://www.cases.quebec-ocean.ulaval.ca/trip/log.asp for more details). The film was first aired in French in Quebec in October of 2004, but has since been aired in English and Japanese for broader international outreach. Also appearing in the film are members of Deming?s astrobiology team, Research Staff member Shelly Carpenter and Doctoral Candidate Llyd Wells. Among the goals of the Deming team?s shipboard program were the tracking of extremophiles held captive in sea ice through the winter season, the measurement of their extracellular enzyme activities as survival mechanisms at record-low temperatures, and the evaluation of viral-bacterial activity in subzero waters and within deeply frozen sea ice. The former work comprises the thesis work of Astrobiology Masters Student Eric Collins; the latter, a significant portion of NAI-supported research by Astrobiology Doctoral Candidate Llyd Wells.

Paleontologist and PI Peter Ward gave a large public lecture as part of the Portland Science series in March 05.

In July of 2005, Deming gave a guest lecture on microbial life in ice at the Vatican Observatory in Castelgandolfo as part of the new international course offering there on Astrobiology (go to http://clavius.as.arizona.edu/vo/R1024/VOSS2005.html for more details).

Co-I Joe Kirschvink from the Cal Tech team reports: The European Geoscience Union inaugurated a public lecture series titled the ?Grand Debates? at their annual meeting in Vienna last May, with the initial debate topics focused on ?Flood Volcanism is the main cause of mass extinctions?, and ?Oxygenic photosynthesis evolved by 3.8 Ga?. Joe and Frances Westall argued the case for late evolution of photosystem-II, against Minik Rosen (of the Danish Geological Survey) and Mike Russel (University of Glasgow). The debates were lively, well covered by the popular press, and constructive.

The Media Front

UW Astrobiologists are frequently asked to provide interviews to the print and broadcast media. They also produce articles for popular and lay-science publications, as well as summary articles in the science press, for example:

In autumn of 2004, oceanographer Deming was the featured scientist in an article entitled ?The Persistent Professor,? which appeared in the autumn issue of Sea Star, an outreach publication by the WA Sea Grant Program. Her astrobiologically relevant work on microbial life in ice was highlighted in the article, along with action photos in the Arctic during the coldest period of the winter season, of significant appeal to the general public.

Paleontologist Roger Buick was interview for The Australian, Knight-Ridder newspaper chain, in addition to an interview for Playboy magazine on subsurface biosphere and abiotic oil.

PI and Paleontologist Peter Ward appeared in a National Geographic TV show about cephalopods as models for aliens, titled ?Alien Encounters?, and appeared on the NOVA three part show, ?Origins?

Astrobiology on the School Front: Interning and Mentoring

UW Astrobiologists are frequently contributing knowledge and expertise to a diverse variety of students in a wide variety of school settings and communities.

Graduate student LaTasha Taylor reports the following mentoring and school presentation activities: The Seattle Black College Fair presented an opportunity to encounter and inform hundreds of high school graduates about the University of Washington?s commitment to diversity, in addition to the interdisciplinary, cutting-edge research in Astrobiology. At Franklin High School I introduced students to the basic concepts of Astrobiology, and assisted them in establishing mentoring relationships with future scientists and engineers. Seattle Mathematics, Engineering, Science Achievement (MESA) at the University of Washington, shares my vision of helping underrepresented (African-American, Native American, Hispanic and female) students to not only achieve their full potential, but make major contributions in the fields of mathematics, engineering, and science. The young women who attended my presentation on Astrobiotechnology had the opportunity to participate in interactive dialog designed to share possibly life-altering information on scholarship, research, and educational opportunities for minority female students.

In summer of 2004, Pierre Monnat, a local high school student in Seattle, continued his volunteer work with UW?s Oceanography laboratory. He was trained by Research Staff member Shelly Carpenter and mentored by Astrobiology Doctoral Candidate Llyd Wells to determine the specific carbon and nitrogen requirements of extremophiles in our culture collection. Pierre was inspired to seek experience in our laboratory as a result of an Open House he attended in the School of Oceanography four years ago (when he was 13 years old), at which time he participated in Deming?s hands-on demonstration of pressure effects on microorganisms and other astrobiology-related activities organized by the Deming team. Pierre has since applied to a number of colleges (with support letters from Deming), been accepted at many, and opted to attend the University of Chicago in fall of 2005.

In February of 2005, Deming visited the historically black college (HBCU) of South Carolina State University for the general purpose of educating minority students on opportunities in astrobiology and related fields through public lectures and the specific purpose of recruiting potential graduate students into the UW Astrobiology (or other) Program(s). In November, 2004 Sullivan made a similar visit to HBCU Tennessee State University in order to strengthen educational and research ties with the nascent Minority Institutions Astrobiology Collaboration.

In March of 2005, Research Staff member Shelly Carpenter continued the Deming lab tradition of offering high-pressure demonstrations to local elementary school students to give them a hands-on understanding of the effects of high pressure on life in a deep ocean (using styrofoam that shrinks visibly when pressurized).

In Spring and Summer of 2005, Deming helped to develop an international Summer School on Climate Change in the Arctic to be held aboard the Russian icebreaker Kapitan Dranitsyn, in the Kara and Laptev Seas, 6?28 September 2005 (with Deming as an onboard instructor), explicitly introducing astrobiology-related subjects to the course curriculum (go to http://www.frontier.iarc.uaf.edu/NABOS/summer_school/agenda.php for more details).

In the microbiology lab, Seattle high school teacher Oliver Jones is working with Jim Staley and colleagues, and will be using this experience for his science classes.

Paleontologist and PI Ward gave 3 one hour talks at Portland area high schools on Astrobiology in March 05, and a keynote at the Oregon Science fair for High School students, in Salem Oregon in March 05.

In September, 2004, Cal Tech Co-I Kirschvink was the seminal speaker at a special Astrobiology meeting of the Sendai area ?High-School Science Association?, Japan. This involved meeting and interacting with about 200 of the ?top? high-school Science majors in the Sendai region (about halfway between Nagoya and Tokyo), as well as with ~ 30 of the high-school science teachers from Sendai Prefecture. Joe gave a complete review of the controversy surrounding ancient life on Mars (in Japanese), and used a microscope system to show carbonate blebs in the Martian meteorite ALH84001, and Hadean zircons of the Early Earth. This was followed by a free-ranging half-day Question and Answer session covering the spectrum from molecular biology through astrophysics. Many students asked advice on how to become a real scientist - which was a refreshing refutation of the typical characterization of the Japanese school system not turning

out original thinkers.

Sullivan gave a talk in February 2005 to the Battle Point Astronomical Association, as well as talked so several print reporters through the year.

Kirschvink also gave a major pubic outreach session on the origin of Atmospheric Oxygen in Terrestrial Planets as the ?Noye Johnoson? lecturer at Dartmouth University last May, to an audience of ~ 500 interested lay and university personnel.

Publications: University of Washington

There are **80** publication entries for the University of Washington

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

Executive Summary: Virtual Planetary Laboratory (JPL/CalTech)

Executive Summary: Virtual Planetary Laboratory (JPL/CalTech)
Principal Investigator: Victoria Meadows
Reporting Period: 2005 (7/04-6/05)

THE VIRTUAL PLANETARY LABORATORY

Laying the Scientific Foundation for the Search for Life Beyond the Solar System

Because of the vast distances to even the nearest stars, the search for life outside our solar system will be undertaken using astronomical “remote-sensing” techniques. The first-generation missions to use these techniques, the NASA Terrestrial Planet Finder and ESA Darwin missions, and the next generation NASA LifeFinder mission will not be able to spatially resolve features on the surface of the planet. While basic information can be gleaned about an extrasolar planet based on the characteristics of the host star and the planet's position in its planetary system, spectroscopy is still our most powerful technique for extrasolar planet characterization. The NASA Astrobiology Institute's Virtual Planetary Laboratory (VPL) uses computer models of terrestrial planets to understand the nature and potential range of spectroscopic signs of planetary habitability and life. The VPL simulates the environments of terrestrial planets, starting with planets in our own Solar System, and moving outward to a larger range of planetary environments and host stars. The disk-averaged spectra of these bodies are then analyzed to identify and assess the detectability the spectral biosignatures that might be encountered by future planet detection and characterization missions. More specifically, the VPL explores the limits of our capability to characterize a distant environment from disk-averaged spectra, by researching the likely atmospheric gases (e.g. O_2, H_2O, O_3, CH_4 and CO_2), surface signatures (e.g. the vegetation red edge) and temporal variability (e.g. due to spatial variations in surface type, or the seasonal “breathing” of a biosphere) that may be seen in this type of data.

The VPL Research Goals, Astrobiology, and NASA

The work undertaken by this group is heavily interdisciplinary, drawing on and synthesizing the expertise of an extremely wide range of disciplines spanning the NASA Science Mission Directorate, including astronomy, geology, planetary science, Earth science, ecology and biology to address a common, focused scientific goal. The VPL's suite of computer models and supporting observational and field work are being used to provide the fundamental research needed to support the remote-sensing detection of life, by improving our understanding of the use of spectra to discriminate between extrasolar planets with and without life. This work is most directly relevant to the Astrobiology Roadmap Goals 1 and 7, on the nature of planetary habitability and the remote-sensing signs of life. However, this year, work undertaken by the VPL Team to understand the remote-sensing signs of habitability and life touched on all 7 Astrobiology Roadmap goals, and was relevant to 15 of the 18 Astrobiology Roadmap Objectives.

The VPL's interdisciplinary research is targeted to provide results relevant to the design and search strategies for future NASA planet detection and characterization missions. However, to achieve this goal, VPL research this year supported 16 international mission or mission concepts, including TPF-C, TPF-I, LifeFinder, the Orbiting Carbon Observatory, ESA Venus Express, Cassini-Huygens, MARVEL , Phoenix, Mars Odyssey, Mars Science Laboratory, the Space Interferometry Mission, Spitzer, Kepler, ESA COROT and GAIA. In addition, the VPL used data from 8 active or previously flown spaceflight missions (Spitzer, Cassini-Huygens, Mars Express, Mars Odyssey, Aqua, Terra, The Hubble Space Telescope and the International Ultraviolet Explorer) as input to its science activities. VPL Team members also provided two-way communication between the astrobiology community and NASA missions as they participated in mission science activities for TPF-C, TPF-I, the Orbiting Carbon Observatory, Venus Express and the Cassini-Huygens mission.

The Virtual Planetary Laboratory, NAI Year 7.

Building the VPL: (8 Research Tasks)

This year, the VPL team continued its efforts to develop and combine computer models of planetary

processes into a series of progressively more comprehensive terrestrial planet models. Significant milestones, particularly in model integration, were achieved. The completed VPL model suite will provide the capability to model terrestrial planet environments in a self-consistent fashion, and output the spectral appearance of these environments to remote-sensing observations. The resultant models are being applied to a number of scientific questions on the environments of early Earth and extrasolar terrestrial planets.

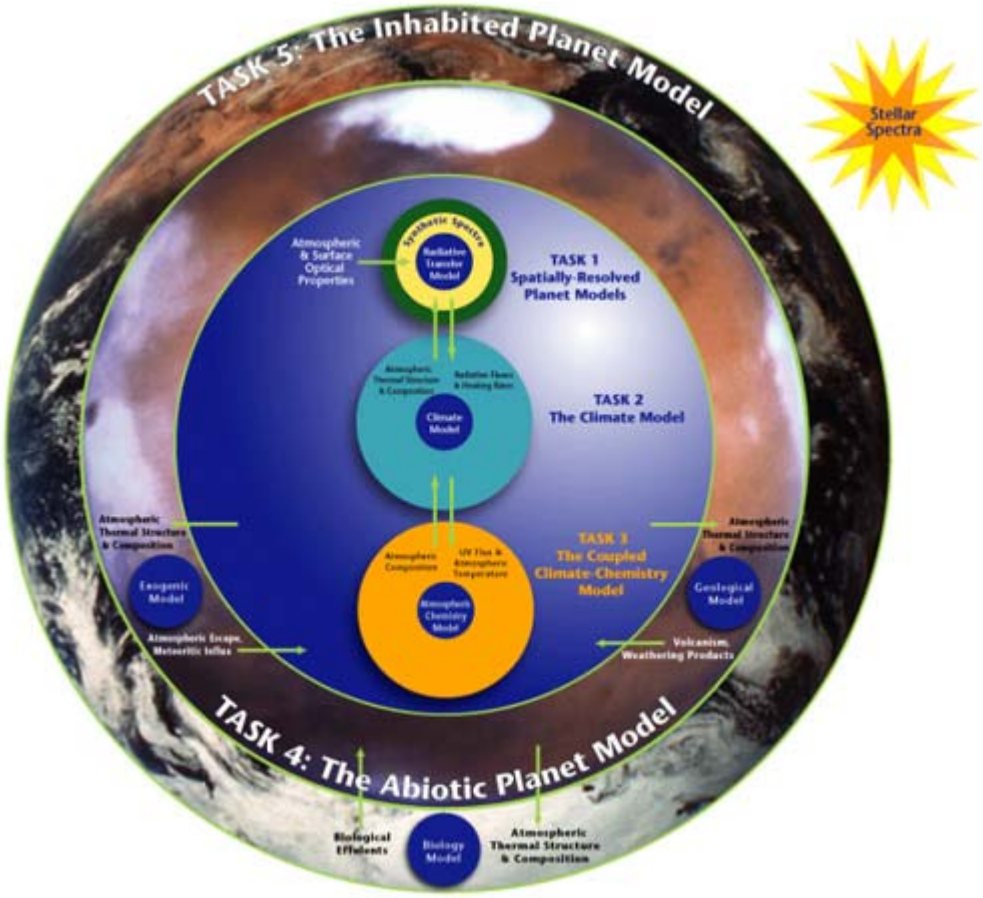

Figure 1.

This effort is characterized by 5 successive component model tasks, the supporting tasks of compilation of a molecular spectral database and a stellar spectra database, and the overarching task of model integration. These tasks and highlighted accomplishments briefly summarized below. More details on task scope and accomplishments can be found in the individual project reports.

Task 1: Spatially-resolved models of terrestrial planets. These models use observed or interpolated data to provide 3-D spectral representations of planets in our own Solar Systems. Research highlights for this year include publication of the Mars model results, and completion and submission of the full Earth model with realistic clouds. Modeling highlights included an improved understanding of the effect of clouds on 1) the disk-averaged spectrum as a function of phase, 2) the visible and MIR light-curves and 3) the detectability of biosignatures in the Earth's spectrum.

Task 2: 1-D Climate Models for Extrasolar Terrestrial Planets. These models yield a globally-averaged description of the surface temperature and vertical temperature distribution for a terrestrial planet. Progress this year included development of a new, faster radiative transfer scheme and the incorporation of a cloud model. The resultant model was used to produce annual cycles of soil and atmospheric temperature for Earth in an elliptical orbit. The model with clouds is being validated against the environments of planets in our own solar system.

Task 3: A Chemistry Model for Extrasolar Terrestrial Planets. This task focuses on the development of a generalized, yet comprehensive, photochemical model for terrestrial planet atmospheres which will interact with the Task 2 climate model to create a self-consistent climate-chemical model. This year the master reaction file set and the coupling with the climate model via the VPL database was completed. The

chemistry model was used to model the chemistry of Titan, and a Snowball Earth. Work was also completed on atmospheric fractionation processes on Mars as an aid to identifying the source of Mars methane.

Task 4: The Abiotic Planet Model: This task develops models of processes at the upper and lower boundaries of the coupled climate-chemical model, including exogenic mass fluxes (dust/meteors/asteroids, atmospheric loss) and surface-atmosphere interactions (chemical weathering, mantle outgassing). This past year saw the interior model, supporting stagnant lid and plate tectonics, integrated into the VPL. Progress was also made on reactive transport models for rock weathering to understand volatile fluxes with a specific study of high-temperature weathering of granite during the Archean. Work was also done on the ablation of organics from meteorites and the chemical kinetics of polycyclic aromatic hydrocarbons in impacts and circumstellar disks.

Task 5: The Inhabited Planet Model: This task provides computer models of life's interaction with the planetary environment for integration with the Task 4 model. Progress this year included the publication of an Archean ecosystem model, and work to understand the photosynthetically active radiative and light harvesting pigments that might be present on Earth-like planets around F, G, and K stars. Progress was also made on coupling a land biosphere model to the VPL. This task also included field trips to sites that provide analogues to possible Early Earth environments. The goals of the field work are to analyze life in highly alkaline aquifers and springs associated with terrestrial serpentinizing bodies, and to work on horizontal gene transfer in environments that contain freshwater stromatolites.

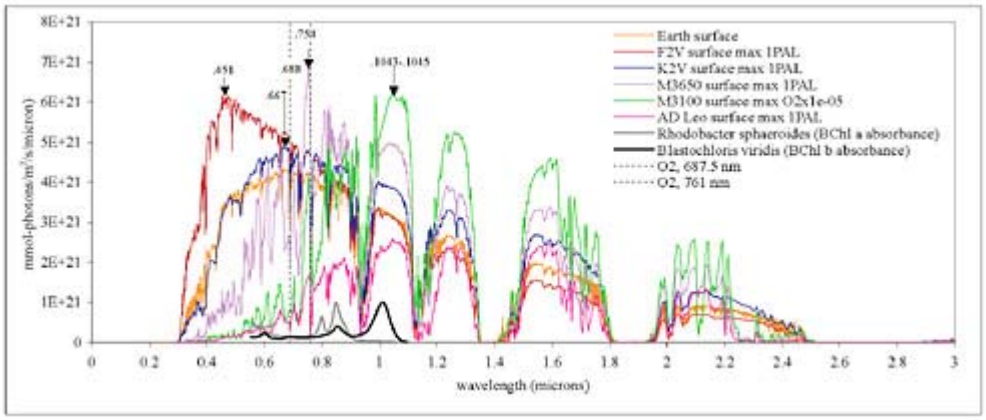

Figure 2. Task 5: VPL calculated surface photon flux densities and candidate wavelengths for peak photosynthetic pigment radiation absorbance on Earth-like planets in the habitable zone of F, K, and M stars. Included for comparison are the Earth's surface photon flux density and the absorbance spectrum of various purple bacteria.

Task 6 and 7: Spectroscopic Databases to Support Extrasolar Planet Modeling: Molecular and Stellar.

This task focuses on collecting molecular absorption information, and preparing full-wavelength, continuous stellar spectra for use by planetary climate and chemistry models. This year the molecular database was updated to include the new HITRAN 2004 database and molecular information over UV and visible wavelength ranges relevant TPF-C. We also worked on a larger sample of spectra of stars (46), and worked on obtaining time-dependent spectra characterizations of active M stars. An initial version of this database, containing continuous UV-FIR spectra of several stars was made public this year. Both databases, molecular and spectral can be found at: http://vpl.ipac.caltech.edu/spectra/ .

Task 8: The Virtual Planetary Laboratory: Synthesis and Architecture

This task focuses on interfacing and integration of the core model components to produce the VPL planetary models described in Tasks 3-5. This year, significant progress was made on interface design, with the VPL climate-chemistry interface developed, and the full coupling of Jim Kasting's climate-chemistry code through the VPL architecture, including a validation run to achieve a convergent run of the Earth's atmosphere. The PlanetDrafter tool to parameterize runs with the VPL was improved in the last year. A new feature, which parses input files to the spectrum generation code from the output of the climate-chemistry model was developed this year.

In addition to core work on the development of the VPL code, this year team members expanded into

several relevant and complementary fields pertaining to habitability and the detectability of biosignatures. These projects are summarized below.

Earth-like Planets Around Other Stars

Continuing work completed in previous years on the environments and spectral appearance of Earth-like planets around F, G and K stars, this year we submitted a publication on models of environments and spectra for Earth-like planets around M. Our models indicated that ozone layers did form, and abundances of reduced biomarker gases were found to be higher on the M-star planets than on Earth, given the same assumed surface fluxes, due to the low near-UV flux from the parent stars. We also showed that the biomarker CH_3Cl, undetectable in the modern day Earth spectrum became greatly enhanced on Earth-like M star planets, being most detectable in the mid-infrared. Work was significantly advanced on modeling Earth-like planets around M stars with time-variable spectra, and we also started simulations of High-CO_2 planetary atmospheres to address whether O_2 and O_3 abiotic abundances resulted in false positives for life.

The Astrophysical Environment and Planetary Habitability.

This task focuses on the effects of transient astronomical radiation events, such as stellar flares and Galactic cosmic rays, on planetary atmospheres and biospheres over time. Work this year focused on identification and quantification of sources of cosmic-ray (CR) variations over a large range of timescales, including parent star CR variations, passage of planetary systems through interstellar density structure, and variations in the star formation rate during the parent star's Galactic orbit.

Exploring Conditions for Habitability on Mars.

In this task, we explored long-term climate, surface and sub-surface characteristics of Mars, including the effects of obliquity changes, and looked for evidence of snow/ice interactions with the atmosphere on Mars today. Results indicated that the Martian atmospheric pressure is remarkably static over time and that a sub-surface water ice boundary would also be largely unaffected by changes in orbital cycle, except during periods of extreme obliquity.

Detectability of Planets and Biosignatures

This task focuses on the question of detectability of planets and biosignatures and uses instrument and data simulation models, retrieval techniques, and the amassed spectra of the Virtual Planetary Laboratory to date. This year, team members worked on algorithms for planet signal extraction for TPF-I, limits for astrometric detection, techniques for detecting planets via analysis of circumstellar disk structure, and explored the use of polarimetry for planet detection and characterization. Work was also done to assess the detectability of planetary characteristics using instrument simulator models for both TPF-C and TPF-I.

VPL Education and Public Outreach

VPL has provided budget and scientists support to develop the “Design a Planet” module of the AstroVenture interactive website for middle school students. AstroVenture highlights NASA careers and astrobiology research. VPL has also funded in-service teachers to earn graduate credits taking the “Astrobiology On-line Course for teachers ”. The VPL E/PO team, with the support of the VPL scientists, has also created a new website with more information and new sections related to Education and Public Outreach. Additionally, there are numerous E/PO efforts and public talks by Dr. Meadows and VPL scientists and an on–line astrobiology course provided by Dr. Siefert at Rice University .

NAI-wide Collaborative Efforts

VPL team members worked in collaboration with CIW and the NAI Astronomy Focus Group to host and participate in the NAI Global Biosignatures Workshop, a pioneering effort to use videoconferencing to support a bi-coastal workshop. VPL team members also organized a second workshop on TPF and Biosignatures in collaboration with the TPF Project, and organized, held and participated in a workshop on

Mars Methane. Team members also participated in the SETI workshop on M stars and Habitability.

Project Reports: Virtual Planetary Laboratory (JPL/CalTech)

Characterization of Terrestrial Planets From Disk-Averaged Spectra: Earths Around Other Stars

Project Investigators: James Kasting, Antigona Segura

Project Progress

Continuing work completed in previous years on Earth-like planets around F, G and K stars, this year we submitted a paper to *Astrobiology* that describes a coupled photochemical-climate model for Earth-like planets around M stars. For two active M-stars (Eps Eridani and AD Leo) we constructed absolute FUV- to far-IR spectral energy distributions using optical and near-infrared observations. These spectra, and spectral models of 3 quiescent M stars were input to the climate-chemistry model to estimated the thickness of the ozone layer and the abundance of various biomarker gases (CH_4, N_2O, and CH_3Cl). We calculated visible to mid-infrared spectra for the resulting planetary environments. All of the M-star planets modeled exhibited observable ozone layers, with ozone column depths on the two active M-stars within a factor of 2 of Earth's (Fig. 1), whereas ozone column depths for planets around quiescent M-stars were up to 8 times smaller. Abundances of reduced biomarker gases were higher on the M-star planets than on Earth, given the same assumed surface fluxes, due to the low near-UV flux from the parent stars. CH_4, for example, had a predicted concentration of ~500 ppmv on the active M-star planets, compared to 1.7 ppmv for Earth (Fig. 2). Little radiation is emitted from Mstars in the 200-300 nm range and the production of $O(^1D)$ and the corresponding abundance of OH radicals in the troposphere of an M-star planet is much lower than on Earth. The result is that both O_2 (or O_3) and reduced biomarker gases have a higher probability of being simultaneously observed on such planets, if present, (Fig. 3), providing a strong indicator for life.

High-CO_2 planetary atmospheres were also simulated using a 1-D photochemical model to address whether O_2 and O_3 abiotic abundances can be in false positives for life. Complete FUV-far-IR spectra were assembled for six sun-like stars and spectrum of the object with the highest stellar UV flux (EK Dra) was used. A paper with the results is being prepared.

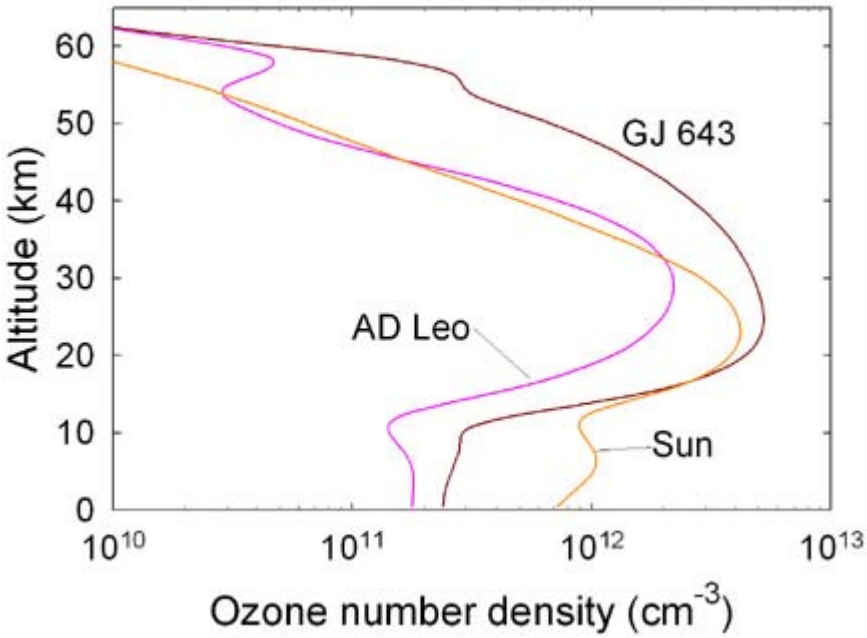

Figure 1. Vertical mixing ratio of methane for Earth-like planets around two M dwarfs and for Earth itself. Planets are identified by their parent stars.

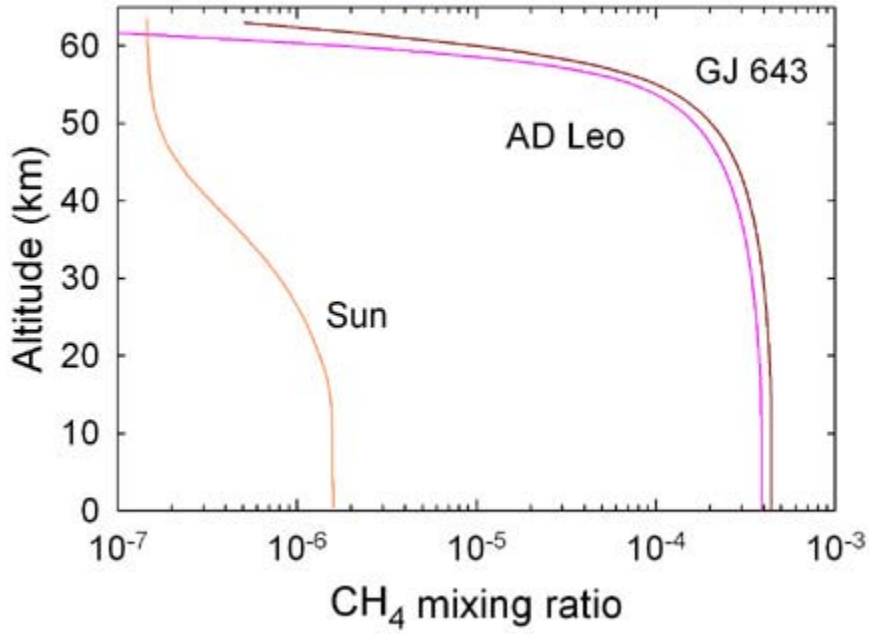

Figure 2. Ozone number densities for a planet like Earth around two active M dwarfs and the Sun.

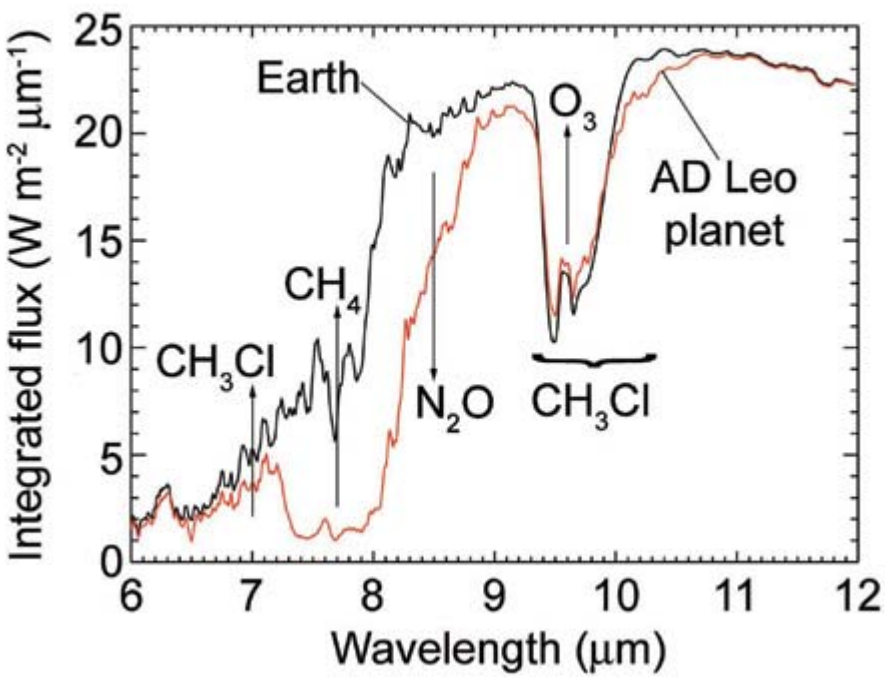

Figure 3. Planetary IR spectra from 6 µm to 12 µm: Black--Earth; red -- An Earth-like planet around AD Leo with the same surface fluxes as the Earth.

Roadmap Objectives

- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2)	Type of Involvement**

	OR Concept (for class 3)	
2	TPF-C and TPF-I	Planning Support,Data Analysis,Background Research,Instrument/Payload Development,Research or Analysis Techniques
3	LifeFinder	Planning Support,Data Analysis,Background Research,Research or Analysis Techniques

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

TPF-C/TPF-I: James Kasting is the chair of the TPF-C Science and Technology Definition Team, and Vikki Meadows is a member of this Team. Vikki Meadows also served on the Terrestrial Planet Finder Science Working Group, through October, 2004. David Crisp is a member of the TPF-I Science Working Group. Martin Cohen is PI of a separate TPF/FS proposal that also involves Meadows, Kasting, Segura, and Velusamy. Our work helps prepare the background materials necessary for interpreting TPF data, when and if they become available.

Jim Kasting is a member of the CoreCam TPF-C Instrument Concept Science Team. Vikki Meadows is a member of the CoreSpec TPF-C Instrument Concept Science Team.

LifeFinder: The work done here will also help provide context and an analysis framework for the higher-resolution, better temporally-resolved spectra planned to be obtained from the NASA LifeFinder mission. Vikki Meadows served as a member of the NASA Strategic Roadmap 4 committee for "Advanced Telescopic Searches for Habitable Environments Around Other Stars", which worked to define long-term goals for the TPF and LifeFinder missions.

Cross Team Collaborations

James Kasting and Antigona Segura are also members of the Penn State Astrobiology team.

Characterization of Terrestrial Planets From Disk-Averaged Spectra: Spatially and Spectrally Resolved Planetary Models

Project Investigators: Victoria Meadows, David Crisp, Giovanna Tinetti

Project Progress

The first generation of NASA and ESA space-based observatories to characterize extrasolar terrestrial planets will only be able to obtain disk-averaged spectra. This year, we completed a 3-D model of the Earth's environment, complete with clouds, and used it to simulate its disk-averaged spectrum and lightcurves (Tinetti et al., 2005). This model includes realistic surface and atmospheric properties from NASA Atmospheric Infrared Sounder (AIRS), and moderate-resolution Imaging Spectrophotometer (MODIS) products and clouds from the International-Satellite-Cloud-Climatology-Project (ISCCP) products. The model was validated against disk-averaged visible to infrared observations of the Earth taken by the Mars Global Surveyor Thermal Emission Spectrometer (MGS-TES), the ESA Mars Express Omega instrument, and ground-based observations of earthshine reflected from the unilluminated portion of the Moon. This comprehensive model produced excellent fits in all three cases and is versatile enough to be used to model the geometry, illuminated and cloud cover on the day an Earthshine dataset is observed. Comparison between the data and the model indicate that several atmospheric species can be identified in disk-averaged earth spectra. At optical wavelengths (0.4-0.9 microns) O_3, H_2O, O_2 and the oxygen dimer (O_4) are clearly apparent. In the mid-IR (5-20 microns) CO_2, O_3 and H_2O are present. CH_4, N_2O, CO_2, O_3 and H_2O are visible in the near-IR (1-5 microns).

We can discriminate different surface types from the Earth's spectra in the visible, but there are almost no differences in the IR. We showed that disk-averaged optical spectra are sensitive to observing phases when clouds are present. Clouds produce dramatic changes in the shapes and intensities of he spectra (variation of up to 400% in the visible and up to 50% in the mid-IR). While the photosynthetic red-edge near 0.6 microns can produce 50% changes in the spectrum on a cloud-free Earth, this signature can be obscured by clouds in disk-averaged spectra. The signature of phytoplankton was searched for, but is sufficiently weak that it is unlikely to be detected.

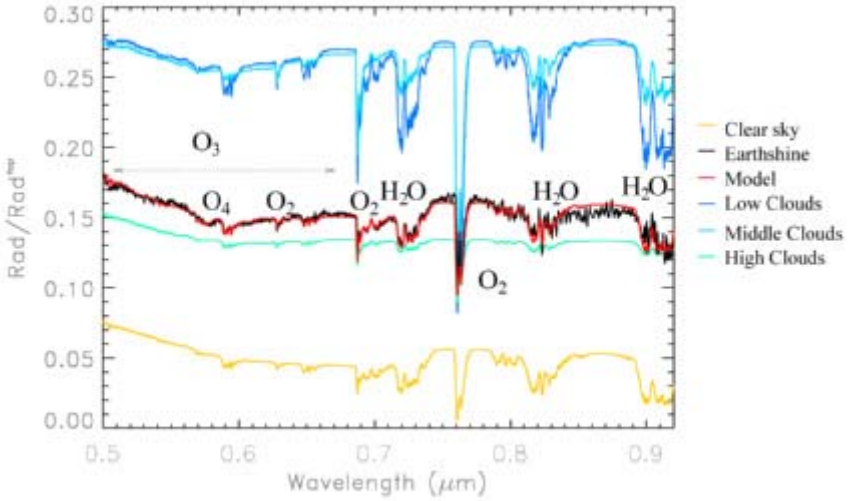

Figure 1. Earthshine spectrum observed from the Steward Observatory of the University of Arizona (black plot) compared with the disk-averaged synthetic spectrum produced in almost the same conditions of illumination and cloud cover (red). The yellow plot at the bottom of the figure, is the disk-averaged synthetic cloud-free spectrum. Plots in light blue show the contribution of different cloud-types. O_2 and H_2O are clearly visible in the spectrum. We believe the absorption features centered near 0.577 and 0.63 can be explained by the oxygen dimer O_4.

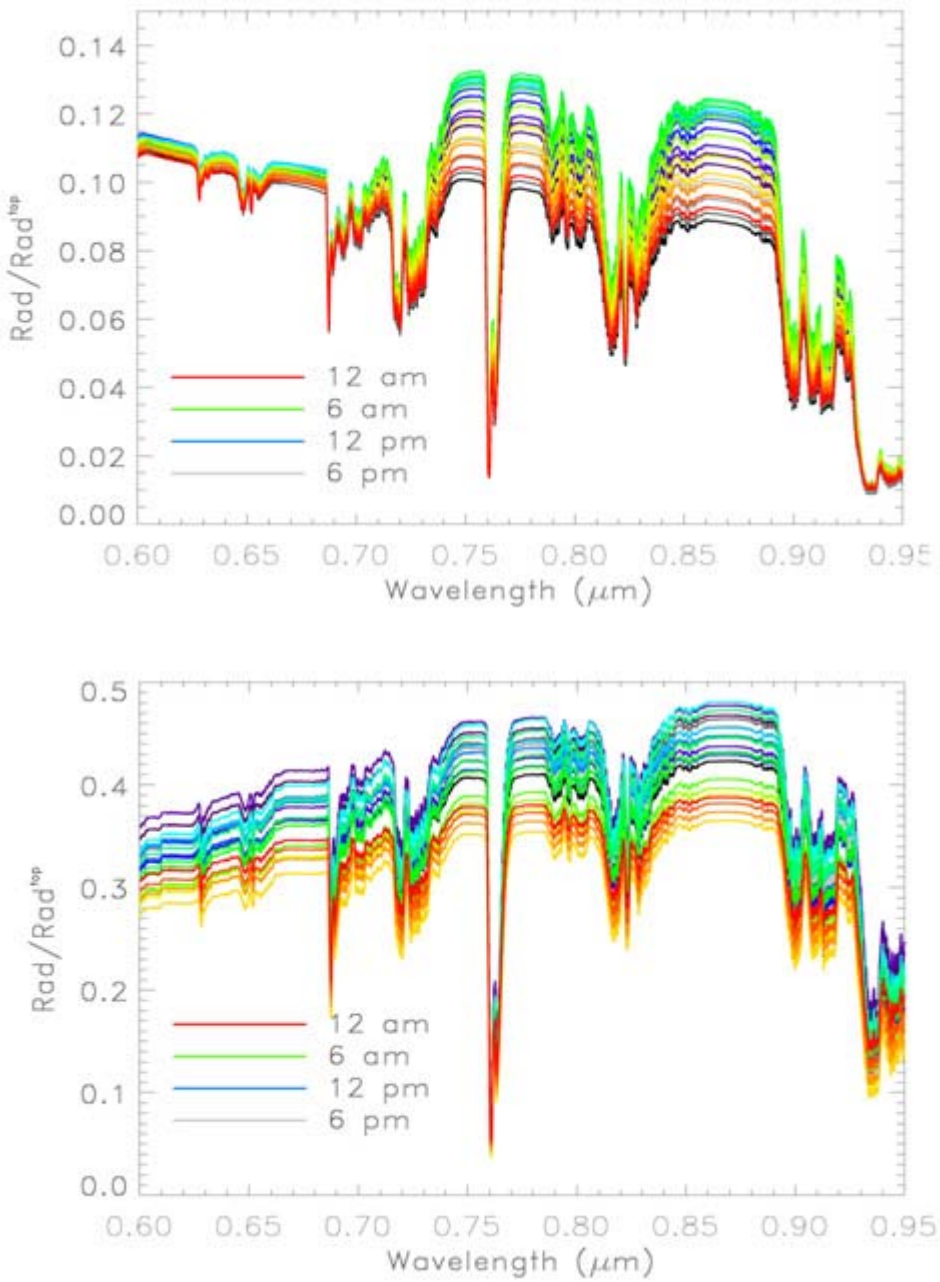

Figure 2. Disk-averaged spectra in the optical of a cloud-free (a) and cloudy (b) Earth seen from different views following the diurnal rotation of the planet. In the clear sky case (a), the red edge (increase of albedo in the ~0.7-1. wavelength range due to vegetation) can not be discriminated when the Pacific Ocean dominates the view, while the peak detectability occurs when Africa and the Eurasian continents provide a view with the maximum land covered by vegetation. When clouds are included (b), the detectability of this surface biosignature becomes very challenging.

Roadmap Objectives

- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
2	TPF-C/TPF-I	Planning Support,Background Research,Instrument/Payload Development
3	LifeFinder	Planning Support,Background Research,Instrument/Payload

Development

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

This project work supports the development of the Virtual Planetary Laboratory modeling suite, which will be used to identify and estimate the detectability of terrestrial planet characteristics to determine whether astronomical remote-sensing techniques will be valide for determining if a detected terrestrial planet is habitable or already supports life. This work is therefore background science for the TPF mission and will provide information that will be valuable for mission planning, including estimates of the minimum and optimum sensitivity, wavelength range and spectral resolution required for both TPF-I and TPF-C.Project Investigator Meadows serves as a member of the TPF-C Science and Technology Definition Team. Project Investigator David Crisp serves as a member of the TPF-I Science Working Group.

Project Investigator Victoria Meadows served as a member of the Roadmap Committee for the NASA Strategic Roadmap 4 on "Advanced Telescopic Searches for Habitable Enivonments around Other Stars" in which long-term goals for the TPF missions and the LifeFinder vision mission were developed.

Cross Team Collaborations

This work was done in collaboration with Dr. Maggie Turnbull, formerly of the Arizona State NAI Team, and now a member of the CIW NAI Team. Dr. Turnbull provided both data and insight into the observing conditions for the Earthshine spectrum, and worked with us on the Earth model papers.

Chemistry Models for Extrasolar Planets

Project Investigator: Mark Allen

Project Progress

This task focuses on the development of a generalized, comprehensive, photochemical model for terrestrial planet atmospheres, by evolving a version of the Caltech/JPL planetary chemistry/transport model, KINETICS. The resulting model interacts with the climate model described in Task 2, to create a self-consistent climate-chemical model.

This year, we finished compiling the master reaction list from individual reaction lists for Venus, Earth, Mars, Jupiter, Saturn, and Titan. This comprehensive set can now be used for a wide range of planetary environments, and template sets for Venus-like, Earth-like, and Mars-like planets were also developed as starting points for simulations.

The interface to link the chemical model and other components of the VPL suite through the VPL database was developed. To improve data input and versatility, different input formats for photochemical parameters are now supported. The same stellar radiation input to the radiative and climate components of the model, albeit degraded to lower resolution, is now used. Finally, the chemical model can now ingest and use climatological data from the VPL database, and transfer computed atmospheric composition data back to the database for use by the climate model, in a fully iterative fashion.

In parallel with the interface to VPL, KINETICS was used to investigate the chemistry of the atmosphere of Titan, and model chemical changes in a Snowball Earth. The latter study showed that a weak Snowball hydrological cycle coupled with photochemical reactions with water vapor would result in steady state production and accumulation of hydrogen peroxide, H_2O_2, which would be released directly into the ocean in the melting at Snowball's end. This phenomenon could explain massive deposition of Mn oxides in post-glacial sediments and could have driven the evolution of oxygen mediating enzymes and oxygenic photosynthesis.

The atmospheric fractionation of CH_4 on Mars was also investigated. Biological processes can fractionate the common isotopologues of methane, although additional fractionation due to photochemistry also occurs. This work on understanding the atmospheric fractionation processes therefore supports the interpretation of isotopic ratios to identify the source of the Mars methane.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 2.1:** Mars exploration
- **Objective No. 2.2:** Outer Solar System exploration
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
1	Cassini-Huygens	Data Analysis
2	TPF	Planning Support,Data Analysis,Background

		Research,Research or Analysis Techniques
2	Mars Volcanic Emission and Life Scout (MARVEL)	Research or Analysis Techniques

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
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Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Cassini-Huygens: The Titan model is being used to interpret Cassini-Huygens data. Prof. Yung is a member of the UVIS Cassini Science Team.

TPF: The VPL Chemistry Model, when coupled with other VPL components, will yield predictions for the atmospheric composition of extrasolar planets in a range of conditions.

Mars Volcanic Emission and Life Scout (MARVEL): The measurement of the atmospheric composition of Mars will be a good prototype for searches for habitable and/or inhabitted extrasolar planets. VPL simulations of Mars can guide measurement objectives for a Mars orbital mission seeking evidence of subsurface life or habitability of Mars. Project Investigator Mark Allen is the Principal Investigator for the MARVEL NASA Mars Scout Mission Concept, a mission to explore the atmospheric chemistry of Mars and look for clues to early habitability and/or life.

Cross Team Collaborations

Mark Allen, the Project Investigator, served on the organizing committee for the NAI Distributed Workshop, "Methane on Mars", held at NASA/Ames Research Center on May 18, 2005. The focus of the workshop was the interpretation of atmospheric methane on Mars in terms of abiotic and biotic sources. A key issue was the chemistry of methane in the Mars atmosphere. Other members of the organizing committee were Bruce Runnegar (NAI Director), Jim Lyons (UCLA IGPP Center for Astrobiology), and Michael Mumma (NASA/Goddard Space Flight Center).

Climate Model For Extrasolar Terrestrial Planets

Project Investigator: David Crisp

Project Progress

We developed a one-dimensional (1-D) climate model to simulate terrestrial planetary environments. A 1-D model that focuses on the physical processes governing the vertical structure and composition of the surface/atmosphere system was chosen as the first step in this investigation because the disk averaged spectrum of a planet is strongly influenced by the vertical distribution of temperature, absorbing gases, and airborne particles. Radiative heating and cooling rates are generated with the Spectral Mapping Atmospheric Radiative Transfer model [Meadows and Crisp, 1996; Crisp, 1997]. This model describes solar and thermal radiation fields in realistic, vertically-inhomogeneous, scattering, absorbing and emitting atmospheres. The vertical convective heat and volatile transport is simulated by a mixing length formulation from a state-of-the-art planetary boundary layer model [Savijarvi, 1998]. Diffusive heat transport within the surface and near-surface atmosphere is simulated by a multi-layer vertical heat diffusion model [Sertorio and Tinetti, 2002]. The Community Aerosol and Radiation Model for Atmospheres [Ackerman, et al., 1995; Jensen, et al., 1994; Toon, et al., 1988] is used to simulate airborne particle nucleation, condensation, evaporation, coagulation, and precipitation for active volatile species or passive aerosols (dust). This model has been used extensively to study clouds on Earth [Ackerman et al. 1995; Jensen and Pfister, 2004; Fridlind et al., 2004]. It has also been applied to the atmospheres of Venus [James, et al., 1997], Mars [Colaprete, et al., 2003; Michelangeli, et al., 1993], and Titan [Barth and Toon, 2004]. The VPL climate model is currently being validated by simulating the environments of terrestrial planets in our solar system. This coming year, it will be used to simulate radiative-convective-conductive equilibrium environments for a range of plausible extrasolar planetary environments.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
2	TPF	Planning Support,Background Research,Instrument/Payload Development
2	Orbiting Carbon Observatory	Project Investigator
2	ESA Venus Express	Science Team Member
2	Planetary Fourier-transform Spectrometer	Project Investigator

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

TPF: This project work supports the development of the Virtual Planetary Laboratory modeling suite, which will be used to identify and estimate the detectability of terrestrial planet characteristics to determine whether astronomical remote-sensing techniques will be valid for determining if a detected terrestrial planet is habitable or already supports life. This work is therefore background science for the TPF mission and will provide information that will be valuable for mission planning, including estimates of the minimum and

optimum sensitivity, wavelength range and spectral resolution required for both TPF-I and TPF-C. The Project Investigator, David Crisp, currently serves as a member of the NASA TPF-I Science Working Group.

Orbiting Carbon Observatory (OCO): D. Crisp is the Principal Investigator of the Earth System Science Pathfinder Orbiting Carbon Observatory (OCO). This mission will make the first space-based measurements of atmospheric CO_2 with the spatial and temporal resolution and precision needed to characterize surface sources and sinks of this important greenhouse gas. These observations will improve our understanding of the Earth's carbon cycle, and facilitate improved predictions of future atmospheric CO_2 concentrations and their effect on the Earth's climate. There is strong synergy between the NAI VPL radiative transfer and climate modeling activities and the analysis tools being developed for OCO.

Venus Express: D. Crisp is a member of the PFS and VMC science teams. In those roles, he is responsible for remote sensing retrieval and thermal balance studies of the Venus atmosphere. The tools being developed as part of the VPL climate modeling task will also be used in those investigations

Database of Molecular Spectroscopy to Support Extrasolar Planet Modeling

Project Investigator: Linda Brown

Project Progress

The database of molecular spectroscopic parameters at http://vpl.ipac.caltech.edu/spectra/ contains a compilation of calculated and experimental linelists combined with a collection of empirical absorption cross-sections for specific molecules of interest to the VPL. The web pages provide spectral plots of the data, supplemental details about the molecule and the sources of information for the entries. The data are sorted by molecule, with separate files for each source. There are currently 62 molecules in the database; more are being added as information becomes available or upon request by VPL members. Data can be absorption cross sections, actual line parameter lists (of line positions, line intensities, lower state transition energies and broadening coefficients), or both. Each molecule may have available data from several different sources and sometimes at the same wavelength. The most common sources are infrared absorption cross-sections based on FTIR spectra recorded at the Pacific Northwest National Lab (PNNL), infrared line lists from the HITRAN (2004) database, and UV cross-sections from personal collections of VPL personnel. Other sources are listed specifically on the page for the individual molecule.

In the past year, all the molecules have been updated, in particular with HITRAN 2004 files and many UV/VIS data sets. Molecular hydrogen was added to the list. The actual data are not distributed via this website, but can be found on the HITRAN website, or requested by the astrobiology community via e-mail. The data reside on the VPL's Planetmaker server for use with the VPL atmospheric modeling program. The information tables and spectral images created for the VPL website were also linked to the HITRAN website (http://cfa-www.harvard.edu/HITRAN/) at the request of the HITRAN manager L. S. Rothman, and the information we collated for interdisciplinary use is now also being used by the wider molecular spectroscopy community.

Methyl fluoride CH_3F	600-6500	-	-	5-177	-	-
Methyl formate $HCOOCH_3$	600-6500	-	-	211-260	-	-
Methyl mercaptan CH_3SH	600-6000	-	-	192.5-309.5	-	-
Methyl nitrate CH_3ONO_2	-	-	-	236-344	-	-
Methyl nitrite CH_3ONO	520-6500	-	-	190-285	190-440	-
Methyl propyl ether $CH_3OC_3H_7$	-	-	-	6.2-206.6	-	-
Methyl radical CH_3	-	-	-	215-217	-	-
Methyl thionitrite CH_3SNO	-	-	-	190-440	280-560	-
Methyl vinyl ketone $CH_2CHCOCH_3$	540-6500	-	-	250-395	-	-
Nitrate radical NO_3	-	-	-	403-691	476-794	-
Nitric acid HNO_3	720-6500	*0-1770*	-	105-210	196-350	-
Nitric oxide NO	600-5000	*0-9273*	-	6.5-207	-	-
Nitroethane $C_2H_5NO_2$	550-6500	-	-	205-320	-	-
Nitrogen N_2	-	*1992-2625*	-	6.2-113	-	-
Nitrogen dioxide NO_2	600-6500	*0-3074*	-	238-666	6.2-827	230-930
Nitrogen oxide cation NO+	-	*1634-2530*	-	-	-	-
Nitromethane CH_3NO_2	600-6500	-	-	190-355	-	-
Nitrous acid HONO	550-6500	-	-	184-274	300-400	-
Nitrous oxide N_2O	535-6500	*0-7797*	-	100-240	170-223	-
Octane C_8H_{18}	600-6500	-	-	5.6-165	-	-
Oxygen O	-	*68-158*	-	-	-	-
Oxygen O_2	-	*0-15927*	-	0-245	242.3-294.1	333-666
Oxygen dimer O_2-O_2	-	-	8794-9945	300-677	335-650	-
Ozone O_3	-	*0-15927*	-	185-253	245-343	230-1084
Pentane C_5H_{12}	570-	-	-	5.6-165	-	-

Figure 1. The current list of astrobiologically significant molecules supported by the VPL Molecular Spectroscopy Database.

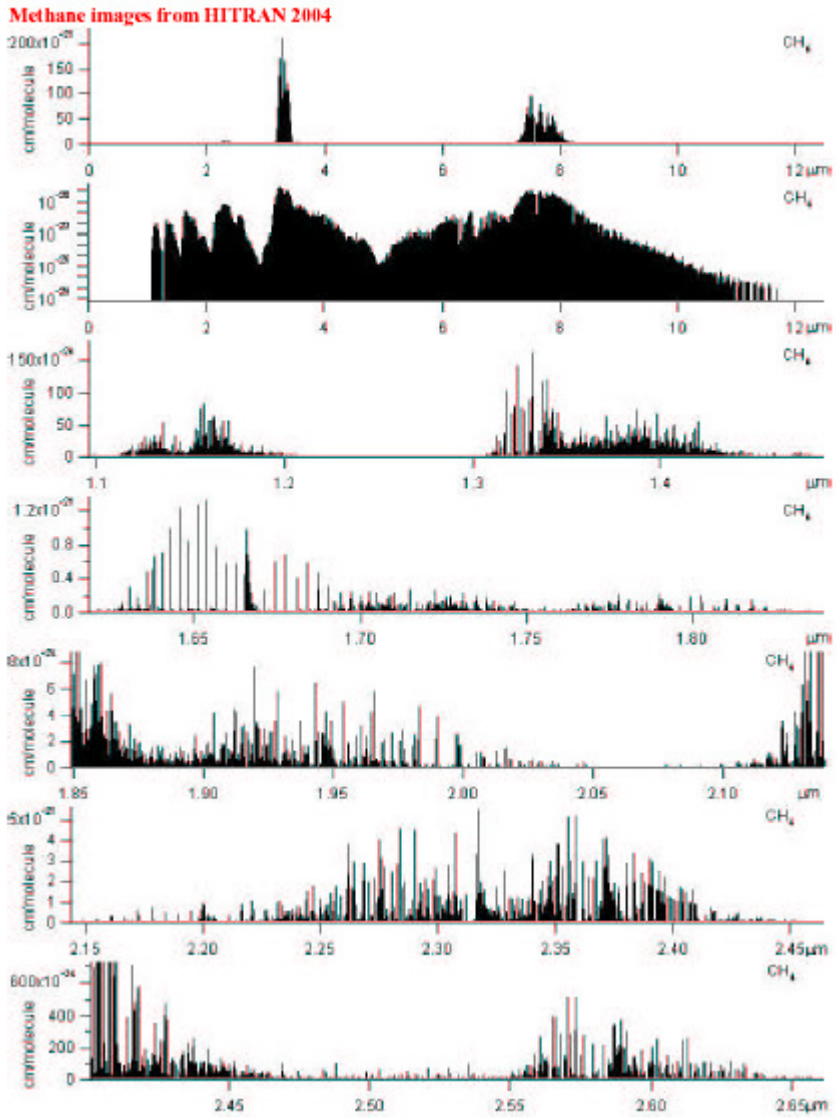

Figure 2. Example spectral images from the database.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
2	TPF-I/TPF-C	Planning Support,Data Analysis,Background Research,Research or Analysis Techniques
3	LifeFinder	Planning Support,Data Analysis,Background Research,Research or Analysis Techniques

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission

Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

This database supports modeling of extrasolar terrestrial planet spectra and can be used to help identify wavelength regions in which particular habitability markers or biosignatures may be detectable.

Database of Stellar Spectra to Support Extrasolar Planet Modeling

Project Investigators: Martin Cohen, John Scalo

Project Progress

M. Cohen has developed complete far-UV to far-IR spectra of a variety of potential host stars from solar analogs to M-dwarfs in their quiescent phase (non-flaring). Optical and infrared spectra are represented using theoretical synthetic photospheres, augmented by, or compared directly with, observed spectra. The UV portions are from empirical low-resolution spectra taken by the International Ultraviolet Explorer that have been corrected and recalibrated for all known errors and artifacts. These have been used as input to codes that couple planetary atmospheric photochemistry with radiative/convective modeling to derive biosignatures run by Kasting and Segura of VPL. The assembly of further spectra of M-dwarf stars in active and quiescent phases is planned.

John Scalo has focused on stellar activity, notably in low-mass cool dwarf stars, as evidenced through their X-ray, FUV, and optical chromospheric characteristics. The current lack of empirical FUV spectra for M-dwarfs in quiescence or at times of only mild activity may be partially addressed by a new data set (Fuhrmeister, B., Schmitt, J. H. M. M., & Hauschildt, P. H. 2005. “PHOENIX model chromospheres of mid-to late-type dwarfs. Astron. Astrophys., in press; astro-ph/0505375). This combines empirical high-resolution optical spectra of 23 cool stars (spectra of 5 of these were recently published) with theoretical models of their chromospheric spectra. If we are able to secure these modeled spectra they can be directly compared with IUE spectra for stars in common, or used as direct substitutes in stars that lack IUE and other FUV spectra.

The results of this work, full wavelength range, calibrated stellar spectra for different spectral types are used by the VPL as input to the planetary models. They are also available to the scientific community as downloadable ascii spectra on the VPL website, at: http://vpl.ipac.caltech.edu/spectra/stellar/frontpage.htm

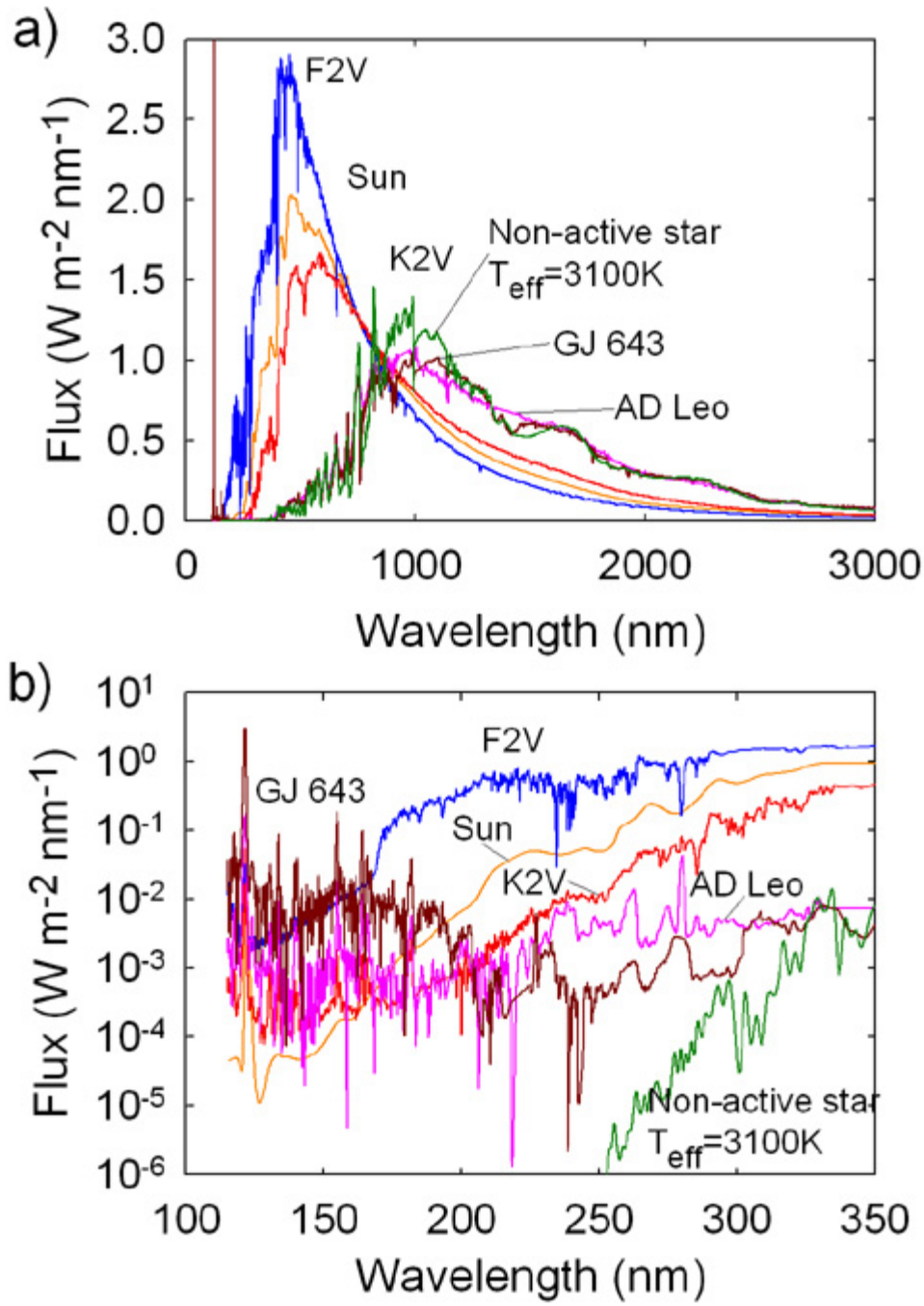

Figure 1. a) Spectra of stars of different spectral types at the top of the atmosphere of a planet on the habitable zone of each star. The F2V star is sigma Bootis located at 12 pc from Earth, its spectrum is shown at 1.68 AU from the star. Solar spectrum from Torr and Torr (J. Geophys. Res., 90, 6675, 985), Mount and Rottman (J. Geophys. Res., 88, 403, 1983), and Atmospheric Ozone 1985 Vol. 1 World Meteorogical Organization. Global Ozone Research and Monitoring Project. Report No. 16. he K2V star is epsilon Eridani 3.2 pc distant from Earth. The planet for this star is located at 0.53 AU form the star. AD Leonis and GJ 643 are chromospherically active M dwarfs with spectral ypes of M4.5V and M3.5V, respectively. The non-active star is a synthetic spectrum of an M5 star taken from the BaSeL website (http://www.astro.mat.uc.pt/BaSeL/). The planets around this stars are located at: 0.16 AU from AD Leo, 0.07 AU from GJ 643, and 0.07 AU from the non-active star. (Details on Segura et al. Astrobiology 3, 689, 2003 and Segura et al. Astrobiology, 2005 submitted)

b) Ultraviolet radiation from the stars shown in anel a). The spectra of the chromospherically active stars, AD Leo and GJ 643, correspond to the minimun observed. (Except for the Sun all data as gathered by Martin Cohen at UC Berkeley)

Examples of full-wavelength stellar spectra compiled by this team for F, G, K and M stars (Plot provided by A. Segura)

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
2	TPF-C/TPF-I	Planning Support,Data Analysis,Background Research,Research or Analysis Techniques
3	LifeFinder	Planning Support,Data Analysis,Background Research,Research or Analysis Techniques

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

TPF-C/TPF-I:

These spectra are used as input to radiative-climate-chemical models of extrasolar terrestrial planets.

Detectability of Planets and Biosignatures: Implications for TPF-C/TPF-I and LifeFinder

Project Investigators: Victoria Meadows, Thangasamy Velusamy

Project Progress

This task focuses on the question of detectability of planets and biosignatures and uses instrument and data simulation models, retrieval techniques, and the amassed spectra of the Virtual Planetary Laboratory to date.

Planet Detection: We developed a new algorithm for planet signal extraction from simulated TPF- I data. The Point Process Algorithm (PPA), uses the prior knowledge that the planets will appear pointlike, and the statistical properties of the planetary system (planets and exo-zodi), modeled within a Bayesian framework. This technique is currently considered the best by the TPF signal extraction group.

We also investigated the limitations on planet detection that would attempt to measure the apparent stellar wobble induced by a planet in a circumstellar disk. Density waves excited by a planet in the circumstellar disk may be an obstacle to the precise measurement of the stellar position required. Our analysis shows that for a $1M_J$ planet, the Space Interferometry Mission observations will not suffer significant contamination by the disk light.

We have taken sub-millimeter astronomical observations of TPF target stars that show an IR excess in Spitzer data and developed a modeling tool to fit our observations of the circumstellar disks. For Fomalhaut at 350 µm we have discovered structure in the disk that is consistent with gravitational perturbation by an unseen planet.

We have also explored high-precision polarimetry as a means detecting estrasolar terrestrial planets.

Habitability and Biosignature Detection: The combined spectroscopic results to date from several of the VPL activities were used to assess the detectability of planetary characteristics and biosignatures. These spectra were run through instrument simulator models for both the coronographic and interferometric designs of TPF to better understand the detectability of characteristics for planets in our own Solar System and planets around other stars. These spectra have been used to support two TPF instrument concept proposals, and the TPF-C science requirements document.

Roadmap Objectives

- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
1	SIM	Planning Support,Background Research
2	TPF-C/TPF-I and INSECT/CoreSpec TPF-C Instrument Concepts	Science Team Member,Planning Support,Data Analysis,Background Research,Instrument/Payload Development,Research or Analysis Techniques
1	Spitzer	Data Analysis
3	LifeFinder	Planning Support,Background Research,Instrument/Payload

Development

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

TPF-C/TPF-I & Insect: The planet detection algorithms are being developed for TPF-I,and the spectra and TPF-I/TPF-C instrument simulators can be used to assess detectability of planetary characteristics by both TPF architectures. Project Investigator Meadows served as a member of the Terrestrial Planet Finder Working Group (through October 2004), and is now a member of the TPF-C Science and Technology Definition Team. She was also a science team member on two TPF-C Instrument Concept proposals, one of which, CoreSpec, an optical spectrometer for planet characterization, was successful in this round. Project Investigator David Crisp serves as a member of the TPF-I Science Working Group.

Spitzer:Techniques developed here have been used to analyze Spitzer data to search for the presence of planets in circumstellar disks. PI T. Velusamy is a Spitzer Guest Observer, and PI V. Meadows is the Spitzer Solar System Observations Scientist for the Spitzer Science Center.

LifeFinder: Project Investigator Victoria Meadows served as a member of the Roadmap Committee for the NASA Strategic Roadmap 4 on ?Advanced Telescopic Searches for Habitable Enivonments around Other Stars? in which long-term goals for the LifeFinder vision mission were discussed and developed.

Cross Team Collaborations

The VPL team (Meadows), working with the CIW team (Seager) and the NAI Astronomy Focus Group, coorganized an NAI workshop on Global Biosignatures in December 2004. This workshop focused on understanding the possible source of biomarkers at the surface, their chemical lifetimes in a habitable planet atmosphere, and the likelihood of their detectability in a planetary spectrum. The workshop was a pilot effort to implement a bi-coastal workshop linked by a single point-to-point videoconference connection and Webex presentations. The workshop was advertised to the Astronomy Focus Group, and attended by NAI members from the VPL (Meadows, Yung, Crisp, Segura, Siefert, Bebout, Tinetti, Kiang), CIW (Seager, Cody, Mix), GSFC (Pedelty), Arizona(Woolf) and PSU(Segura, Siefert). A publication on the outcome of the discussions is being drafted.

The VPL team (Meadows, Chernobieff, Engler) also worked in partnership with the TPF Project Office on the scientific organization and logistics for a second workshop on Biosignatures for TPF which was is to be held in July 2005. This interdisciplinary workshop will include participant from the broader scientific community, and NAI participants from the Ames, VPL, Arizona, Pennsylvania State University and University of Washington Lead Teams.

Exploring Conditions for Habitability on Mars

Project Investigator: John Armstrong

Project Progress

In this task we explored long-term climate, surface and sub-surface characteristics of Mars, including the effects of obliquity changes, and looked for evidence of snow/ice interactions with the atmosphere on Mars today.

We have used a 1 Gyr integration of the Martian orbit and a seasonally resolved energy balance climate model (the NASA Ames General Circulation Model (Haberle et al., 2003) to understand Martian atmospheric pressure evolution over long periods. We found that the Martian atmospheric pressure is remarkably static over time, and decreases both at high and low obliquity. We also explored the distribution of potential wind surface erosion with respect to orbital parameter variations, and quantified the sensitivity of wind erosion to changes in global mean surface pressure.

Water ice is believed to exist in the regolith over much of the Martian surface, and might provide a water/ice boundary that could harbor microorganisms .To determine the sensitivity of this putative water/ice boundary to seasonal and orbital cycle changes we used a latitude-dependent regolith diffusion model that computes subsurface temperatures (to 3-6 km) and tracks the water/ice boundary. Using the calculation of Mars' orbit over 1 billion years, we show the boundary is largely unaffected by changes in the orbital cycle, except during prolonged events of extreme obliquity. We also used the model to compute molecular diffusion of methane in the regolith, and use recent observations of atmospheric methane abundance to constrain Mars' potential subsurface ecosystem.

Data on Korelev crater from the Mars Odyssey Thermal Emission Imaging System, and Thermal Emission Spectrometer (TES) were combined with models of annual surface temperature variations to determine the nature and behavior of deposits within the crater. This work may help constrain polar processes, and provide context for the Phoenix polar lander. TES spectra were also used to monitor atmospheric water vapor levels near suspected snowpack sites, but no interaction above the background regolith was found.

Roadmap Objectives

- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 2.1:** Mars exploration

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
1	Phoenix (Mars Scout Mission)	Background Research
2	TPF-C/TPF-I	Planning Support,Background Research
1	Mars Odyssey	Data Analysis,Background Research,Research or Analysis Techniques
2	MSL	Planning Support,Background Research

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Phoenix (Mars Scout Mission): The nature of crater deposits on Mars may help constrain polar processes, providing context for the Phoenix polar lander mission.

TPF-C/TPF-I: Understanding the processes that affect long-term habitability of terrestrial planets is important background research for the terrestrial planet finder missions.

Model Synthesis and Architecture

Project Investigator: John Armstrong

Project Progress

The Virtual Planetary Laboratory interface and integration team has developed the proto-type VPL Online Community Tool. The tool allows VPL community users to access steady-state Earth climate and chemistry components coupled through a SQL database, with the added ability to compute synthetic spectra of the model results. The core components of the model are integrated using a custom set of Application Programming Interfaces (APIs). In addition, the distributed computing network manages several parallel, independent calculations in spectrum generation, improving the performance of the most time-intensive portion of the model.

Specific Progress includes:

- **Development of APIs:** The draft specification for the VPL interface has been translated into a functioning F95 library that can be used by any VPL module. Modules can now connect to and initialize MySQL databases, read/write scalar data and vector arrays, and have the ability to record model progress in the history database through history log functions.
- **Development of the online 'Planet Drafter' tool:** The 'Planet Drafter' allows users to load database parameters from pre-defined templates, modify these, or upload custom templates. Online development tools are available that allow users to query database parameters and plot the results of model runs.
- **Integration of climate code and chemistry code using the online tools and the VPL API:** Modified versions of Jim Kasting's climate code and chemistry code are now integrated using the framework provided by Planet Drafter and the VPL API. The full parameter space has yet to be tested, but convergent, coupled climate-chemistry models for the present-day earth have been achieved.
- **Synthetic spectrum calculation:** The VPL allows users to compute synthetic spectra from the results of the coupled climate/chemistry model. Users choose the atmospheric components to include in the model, and the job manager distributes independent line-by-line absorption calculations automatically on the computing cluster.

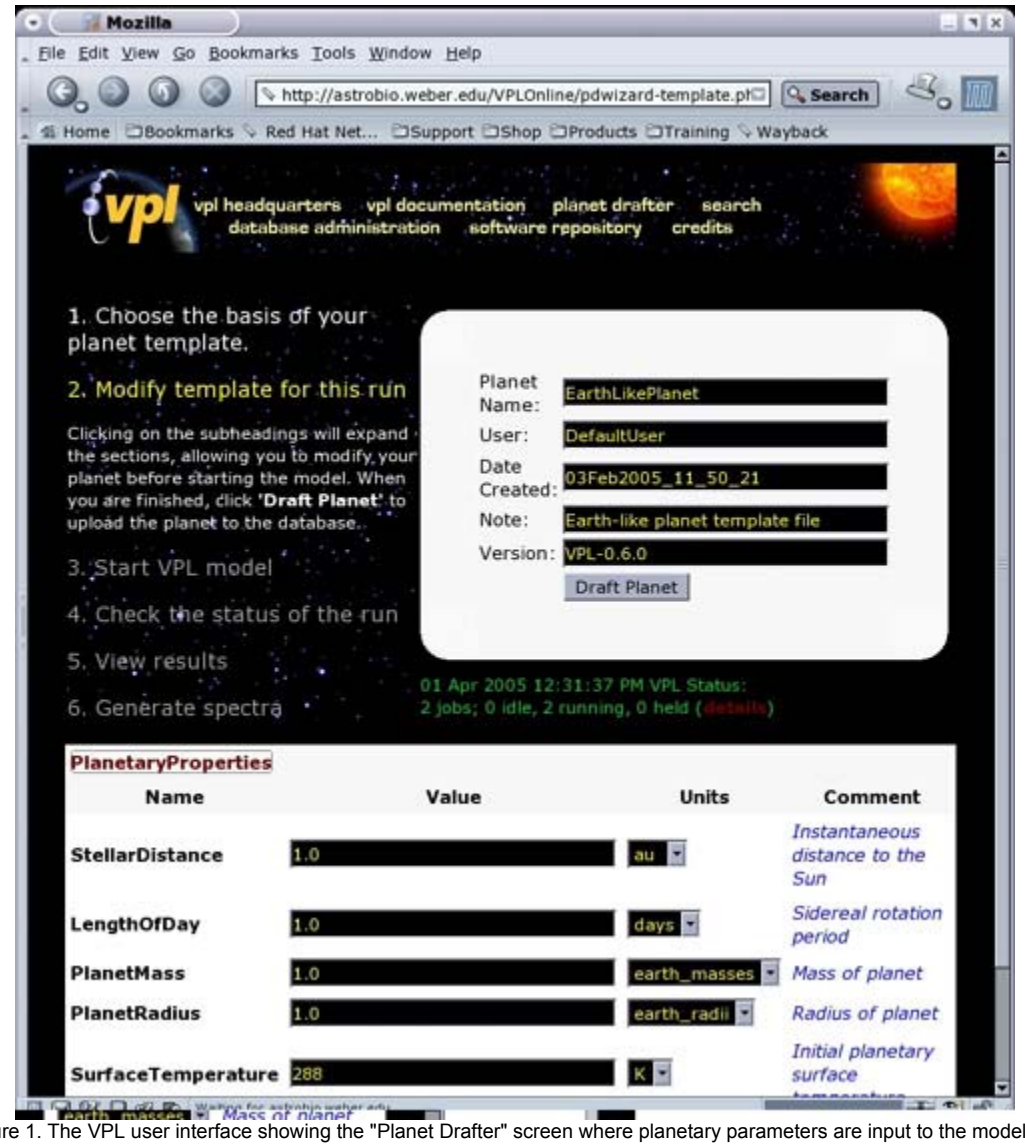

Figure 1. The VPL user interface showing the "Planet Drafter" screen where planetary parameters are input to the model run.

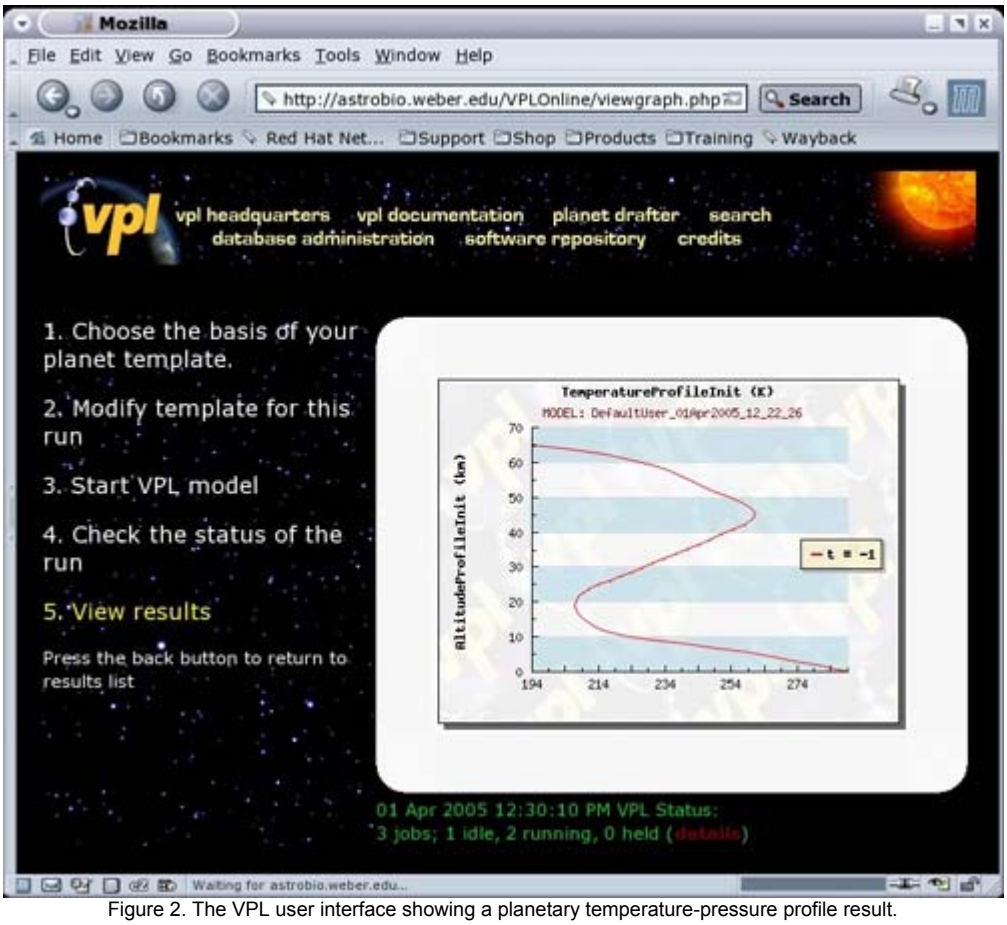

Figure 2. The VPL user interface showing a planetary temperature-pressure profile result.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
2	TPF-C/TPF-I	Planning Support,Data Analysis,Background Research,Research or Analysis Techniques
3	LifeFinder	Project Investigator,Planning Support,Data Analysis,Background Research,Research or Analysis Techniques

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

The VPL Online Community Tool will allow users to compute synthetic spectra for a host of planetary models, providing input for mission design, and eventual analysis of mission data from TPF-C/TPF-I and LifeFinder.

The Astrophysical Environment and Planetary Habitability

Project Investigator: John Scalo

Project Progress

We have examined the effects of transient astronomical radiation events, such as stellar flares and Galactic cosmic rays, on planetary atmospheres and biospheres over time. Work this year focused on identification and quantification of sources of cosmic-ray (CR) variations over a large range of timescales, including parent star CR variations, passage of planetary systems through interstellar density structure, and variations in the star formation rate during the parent star's Galactic orbit.

We calculated the statistics of amplitudes, timing, and durations of CR flux and spectrum variations on terrestrial-like planets with different parent star types, ages and Galactic locations. We modeled the variation in screening of lower-energy CRs as the astrosphere (analogue of heliosphere) expands and contracts during passage through the interstellar medium (ISM). We use a simple pressure balance model for the astrosphere size, a convection-diffusion model for CR transport, and an ISM model based on 3D MHD simulations that realistically captures the density, velocity, and magnetic field variations that control the astrosphere size. Planetary magnetospheric screening is included using empirical terrestrial magnetic field variation statistics, with the planetary field intensity a parameter. Statistics for cosmic ray fluxes were accumulated using ~10^6 planetary system trajectories through model clouds of different mean densities.

Scalo, in collaboration with P. Padoan (UCSD), discovered a new source of CR flux variation, intrinsic to CR propagation through the ISM which should vary by one to two orders of magnitude in the cool ISM. The effect of this flux variation on planetary systems passing through the ISM was compared to the astrospherically-induced variations.

A modestly enhanced CR flux would contribute significantly to the exogenous and total DNA damage and mutation rate, and may also modify atmospheric chemistry. Population genetics models are used with stochastic mutation rates and selection coefficients to examine the effects on genomic diversity and specific problems like mutation fixation and extinction timescales and the rate of evolution. The importance of CR variations on population genetics compared to UV variations due to flaring in young and low-mass stars is being compared.

Roadmap Objectives

- **Objective No. 4.3:** Effects of extraterrestrial events upon the biosphere
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
2	TPF-C/TPF-I	Planning Support,Background Research

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

Understanding astrophysical effects on habitability are important for selecting TPF targets stars that are most likely to harbor habitable worlds.

The Virtual Planetary Laboratory - The Life Modules

Project Investigators: Nancy Kiang, Robert Rye

Project Progress

Coupled model of the anaerobic, early Archean biosphere, prior to the origin of oxygenic photosynthesis (Kharecha, Kasting, and Siefert). This model includes organisms that metabolize using H_2, H_2S, and Fe^{++} as reductants. A primary goal was to estimate the production rate of methane. For reasonable assumptions about hydrogen outgassing and escape rates, CH_4 production should have been within a factor of 3 of the modern value, ~500 Tg CH_4/yr. In the low-O_2 Archean atmosphere, this would have been enough to produce CH_4 concentrations of 1000 ppmv, or higher. Such CH_4 concentrations could have helped to keep the climate warm despite reduced solar luminosity at that time.

Horizontal gene transfer (HGT) and its effect on genome coalescence (Siefert). The effect of HGT on cyanobacterial genomes and the *Bacilliaceae* lineage has been examined using a bioinformatics approach. It is found that genes can be defined that are both unique and less likely to be transferred in each lineage of bacteria.

Analysis of life in aquifers and hyperalkaline (pH > 11) dilute (<100 ppm total dissolved solids) springs associated with terrestrial serpentinizing bodies (Rye, Johnson). We are characterizing the microbial community structure at the Cedars site, California. Analysis of data from DGGE experiments has yielded a preliminary tree of roughly 20 novel organisms. Media development has now allowed us to isolate a number of pure cultures, all of which map within the *Betaproteobacteria*. This site continues to serve as a model system for the simulation of life at the surface of young terrestrial bodies.

Photosynthetically active radiation and light-harvesting photosynthetic pigments on Earth-like planets around F, K, and M stars (Kiang, Segura, Siefert, Tinetti, Cohen, Meadows). A paper is soon to be submitted on our extensive survey of Earth's photosynthetic organisms, comparing their metabolisms, pigments, reflectance spectra, and environmental niches. We have identified strong candidate wavelengths of photosynthetic pigment light absorption for organisms evolved on Earth-like planets orbiting F, K, and M stars with different atmospheric compositions (Figure 1), thus defining potential alternative biosignatures for remote detection.

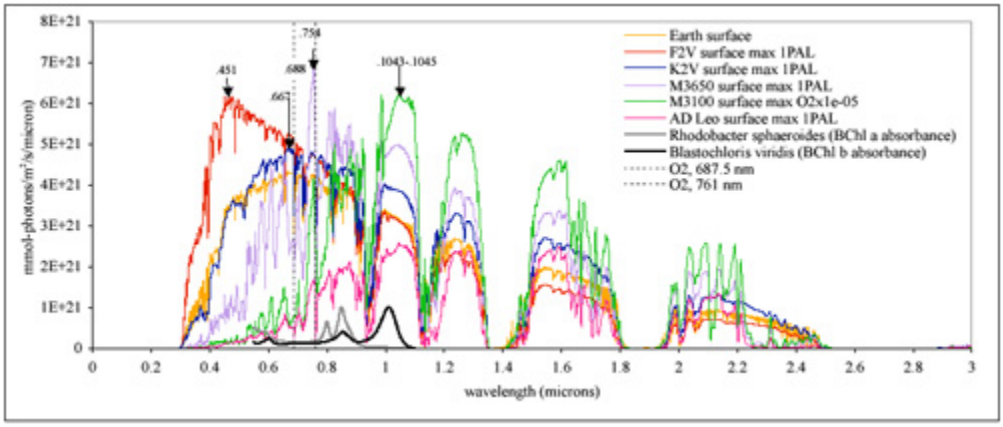

Figure 1. Surface photon flux densities and candidate wavelengths for peak photosynthetic pigment radiation absorbance on Earth-like planets in the habitable zone of F, K, and M stars. Included for comparison are the Earth's surface photon flux density and the absorbance spectrum of various purple bacteria.

Figure 2. Ultrabasic springwaters issuing from anoxic aquifers within the CedarsPeridotite typically emerge supersaturated with respect to hydrogen andmethane at 18.0 degrees C and with pH values between 9 and 11.8.

Roadmap Objectives

- **Objective No. 3.2:** Origins and evolution of functional biomolecules
- **Objective No. 3.3:** Origins of energy transduction
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 4.2:** Foundations of complex life
- **Objective No. 5.3:** Biochemical adaptation to extreme environments
- **Objective No. 6.1:** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- **Objective No. 6.2:** Adaptation and evolution of live beyond Earth
- **Objective No. 7.1:** Biosignatures to be sought in Solar System materials
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission	Mission Name (for	Type of Involvement**

Class*	class 1 or 2) OR Concept (for class 3)	
2	TPF-C/TPF-I	Planning Support,Data Analysis,Background Research,Research or Analysis Techniques
3	LifeFinder	Planning Support,Data Analysis,Background Research,Research or Analysis Techniques

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

TPF-C/TPF-I: This work provides information on microbial life and processes for input to the VPL modeling. In turn, this work allows us to better understand the signs of microbial life, and the metabolic byproducts that may be identifiable on other planets. Note that Co-I Jim Kasting serves as the chair of the TPF-C Science and Technology Definition Team (TPF-C STDT) and Collaborator Victoria Meadows serves as a member of the TPF-C STDT.

LifeFinder: Note that Collaborator Victoria Meadows served as a member of the NASA Strategic Roadmap 4 writing committee, for "Advanced Telescopic Searches for Habitable Planets Around Other Stars" which worked to define long-term goals for the LifeFinder mission

Field Expeditions

Field Trip Name: Cuatro Cienegas
Start Date: 3-10-2005 **End Date:** 3-17-2005
Continent: North America **Country:** Mexico
State/Province: Cohauila **Nearest City/Town:** Cuatro Cienegas
Latitude: 10.17ºN **Longitude:** 66.90ºW
Name of site(cave, mine, e.g.): Cuatro Cienegas **Keywords:** Desert springs, stromatolites
Description of Work: Bacterial Census
Members Involved:
Janet Siefert
Victoria Meadows
Brad Bebout

Field Trip Name: Cabrillo Marine Aquarium
Start Date: 2-25-2005 **End Date:** 2-25-2005
Continent: North America **Country:** USA
State/Province: California **Nearest City/Town:** San Pedro
Latitude: 34º 1' N **Longitude:** 118º 29' W
Name of site(cave, mine, e.g.): Cabrillo Marine Aquarium **Keywords:** marine algae, reflectance spectra
Description of Work: Collect samples of marine algae for lab measurement of reflectance spectra
Members Involved:
Nancy Kiang

Field Trip Name: Cedars Trip
Start Date: 6-17-2004 **End Date:** 6-18-2004

Continent: North America
Country: USA
State/Province: California
Nearest City/Town: Cazadero
Latitude: 38° 31' N
Longitude: 122° 49' W
Name of site(cave, mine, e.g.): The Cedars
Keywords: methane gas sampling, C and H isotopes
Description of Work: sample collection: Methane gas, and water for isotopic and microbiologicalcensus
Members Involved:
Orion Johnson

Field Trip Name: Cedars Trip
Start Date: 8-6-2004
End Date: 8-10-2004
Continent: North America
Country: USA
State/Province: California
Nearest City/Town: Cazadero
Latitude: 38° 31' N
Longitude: 122° 49' W
Name of site(cave, mine, e.g.): The Cedars
Keywords: methane gas sampling, C and H isotopes
Description of Work: sample collection: Methane gas, and water for isotopic and microbiologicalcensus. Collection of water samples for organic C analysis.
Members Involved:
Orion Johnson
Kenneth Nealson

Field Trip Name: Cedars Trip
Start Date: 9-17-2004
End Date: 9-20-2004
Continent: North America
Country: USA
State/Province: California
Nearest City/Town: Cazadero
Latitude: 38° 31' N
Longitude: 122° 49' W
Name of site(cave, mine, e.g.): The Cedars
Keywords: methane gas sampling, C and H isotopes
Description of Work: sample collection: Methane gas, and water for isotopic and microbiologicalcensus. Glass slides deployed for ultrabasic biofilm formation experiments.
Members Involved:
Orion Johnson

Field Trip Name: Cedars Trip
Start Date: 10-16-2004
End Date: 10-18-2004
Continent: North America
Country: USA
State/Province: California
Nearest City/Town: Cazadero
Latitude: 38° 31' N
Longitude: 122° 49' W
Name of site(cave, mine, e.g.): The Cedars
Keywords: methane gas sampling, C and H isotopes
Description of Work: sample collection: Methane gas, and water for isotopic and microbiologicalcensus. Filtered samples collected and glass slide biofilms collected for isolation of clones
Members Involved:
Orion Johnson

Cross Team Collaborations

Coupled model of the anaerobic, early Archean biosphere, prior to the origin of oxygenic photosynthesis (Kharecha, Kasting, and Siefert). This work ties in closely with recent work on hydrogen escape by the University of Colorado group (Tian et al., Science 308, 1014, 2005). Their work suggests that hydrogen concentrations in the Archean atmosphere may have been significantly higher than previously thought. Our

work shows that much of this H_2 may have been converted to CH_4 by methanogens. Feng Tian will come to Penn State on an NAI postdoc next year to continue this collaboration.

Self-consistent Atmospheres and Different Orbital Geometries for Extrasolar Terrestrial Planets: Being Prepared for the Unexpected

NAI-NRC Postdoctoral Fellow : Giovanna Tinetti

Project Progress

Any extrasolar terrestrial planet directly detected by the next generation of NASA and ESA space missions will be resolved only as a point source. As part of my collaboration with the Vitual-Planetary-Laboratory, I have worked to simulate disk-averaged spectra and light-curves of Mars-like and Earth-like planets (Tinetti et al., 2005). The models developed for those simulations were validated against disk-averaged observations of Mars and Earth. Synthetic spectra were generated for a variety of conditions, including cloud coverage, phase and viewing angle geometry, from the visible to IR. We found clouds deeply affect the intensities and shape of the Earth spectra by masking, reducing, or even enhancing atmospheric and surface features. In particular, surface biosignatures due to land and marine vegetation might be visible in some favorable conditions of season/concentration/viewing-angle, but are hard to detect when realistic cloud cover is assumed. This work was done in collaboration with an other VPL team members, and members of the broader Earth science and oceanography community at JPL (E. Fishbein , E. Bosc, B. Kahn)

Probing planetary atmospheres by observing atmospheric transmission spectra during stellar occultations is another effective method currently used to characterize giant exoplanets. As part of a collaboration with the Institute of Astrophysics of Paris (with D, Ehrenreich, A. Lecavalier des Etangs, A. Vidal-Majar, F. Selsis) , w e developed a model to simulate atmospheric signatures of transiting Earth-size exoplanets. In Ehrenreich et al.(2005) we evaluate the possibility of detecting molecules such as H_2O, CO_2 , O_3 , O_2 etc. in their UV to Near-IR transmission spectra. In this work we study a variety of planets with different sizes (from 0.5 to 2 Earth-radii) and atmospheres (Venus-like, Earth-like and Ocean Planets), with and without cloud contributions, and we constrain the instrument performance needed to achieve those observations. We found that Venus-like planet atmospheres are the most challenging to characterize with this technique, and the ones of volatile-rich satellites of giant planets, or those of Ocean planets are the easiest. Moreover, our results show that later-type stars are better for characterizing planets in transit.

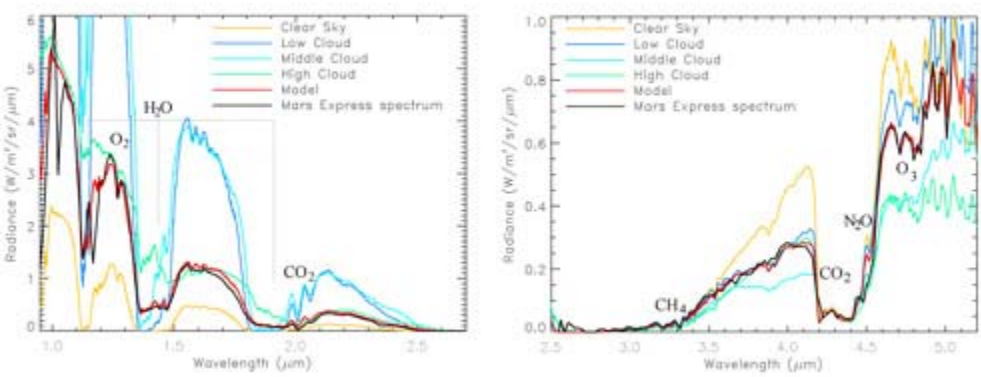

Figure 1. Comparison of the model (red spectrum) with Mars Express-Omega observations (black spectrum). The yellow plot is the disk-averaged synthetic cloud-free spectrum. Plots in light blue show the contribution of different cloud-types. The model does not fit the sharp absorption features near 1.02 and 1.2 microns. These might be instrument artifacts. Other data in the same wavelength range do not contain these features

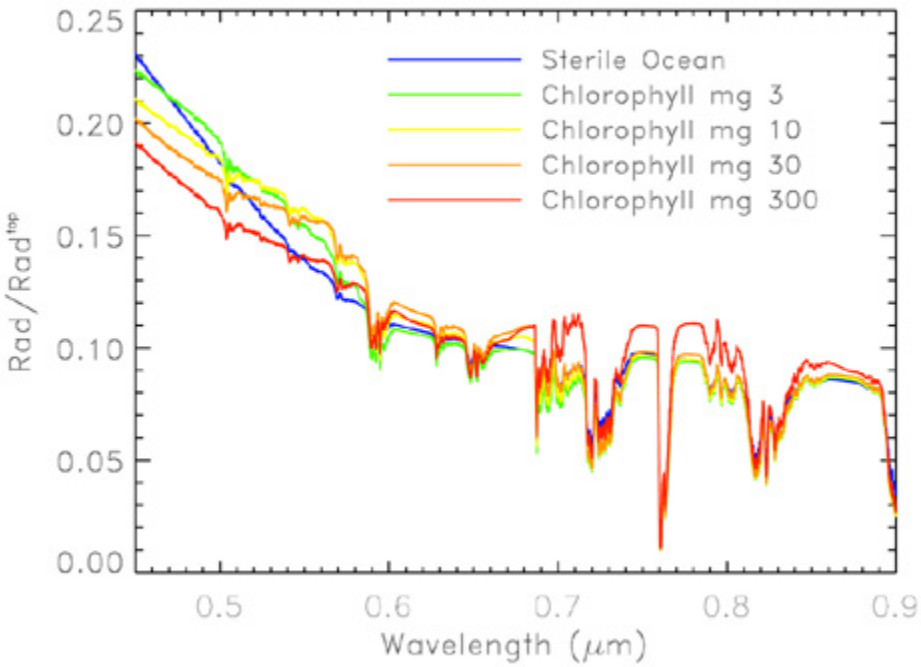

Figure 2. Disk-averaged synthetic spectra of a cloud free, predominantly ocean-view of the Earth, with concentration of plankton increasing from 0 to 300 mg/m3. For present day Earth the average concentartion hovers between 0.1 and 10 mg/m3, with peaks up to 30 mg/m3.

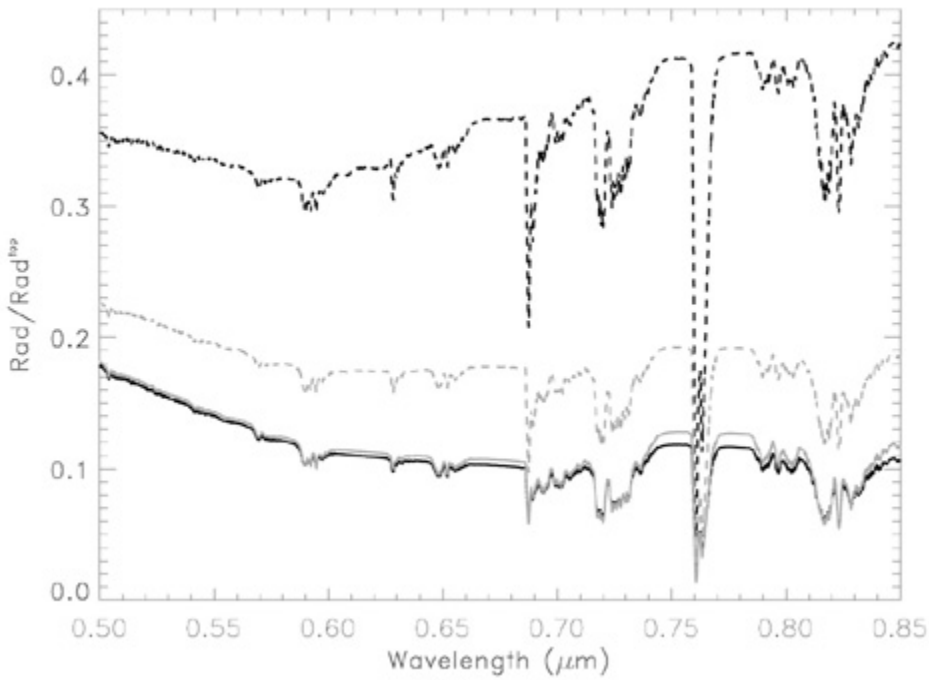

Figure 3. Time-disk-averaged of the earth: daily average of cloud free (solid lines) and cloudy Earth (dashed lines) in the optical. Black lines: fully illuminated disk; grey lines: dichotomy. The NDVI index calculated for these cases confirms the presence of vegetation for the clear sky cases and the cloudy dichotomy. Ambigous situation for cloudy, fully illuminated case.

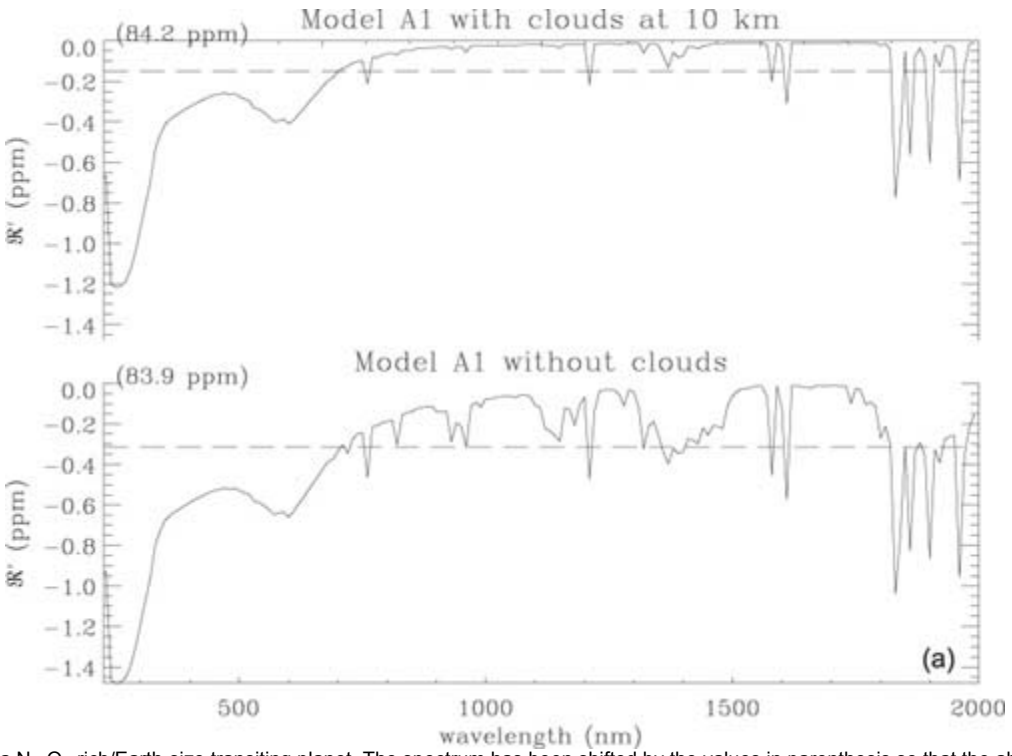

Figure 4. Spectrum ratio for a N_2-O_2 rich/Earth-size transiting planet. The spectrum has been shifted by the values in parenthesis so that the absorption by the solid disk of the planet is 0 ppm. In the cloudy case, the solid disk is increased by the cloud layer.

Roadmap Objectives

- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
1	NASA Kepler	Background Research,Research or Analysis Techniques
1	NASA's Aqua and Terra (AIRS, MODIS)	Other
1	ESA Mars Express (Omega)	Other
1	Cassini	Data Analysis
2	TPF-C/TPF-I	Planning Support,Background Research,Research or Analysis Techniques
2	ESA Darwin	Planning Support,Background Research,Research or Analysis Techniques
3	LifeFinder	Planning Support,Background Research

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
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2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

NASA's Aqua and Terra (AIRS, MODIS): Used atmospheric data from these missions as input to Earth

modeling

ESA Mars Express (Omega): Use of spectra for model validation

Cassini: Use of data as input/validation to Titan modeling

Cross Team Collaborations

Margaret Turbull, NAI-NRC (Carnegie Institution of Washington) provided the earthshine spectra, used to validate the 3-D earth model. Thanks to her experience with earthshine data analysis, her contribution was very useful not only during the phase of validation but also for the retrieval process of surface/vegetation signature in the disk-averaged spectra of the Earth

The Abiotic Planetary Model: The Upper and Lower Boundary Condition on the Atmosphere

Project Investigators: Robert Rye, Francis Nimmo, Monika Kress

Project Progress

Internal Processes and Habitability : A preliminary version of the generic terrestrial planet thermal evolution code has been completed and integrated with the VPL. This model calculates melt generation and volatile fluxes as a function of time for either stagnant-lid or plate tectonic cases. Species currently tracked include H_2O, CO_2 , SO_2 and radiogenic noble gases.

Team members also explored serpentinization, the most massive aphotosynthetic energy source, as potential food for microbes, reviewed the history of Earth's oxygen, and concluded that methane-aided hydrogen escape did indeed supply oxygen to superficial reservoirs, and used the presence of chert clasts and sands to constrain the Earth's surface temperature at ~3.2Ga to less than 50C.

Weathering: We continued work on the weathering of rocks and soils. Our black shale weathering model indicated that most ancient organic matter would be oxidized before reaching the surface, except for very rapid erosion rates. We have assembled mineralogic compositions for typical igneous rock types in preparation for modeling weathering of abiotic terrestrial planets, with special focus on fluxes of volatile gases that could, over time, change planetary atmospheric compositions. We also explored the implications of hypothesized high-temperature Archean conditions on granite weathering, and found that the mineral modes at the surface were dramatically affected. Modeling of contact metamorphism was initiated with the ultimate goal of addressing long-term surface CO_2 fluxes.

Exospheric Processes: We continued our study of the delivery of organics to habitable planets, including work on the ablation of organics from micrometeoroids, in collaboraiton with Don Brownlee (U. Wash) and George Cody (CIW), and new work on the chemical kinetics of polycyclic aromatic hydrocarbons (PAHs) in impacts and in circumstellar disks. PAHs would have been a potentially important source of carbon on the early earth and on other habitable planets, both as an abundant source of prebiotic carbon and a component of haze formation, which could have provided a UV shield in anoxic atmospheres. Work was also performed on the difficulty of forming hydrocarbon aerosols without methane in extrasolar giant planet atmospheres, and large impacts on Solar System bodies.

Roadmap Objectives

- **Objective No. 1.1:** Models of formation and evolution of habitable planets
- **Objective No. 1.2:** Indirect and direct astronomical observations of extrasolar habitable planets
- **Objective No. 3.1:** Sources of prebiotic materials and catalysts
- **Objective No. 4.1:** Earth's early biosphere
- **Objective No. 7.2:** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	Mission Name (for class 1 or 2) OR Concept (for class 3)	Type of Involvement**
2	TPF	Planning Support,Background Research,Instrument/Payload Development

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
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3. Long-lead future mission / societal issues (e.g., far-future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co-I, Science Team member, planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

This project work supports the development of the Virtual Planetary Laboratory modeling suite, which will be used to identify and estimate the detectability of terrestrial planet characteristics to determine whether astronomical remote-sensing techniques will be valide for determining if a detected terrestrial planet is habitable or already supports life. This work is therefore background science for the TPF mission and will provide information that will be valuable for mission planning, including estimates of the minimum and optimum sensitivity, wavelength range and spectral resolution required for both TPF-I and TPF-C

Cross Team Collaborations

VPL Team member Dr. Monika Kress is collaborating with Don Brownlee (U. Wash NAI) and George Cody (CIW NAI) to study of the delivery of organics to habitable planets. They are working on a publication together

EPO Reports: Virtual Planetary Laboratory (JPL/CalTech)

Mars Planet Days

David Crisp served on a panel to provide an overview on the field of Astrobiology, and to answer questions about the detectability of biosignatures in the spectra of Mars and other planets, as a part of the public outreach event titled "Mars Planet Days" held in Milazzo Sicily on August 27-28, 2004.

Design a Planet

Nancy Kiang participated in the content review of the "Design a Planet" module of the AstroVenture Educational website for K-12. My contribution involves inputs of planetary parameters to achieve a habitable planet. I also provided recorded narration.

NAI Methane on Mars Workshop

Mark Allen was on the scientific organizing committee and chaired a portion of the workshop

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University Talk

Giovanna Tinetti presented a talk entitled: "Cloud microphysics: report on the Community Aerosol and Radiation Model" for the Department of Planetary Sciences (GPS), at California Institute of Technology in Pasadena, CA

Invited Talk

Giovana Tinettie was invited to present a talk entitled: "Characterizing extrasolar terrestrial planets with disk-averaged spectra" at the Institute d'Astrophysique de Paris, (IAP), in Paris, France,

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AstroVenture module

AstroVenture (http://astroventure.arc.nasa.gov) is an educational, interactive, multimedia Web environment highlighting NASA careers and astrobiology research in the areas of Astronomy, Geology, Biology and Atmospheric Sciences. VPL has provided budget as well as scientists support for the developing group to create the last module: ?Design a Planet.?

Astrobiology Online Course

This course was developed and is taught by teams of scientists, high-school teachers, and science educators. Over a 16-week period, participants connect to their classes and interact with each other and with the instructor. VPL has provided funds to subsidize the costs for offering 25 in-service teachers the opportunity to earn three graduate semester credits in an Internet-delivered ASTROBIOLOGY FOR TEACHERS course. The course was offered in Fall 2004 and clearly indicated funding support from VPL as part of the National Science Teachers Association Professional Development Institute and the National Teachers Enhancement Network (http://www.scienceteacher.org).

Astrobiology Presentation

Prof. Leslie Parr, SJSU Biology, invited Monika Kress to give a presentation on astrobiology to her graduate class on Evolution which meets on Wednesday nights from 6:30-9:20. Dr. Kress gave a lecture and then facilitated a discussion on the origin of the universe, stars, planets, the Earth and life.

Talk

Dr. Monika Kress gave a talk for the SJSU Biology Department's weekly seminar on Finding Martian Meteorites

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Talk

Monika Kress gave a talk for the SJSU Physics Department's weekly seminar on Hunting Meteorites in Antarctica

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Inivted Speaker and Session Moderator

Monika Kress was invited to be a speaker and session moderator at the Gordon Research Conference on Origin of Solar Systems. Dr. Kress moderated the session entitled: "Comparative Planetology: Is the Earth Unique?"

Talk

Monika Kress was invited to talk to AP Environmental Science class about doing research in Antarctica, and her career as a scientist at Mercer Island High School, Seattle, Washington.

Design a Planet

Dr. Monika Kress participated in "Design a Planet", an EPO effort with the VPL.

Journal Referee

Dr. Kress served as a referee on 5 manuscripts submitted to the journals Icarus (2), Astrobiology, Planetary & Space Science, andAdvances in Space Research

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Webpage Creation

Dr. Monika Kress is developing a personal webpage to highlight my research and teaching activities: www.physics.sjsu.edu/facstaff/mkress

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Bi-Lingual Talk

Dr. Antigona Segura-Peralta gave a talk entitled, "La Tierra alrededor de otras estrellas: detectando las se?ales de la vida" (Earth around other Stars: Detecting the signatures from life) at the Institute of Astronomy, National Autonomous University of Mexico (UNAM), in Mexico City, MX.

Bi-Lingual Talk

Dr. Segura-Peralta gave a talk entitled, "Determinacion de biomarcadores en planetas habitables alrededor de otras estrellas" (Characterization of biomarkers on habitable planets around other stars) at the Institute of Geophysics, National Autonomous University of Mexico (UNAM). Mexico City, MX.

Bi-Lingual Talk

Dr. Segura-Peralta gave a talk entitiled, "Vida en otros mundos" (Life on other worlds) to the Latin American Student Association at Penn State University, Pennsylvania.

Spanish Newspaper Interview

Dr. Antigona Segura-Peralta was interviewed by Diario Monitor, a newspaper in cirulation in Mexico City. Piece was entitled, "En busca de la vida en planetas distantes" (Looking for life on distant planets). The interview was performed by Thelma Gomez Duran.

Spanish Radio Station Interview

Dr. Segura-Peralta was interviewed for Radio Bienestar (Mexico City, MX), AM 1320, by Michelle Solana, Subject: "Search for life on other planets".

Spanish Radio Station Interview

Dr. Segura-Peralta was interviewed for Radio Bienestar (Mexico City, MX), AM 1320, by Eduardo Alvarez, Subject: Astrobiology.

Radio Interview

Dr. Victoria Meadows was Pre-taped for local radio station in New York. Topics: Navigator Program/extrasolar planets.

SETI On-Line Newspaper Interview

Dr. Meadows was pre-taped by Seth Shostak (SETI Institute) at the NAI General Meeting. Topics: TPF, extrasolar planets

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Consultant

Dr. Meadows was invited to consult and act as "talking head" For Discovery's "Alien Planet" TV special, on characterizing extrasolar planets.

JPL Interview

Dr. Meadows was interviewed for "Scientific Highlight" section for Org 700, in JPL 2004 Annual Report, characterizing terrestrial planets, VPL.

National Geographic Interview

Victoria Meadows was interviewed for National Geographic Article, "Searching The Stars for New Earths", Links between recent discoveries in our own solar system, and the newly discovered extrasolar planetary systems. Dr. Meadows provided conceptual graphics for the article as well.

Research Interview

Dr. Meadows provided the NOVA Origins series, several interviews, graphics material, and a TV interview that was not included in the final program. Topics included: TPF, spectroscopic characterization of planets.

Scientific Input

Dr. Vikki Meadows provided scientific input, including synthetic spectra to Matt Bobrowkski of STScI for participation in EPO products as tie-ins to the NOVA Origins series.

Newspaper Interview

Dr. Meadows was interviewed by Reuters on Earth analogs for early Earth life and the ramifications for extrasolar planet characterization, during a VPL field trip to a freshwater stromatolite site in the Chihuahuan Desert.

On-Line Science Website

Dr. Meadows participated in the content review of the "Design a Planet" module of the AstroVenture Educational website for K-12. Her contribution involves inputs on star-planet characteristics for habitability, as well as a recorded narration.

Video Narration

Dr. Meadows narrated an Astroventure video on VPL and provided material for 2-pager on habitable planets. (Video prototype is at: http://quest.arc.nasa.gov/test/AV/DAP/movie.html)

On-Line Website

Dr. Meadows helped review the Astroventure Build a Planet module draft. This module will be implemented on the website later this year.

Astronomy Now Interview

Dr. Meadows gave a phone interview on VPL with journalist, which resulted in 2-page article in VPL in Astronomy Now.

Scientific Games Prototype

Dr. Meadows is working with Scholastic Publishing for a version of the Lifefinder game and featured scientist interview.

Talk

Dr. Meadows was invited by Sally Ride to give a talk on characterizing extrasolar terrestrial planets at the Sally Ride Educator's Institute in La Jolla, but the entire workshop was cancelled.

Talk in Australia

Dr. Meadows gave a talk entitled, "The Virtual Planetary Laboratory: Towards Characterizing Extrasolar Terrestrial Planets", at The Australian Center for Astrobiology, Macquarie University, Sydney. She was Invited by Malcolm Walter.

Talk at CIW

Dr. Meadows gave a talk on "Synthetic Terrestrial Planet Spectra in the Mid-Infrared", at the TPF-Science Working Group, at CIW. She was invited by Steve Unwin of JPL.

Seminar Talk

Dr. Vikki Meadows gave a talk entitled, "The Virtual Planetary Laboratory: Towards Characterization of Extrasolar Terrestrial Planets", at the IPAC Seminar Series, held at California Intitute of Technology.

Talk

Dr. Meadows gave a talk entitled, "Characterizing Extrasolar Terrestrial Planets". The presentation detailed the links between TPF and Earth Science and was presented to Ghassem Asrar, NASA HQ. Dr. Meadows was invited by Dan Coulter of JPL.

Talk

Dr. Meadows was invited by Sara Seager of CIW to give a talk on, "Characterizing Extrasolar Terrestrial Planets". The talk was given at the NAI Biosignatures Workshop at IPAC in California Institute of Technology

Talk

Vikki Meadows as invited to give a talk entitled, "The Virtual Planetary Laboratory: Towards Characterizing Extrasolar Terrestrial Planets", at the Renssalaer Polytechnic Institute, Troy, NY It was for their Astronomy Seminar Series. She was invited by Jim Ferris of RPI.

Talk

Vikki Meadows gave a talk entitled, "Towards Understanding Extrasolar Planet Environments", invited presentation to the NRC panel on the "Limits of Life" at UC-Irvine. Dr. Meadows was invited by David Smith.

Service

Dr. Victoria Meadows served in the Scientific Organizing Committee for the TPF/Darwin International Conference "Dust Disks and the Formation, Evolution and Detection of Habitable Planets", in San Diego, CA.

Service

Dr. Meadows served on the Science Organizing Committee for the NASA Astrobiology Institute General Meeting, held in Boulder, Colorado.

Session Chair

Dr. Meadows served as a session chair at the NASA Astrobiology Institute General Meeting, for session on "Are Habitable Planets Common In The Universe?"

Talk

Dr. Vikki Meadows gave talk entitled, "The Spitzer First Look Survey - Ecliptic Plane Component ", at the Division of Planetary Sciences Meeting, in Louisville, Kentucky. Dr. Meadows was invited by Dale Cruikshank of NASA Ames.

Service

Dr. Meadows served as a session co-chair for session 42, Spitzer Space Telescope Special Session, at the 36th Annual Meeting of the Division of Planetary Sciences, in Louisville, KY.

Service

Dr. Meadows was invited to serve on a Scientific Organizing Committee for NASA HQ Code Y/Code S joint workshop on Earth Sciences and Astrobiology. Working with Michael Meyer, Michael New and Woody Sullivan, NASA HQ.

This activity has subsequently been put on hold.

Invited to Review

Dr. Meadows was invited to review a 70 page report on "The Astrophysical Context for Life" for the National Academy of Sciences Committee on the Origin and Evolution of Life.

Proposal Referee

Dr. Meadows was asked to referee two proposals to the NASA Astrobiology Institute Strategic Fund, one on extrasolar planet searches, the other on spectrograph development for astrobiology.

Invited to join

Dr. Meadows was invited to join the NRC panel on the Limits of Organic Life In Planetary Systems but declined the invitation due to workload.

Service

Vikki Meadows co-chaired the NAI Biosignatures Workshop with Sara Seager.

Talk

Dr. Monika Kress gave a talk on Antarctic meteorites for the NASA Ames Astrochemisty Laboratory

Collaborations

As part of the new VPL EPO program and working with new EPO lead, Doris Daou, Vikki Meadows have set up EPO collaborations with the Astroventure project (Ames), for their "Build Your Own Planet" interactive web module, the California Academy of Sciences for their scientist profiles exhibit, Griffith Observatory and UCLA for a Distinguished Speaker Series in Astrobiology, and the U. of Arizona, for their Teacher's Online Course in Astrobiology

Service

Dr. Vikki Meadows co-chaired the TPF-C Biosignatures Workshop with Paul Falkowski, which was held at Spitzer Science Center at California Institute of Tecnology in Pasadena, CA.

Publications: Virtual Planetary Laboratory (JPL/CalTech)

There are **96** publication entries for the Virtual Planetary Laboratory (JPL/CalTech)

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Name:Maggie Turnbull
Project Role: Collaborator
Institution: Arizona State University
Projects | Publications | Update Profile

Name:Thangasamy Velusamy
Project Role: Co-Investigator
Institution: Jet Propulsion Laboratory
Projects | Publications | Update Profile

Name:Jason Weibel
Project Role: Postdoc
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Projects | Publications | Update Profile

Project Reports: NAI Central

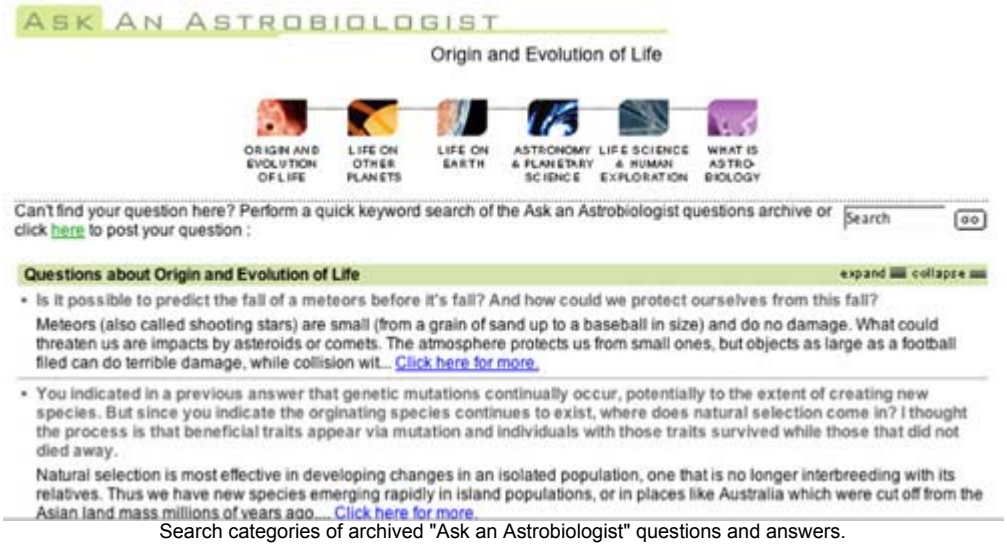
Ask an Astrobiologist

Project Investigator: David Morrison

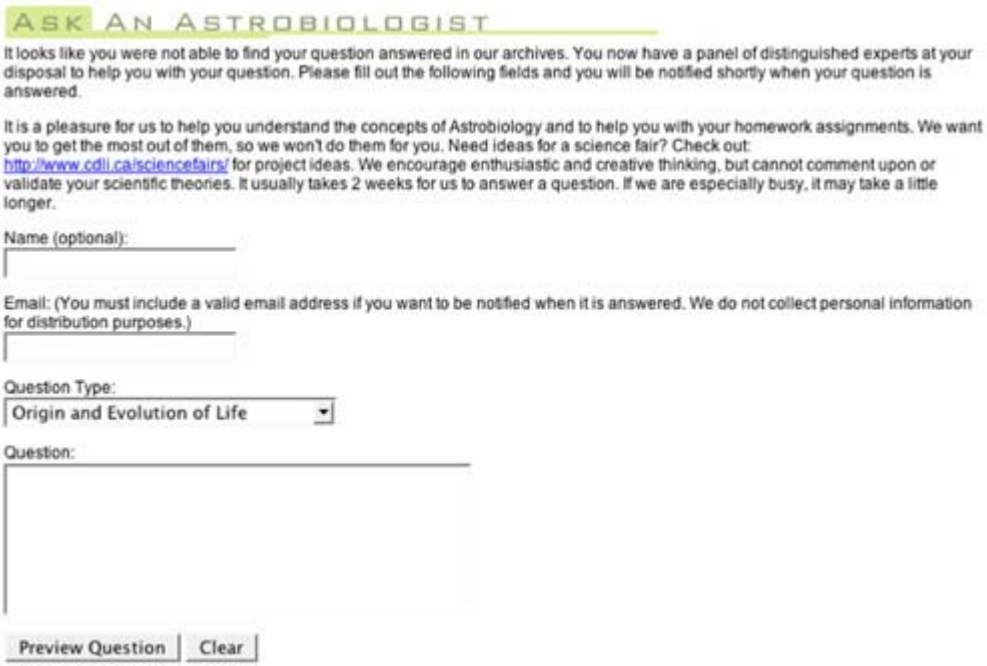
Project Progress

The "Ask an Astrobiologist" section of the website, containing more than 700 answers to public questions received over the past 5 years, is the most frequently accessed part of the NAI website. This feature allows users to submit questions directly and receive an e-mailed response. The site received more than 200 questions last year on topics ranging from the possibilities of life on Mars and Titan to the requirements for becoming an astrobiologist. The most frequent questions dealt with life on Mars (not surprising given the MER publicity), the Miller-Urey Experiment (a subject included in many high school and college biology courses), and the requirements for habitability of other worlds. Other classes of frequently asked questions were on biological evolution, the SETI Institute, and the life-support requirements for humans in space or on Mars. There are also many questions received about elementary astronomy, from the Big Bang to black holes, and about past NASA programs such as Apollo. While no data are collected on users, it is possible to assess the questioners by vocabulary and language of the posted questions. It appears that the users range from young students to post-graduate members of the astrobiology community.

David Morrison, the NAI Senior Scientist, addresses his answers accordingly. The responses he writes are brief, usually no more than 150 words, often with web references for further information. All answers are archived and searchable by future users. Webpages are posted and maintained by Marco Boldt. To visit this section of our website go to http://nai.arc.nasa.gov/astrobio/index.cfm



Search categories of archived "Ask an Astrobiologist" questions and answers.



ASK AN ASTROBIOLOGIST

It looks like you were not able to find your question answered in our archives. You now have a panel of distinguished experts at your disposal to help you with your question. Please fill out the following fields and you will be notified shortly when your question is answered.

It is a pleasure for us to help you understand the concepts of Astrobiology and to help you with your homework assignments. We want you to get the most out of them, so we won't do them for you. Need ideas for a science fair? Check out: http://www.cdli.ca/sciencefairs/ for project ideas. We encourage enthusiastic and creative thinking, but cannot comment upon or validate your scientific theories. It usually takes 2 weeks for us to answer a question. If we are especially busy, it may take a little longer.

Name (optional):

Email: (You must include a valid email address if you want to be notified when it is answered. We do not collect personal information for distribution purposes.)

Question Type:

Origin and Evolution of Life

Question:

Preview Question | Clear

Post your own question not found in the archives and have it answered by an astrobiologist.

Mission Statement Goals

- **Goal:** training the next generation of astrobiology researchers
- **Goal:** supporting outreach by providing scientific content for K-12 education programs, teaching undergraduate classes, and communicating directly with the public

Astrobiology Field Guide

Project Investigator: Daniella Scalice

Project Progress

Conceived several years ago by NAI's then Director Barry Blumberg, and NAI's then E/PO Manager Krisstina Wilmoth, the goal of Astrobiology Field Guide (AFG) is to engage 'students of all ages' with the ongoing field expeditions of today's astrobiologists as they explore the ends of the Earth searching for clues to life's origin, evolution, and distribution in the Universe. The Astrobiology Field Guide will be a digital media tool to enable users in museum settings to explore virtually selected geographic ‘hotspots’ on the Earth that represent NAI field research sites. The user will navigate a virtual globe to the hotspot of their choice, then interact with words and images to experience both the research itself and the process of engaging in it.

This year, Daniella Scalice participated in a collaboration with a scientist from the Australian Centre for Astrobiology, and a digital animator to create an animated demonstration of this product concept. This demonstration focuses on one hotspot, the Pilbara Desert in Western Australia, highlighting how researchers there are interpreting the exquisitely preserved, 3.4 billion year old sedimentary rocks to constrain competing hypotheses which could describe the potential biogenicity of structures contained within them.

This animation will be used to demonstrate the product concept to informal education experts who will provide feedback on concept and product design. This advice will inform future efforts to fabricate the AFG, an effort that will provide impetus for collaboration among NAI E/PO Teams. E/PO Leads can partner with team scientists to bring their field sites to life in the AFG.

Mission Statement Goals

- **Goal:** supporting outreach by providing scientific content for K-12 education programs, teaching undergraduate classes, and communicating directly with the public

Collaborative Tools (CT) and the CT Working Group (CTWG)

Project Investigator: Estelle Dodson

Project Progress

Designed as a virtual institute with distributed members across the country and even around the globe, NAI has explored various technologies to support scientific collaborations. During the last year, Estelle Dodson reevaluated the approach to collaborative tools. After five years of observing usage of the tools, she found significant differences in each group, resulting in a wide variety of requirements. As a result, NAI now focuses on providing a suite of tools and expertise and training in how to best select and adopt the tools to fit the usage patterns of a research group. NAI attempts to customize and tailor tools to individual teams and groups whenever possible to allow for the most flexibility in meeting needs and requirements for unique collaborations. A crucial part in the adoption process is the CTWG made up of members of the NAI teams with a wide range of expertise from information technologies to organizational behavior and graphic design. This highly skilled group shares knowledge about products, tests hardware and software and contributes to the community-wide adoption of the collaboration tools.

The two most commonly used tools in the NAI community have been WebEx and the **Polycom videoconferencing systems**. Polycom is one of the industry leaders in videoconferencing systems, providing high quality, simple, reliable, protocol based (H323 and H320) videoconferencing capabilities. Polycom systems have been provided to each NAI Team, enabling simple and high quality videoconferencing capabilities between all the teams at any time. In some cases, Polycoms or the ViaVideo desktop videoconferencing systems have been provided to co-Investigators at additional institutions, expanding the possibilities for both cross-team and intra-team collaborations. Support of ISDN lines for the Polycom systems was discontinued this year, and use of Internet Protocol (IP) connections were substituted after quality and reliability testing were completed. IP connections have been successful, even surpassing the quality of ISDN in some cases. This shift resulted in a significant savings for the Institute. ISDN connections are still supported through the Multi-point Controller Unit Bridge at Ames, but the lines are no longer paid for by NAI.

WebEx is a real-time browser based meeting application that allows people to share files and applications from any computer on the internet. With WebEx, shared documents for a meeting are cached locally on each participant's machine, so that when a "presenter" advances a slide, image or document, all the other sites' slides are advanced instantly, avoiding latency issues seen in comparable software. This has worked extremely well in the virtual seminar series. WebEx also provides real-time chat and polling capabilities, video streaming, application sharing, desktop sharing and web sharing. With application sharing and desktop sharing, participants can use each other's software or operating system remotely. This allows for real-time collaboration on authoring papers, analyzing data, running experiments etc.

Mission Statement Goals

- **Goal:** exploring new approaches using modern information technology to conduct interdisciplinary and collaborative research amongst widely-distributed investigators

Conferences and Workshops

Project Investigators: Shige Abe, Edward Goolish

Project Progress

During this past year the NAI supported numerous workshops, conferences and meetings, through its Conference and Workshop Fund, as an additional mechanism for growing the overall community of astrobiology and for advancing the specific strategic goals and objectives of the Institute. These activities serve to train future astrobiologists, cultivate relationships with other international astrobiology organizations, and to advise NASA in its mission of exploration. During this past year NAI Central was instrumental in the success of, among others, the following activities:

- **Gordon Conference on Applied and Environmental Microbiology**; July 2005
- NAI Co-Sponsored two sessions of a **Short-Course on Planetary Protection**, 2004 and 2005
- **Terrestrial Planet Finder Biosignatures Workshop** (Summer 2005). Initiated by Charles Beichman, this NAI-supported workshop is providing direct input to NASA mission planning
- **The Earth System Processes 2 Meeting** (Calgary, August 2005): NAI supported two sessions related to astrobiology (including a session on 'The Future of Solar System Exploration' organized by Jack Farmer), competitive student travel grants (announced in *Nature*), and also arranged for decreased registration costs for NAI Members

Efforts are already underway by NAI Central in the planning and funding of these important activities for late 2005 and 2006:

- **Protostars and Planets V** (October, 2005, Hawaii), with a special workshop on disk chemistry and evolution to support the NAI's Collaborative Science Plan
- **Molecular Geomicrobiology: From Genes to Microbes**; December 2005, San Francisco (Co-sponsored by The Mineralogical Society of America, Jill Banfield and Ken Nealson Co-organizers); NAI Cental is supporting the travel of 20 students to this interdisciplinary event
- **International Conference on Alpine and Polar Microbiology**; March 2006, Innsbruck, Austria

Mission Statement Goals

- **Goal:** carrying out, supporting and catalyzing collaborative interdisciplinary research
- **Goal:** training the next generation of astrobiology researchers
- **Goal:** providing scientific and technical leadership on astrobiology investigations for current and future space missions
- **Goal:** exploring new approaches using modern information technology to conduct interdisciplinary and collaborative research amongst widely-distributed investigators
- **Goal:** supporting outreach by providing scientific content for K-12 education programs, teaching undergraduate classes, and communicating directly with the public

Cooperative Agreement Notices (CAN)

Project Investigator: Edward Goolish

Project Progress

During this past year Ed Goolish prepared and released on schedule NAI's fourth Cooperative Agreement Notice (CAN Cycle-4). Working in collaboration with NASA HQ, the NAI developed this document during early 2005 and met its release target date of July 25, 2005. Proposals will be due October 28, with selections expected in the April/May timeframe of 2006. This standard of timeliness continues to build-on the NAI's reputation for the regular and dependable release, review, selection and funding of its member's work.

Mission Statement Goals

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Directed Discretionary Fund

Project Investigators: Shige Abe, Edward Goolish

Project Progress

The NAI has established a Directed Discretionary Fund (DDF) to support, for one year, research projects that are unlikely to achieve support through other avenues and that address the scientific and collaborative goals of the Institute, particularly submissions that benefit multiple teams.

Projects funded in 2005:

- **Tektite Collection and Analysis at Southeast Asian Airbust Site** – J. Wasson, UCLA - to examine the hypothesis of an airburst over SE Asia, 0.77 Ma ago, by comparing the chemical and isotopic compositions of layered tektites with those of the local soils

- **Ecosystem Function and Genome Evolution in Desert Thermal Springs** – J. Siefert, Rice University – examining the effects of nutrient cycling and stiochiometric constraints on ecosystem function and genome evolution

- **Horizontal Gene Transfer Special Publication** – T. Barkay, Rutgers University - supported free online access in Nature Reviews Microbiology to papers resulting from an NSF and DOE sponsored workshop on Horizontal Gene Flow in Microbial Communities

- **Enabling Astrobiology on SOFIA with Grisms** – D. Jaffe, L. Allamandola, ARC - funding for a set of silicon grisms for the SOFIA telescope to permit quantitation and identification of interstellar molecules and grains

- **Development of a New Indicator of Formation Temperature in Carbonate Minerals Using 13C-18O Isotope \"Clumping\"** - E. Young, UCLA – hardware development for a MAT 253 stable isotope ratio mass spectrometer system to determine simultaneous collection of isotope ratios

- **Collaborative Field Campaign with the Kamchatka Microbial Observatory** – A. Colman, CIW – microbiological and geochemical research in a hot spring environment

NAI Central facilitated rapid review and approval of the 2005 DDF proposals, and efficient disbursement of funds, enabling researchers to create new cross-institutional and international collaborations, increasing public awareness of astrobiology research, developing valuable community outreach programs and augmenting other funding sources to provide additional opportunities for data collection, yielding greater returns on the research investment.

Mission Statement Goals

- **Goal:** carrying out, supporting and catalyzing collaborative interdisciplinary research
- **Goal:** training the next generation of astrobiology researchers

Education and Public Outreach

Project Investigator: Daniella Scalice

Project Progress

NAI Central is often the first point of contact for enquiries regarding astrobiology education, and is in the position to field requests for materials, provide references to scientists and educators within NAI for outside organizations, support individual scientists' E/PO endeavors as well as those of the E/PO working group, and represent astrobiology and the NAI to the larger NASA education community. Examples of this work include advising and liaising with the producers of an upcoming astrobiology public television series, attending the NASA Origins and Solar System Exploration Education Forums' monthly telecons, advising an NAI Co-I on his E/PO plans for another grant to which he was applying, and managing the loan of NAI Central's video equipment among several Lead Teams for their outreach products. NAI Central also manages the astrobiology E/PO events and news on the NAI website.

NAI Central also coordinates the NAI E/PO Working Group. This group meets once monthly via tele/videocons where all manner of topics are raised. This year, the E/PO Leads have discussed professional development issues such as evaluation, collaborating with other NASA programs such as the Explorer Schools, E/PO funding opportunities, E/PO representation on the NAI Executive Council, and planning for E/PO at the NAI 2005 General Meeting. NAI Central takes responsibility for all reporting requirements to Headquarters, and coordinates, reviews, and edits E/PO input to the NAI Annual Report.

The NAI E/PO Working group met several times via telecon this year to prepare for the NAI 2005 General Meeting. As a group, they brainstormed seven oral presentation abstracts for the Scientific Organizing Committee to consider placing within the three or four open slots available to E/PO. Because of the caliber of these abstracts, all seven were chosen for presentation, one within each scientific theme at the meeting. Individual team projects were presented as posters, and an E/PO demonstration area was hosted for three evenings during the poster sessions.

NAI Central, because of its contact with other NASA mission E/PO programs and external organizations, can and does bring collaborative opportunities to the E/PO Working Group. This year, NAI Central brokered relationships for its Lead Teams with the Disney IMAX film Aliens of the Deep, the traveling exhibit Alien Earths from the Space Science Institute, and The Science Study of Navajo Astronomy from ArtReach Int'l. In March 2006, NAI Central sponsored a professional development workshop for the E/PO Working Group focused on best practices in informal education. The workshop was centered around the emerging education program for Alien Earths, and was led by the exhibit's design team.

This year, NAI Central sponsored the E/PO Collaborative Fund. Designed to promote collaboration between the teams and provide room for expansion of existing programs as well as innovation, the Fund offered $100,000 to the E/PO Working Group. NAI Central served to coordinate reviews for the proposals, and manage transfer of funds to various sites. Through the Collaborative Fund, E/PO Leads enriched their teams' programs by providing materials and university credits to teachers attending their workshops, bringing astrobiology education speakers into professional science meetings, providing professional development for E/PO Leads, and increasing exposure to astrobiology curriculum materials and outreach products. Fiscal Year 2006 will see the expansion of the Fund into two opportunities: The Collaborative Fund, and the Team Fund, each at $100,00.

Krisstina Wilmoth is the responsible civil servant for the entire NAI E/PO Program, and provides advocacy, oversight, and vision. Daniella Scalice manages all the activities of the working group as described above.

Projects Managed at NAI Central

Astrobiology Education Poster (http://nai.arc.nasa.gov/poster/index.cfm)

Based on their interactions with teachers in various venues, the NAI E/PO leads conceived the idea of creating a poster for classrooms with several activities on the back. At that time, it made sense for NAI

Central to coordinate the production of this product, and organize input from the individual teams. A poster is a type of educational product that is useful in classrooms to introduce or highlight specific content. A teacher who is interested in teaching astrobiology can use this poster in several ways without carving large amounts of time from their already overburdened curriculum.

Bearing that in mind, NAI Central and the SETI Institute designed this poster to include eye-catching graphics, an extended background reading, and three field-tested, classroom-ready activities. The distribution plan was designed to align with the shorter-term interaction with the material one expects when that material is presented in a poster. The production team employed a “shallow, broad” distribution plan that favored exposure to the product over in-depth training with it. The product was completed, and distribution began in 2004. 59,000 copies were delivered to teachers through four professional journals:

- The American Association of Physics Teacher’s The Physics Teacher
- The National Science Teacher’s Association’s Science Scope
- The National Science Teacher’s Association’s The Science Teacher
- The International Planetarium Society’s The Planetarian

An additional ~20,000 copies have been distributed by request to NAI’s 16 Teams, numerous teachers and small museums, and various NASA-affiliated informal and formal education contacts: National Park Service, California Science Teachers Association, State of Hawaii Libraries, Girl Scouts of America, Space Place, NASA Explorer Schools, National AfterSchool Association, NASA Aerospace Education Specialist Program, George Mason University, University of Texas, Dallas, Council for Exceptional Children, Astrobiology Journal, NASA Solar System Education Forum teacher packets, Utah “Expanding Your Horizons” Program, Pacific Science Center, Harvard-Smithsonian Center for Astrophysics, California Academy of Sciences, National Science Teacher’s Association, Astronomical Society of the Pacific, Oregon Science Teacher’s Association, Ohio Space Grant Consortium, and the University of Connecticut.

Daniella Scalice coordinated the content for the poster, managed it’s field testing, and planned and executed its distribution. Julie Fletcher designed and managed the production of the poster.

Astrobiology Field Guide

Conceived several years ago by NAI’s then Director Barry Blumberg, and NAI’s then E/PO Manager Krisstina Wilmoth, the goal of Astrobiology Field Guide (AFG) is to engage 'students of all ages' with the ongoing field expeditions of today's astrobiologists as they explore the ends of the Earth searching for clues to life's origin, evolution, and distribution in the Universe. The Astrobiology Field Guide will be a digital media tool to enable users in museum settings to explore virtually selected geographic ‘hotspots’ on the Earth that represent NAI field research sites. The user will navigate a virtual globe to the hotspot of their choice, then interact with words and images to experience both the research itself and the process of engaging in it.

This year, NAI Central E/PO staff participated in a collaboration with a scientist from the Australian Centre for Astrobiology, and a digital animator to create an animated demonstration of this product concept. This demonstration focuses on one hotspot, the Pilbara Desert in Western Australia, highlighting how researchers there are interpreting the exquisitely preserved, 3.4 billion year old sedimentary rocks to constrain competing hypotheses which could describe the potential biogenicity of structures contained within them.

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Other Projects with NAI Central Contribution

Astro-Venture (http://astroventure.arc.nasa.gov) is an educational, interactive, multimedia Web

environment focusing on astrobiology. Developed by the Office of Education at NASA Ames Research Center and funded in part by NAI Central, this educational site, designed for students in grades 5 - 8, allows students to role-play NASA occupations to learn about what makes a planet habitable to humans. Astro-Venture is divided into five sections: Astronomy, Biology, Geology, Atmospheric Sciences, and Design A Planet. Each of the first four sections includes on-line multimedia modules and lessons. NAI provides scientific review and experts for webcasts and webchats. This year, the final three multimedia modules were completed and launched: Geology Mission, Biology Mission, and the long-anticipated Design a Planet. In addition, all four educator guides were revised based on feedback from Space Science reviews and a nation-wide pilot test conducted in Fiscal Year 2004. The Astro-Venture team led numerous workshops with both teachers and students throughout the country including workshops with first and second-year NASA Explorer School teachers. Astro-Venture was recognized with a SpaceAct Award and a Webby Worthy Award.

Astrobiology for Teachers: An Online Graduate Course

NAI supports teachers from across the US to enroll in a semester-long graduate course in astrobiology. The online course is one of several offered by Montana State University in conjunction with the National Science Teacher Association. The two main goals of the course are (1) to provide information on the central concepts related to the field of astrobiology and (2) to provide experiences with using student-centered and inquiry-based curriculum materials for teaching astrobiology that are aligned with the National Science Education Standards. The course materials are astrobiology texts in common use, recent peer-reviewed journal articles related to astrobiology, and a specially designed set of lab activities, Life in the Universe Activities Manual published by Prather, Offerdahl, & Slater, 2003, Addison Wesley. While the course is asynchronous which allows participants to complete the work on their own time schedules, teachers must log in for daily science and pedagogy discussions and to complete several group projects during the semester. The course is evaluated summatively using the following data sources: (i) teacher-participant performance in the course overall; (ii) teacher-participant performance on exams; and (iii) teacher-participant comments on the course from the teachers' electronic community discussion groups. The course was taught in the Fall 2003, Spring 2004, Fall 2004, and Fall 2005 semesters, and 24 and 23 teachers completed the course, respectively. Information regarding upcoming courses can be found at http://btc.montana.edu/ceres/astrobiology/.

Alien Earths: Traveling Museum Exhibit

The Space Science Institute (SSI) of Boulder, CO led the development of Alien Earths, a 3000 square foot traveling museum exhibit, with funding from NSF and several NASA partners. NAI Central has provided funding to support the education and professional development program associated with it. Exhibit content focused on the search for life and habitable planets around distant stars. The exhibit opened at the Lawrence Hall of Science (LHS) in Berkeley, California in February 2005, and is expected to visit at least seven more venues in the next few years, reaching hundreds of thousands of people.

Only weeks after the opening of the exhibit at LHS, the education team for the Alien Earths exhibit conducted a two-day, on-site workshop on informal science education for NAI E/PO leads, which was sponsored by NAI Central. The workshop led to specific involvement in Alien Earths education at near-by host-venues (e.g. Louisville KY in the Spring of 2006).

NAI support and on-going interactions between SSI and NAI educators and scientists have resulted in the development of the educational products and programming for the Alien Earths exhibit.

With the impending launch of a new version of the Alien Earths Education website, additional consultations and reviews with NAI educators and scientists is expected. In particular, we envision making use of NAI's Ask-an-Astrobiologist web-based utility. We hope to make an arrangement with Dr. David Morrison that can provide special access and quicker turn-arounds for questions submitted by museum educators from Alien Earths host sites.

Voyages Through Time: High School Curriculum

In partnership with NAI, the National Science Foundation, the California Academy of Sciences, and San

Francisco State University, the SETI Institute has developed Voyages Through Time (VTT), a standards-based integrated science curriculum for high school centered on the unifying theme of evolution. Scientists, teachers, curriculum writers, and media specialists have created six CD-ROM modules that integrate astronomical, geological, and biological sciences. The sequence of lessons in each module is designed to promote students' understanding of science and skills as defined by the National Science Education Standards and Benchmarks for Science Literacy. The six modules, Cosmic Evolution, Planetary Evolution, Origin of Life, Evolution of Life, Hominid Evolution, and Evolution of Technology, use the constructivist approach of engage, explore, explain, elaborate, and evaluate (Biological Sciences Curriculum Study, 1996) as an instructional framework. NAI Central funded the VTT National Field Test and a CD-ROM sampler of the curriculum. The National Field Test took place from September 2001 through July 2002 in over 80 classrooms in 28 states. Teacher feedback was very positive, and the curriculum was revised following the national test evaluation summary reports. NAI Central funded the revision and production of the CD-ROM samplers of the curriculum. The samplers provide astrobiology activities for the classroom. Over 3000 free CD-ROM samplers were distributed at science teacher conferences, science conferences, workshops, and short courses this year. The curriculum was published in August 2003. More information about VTT can be found at http://www.voyagesthroughtime.org.

Mission Statement Goals

- **Goal:** supporting outreach by providing scientific content for K-12 education programs, teaching undergraduate classes, and communicating directly with the public

Executive Council

Project Investigator: Krisstina Wilmoth

Project Progress

The NAI's Executive Council (EC) is made up of the Principle Investigators of each of the 16 research teams plus the Executive and Scientific Directors of the NAI. Additional participants include an elected representative from the Education and Public Outreach Working Group, currently Emily Co-Babe-Ammann, and the rest of the NAI's senior staff including the two Assistant Directors and the Senior Scientist. The council meets monthly, by videoconference 8-9 times per year and in person the other 3-4 times. The Executive Council:

- Initiates discussions and provides timely advice on issues such as research objectives, mission opportunities, and technology development priorities;
- Considers and recommends action on proposals to form Focus Groups and other similar bodies;
- Considers and recommends action on proposals for international partnerships;
- Evaluates and recommends action on unsolicited proposals to the Institute Strategic Fund; and
- Comments on the conduct of the Institute, considering and recommending metrics and evaluative approaches to assess the NAI's progress towards its objectives.

Meetings of the EC are generally open though may include closed sessions for voting on proposals or other sensitive topics. In person meetings of the EC often include an in camera session for the Principle Investigators or their delegates to discuss matters of interest to them. Other regular invitees to the meetings include representatives from the Astrobiology Program, the Exobiology Program, and the Earth Science Division at NASA Headquarters as well as the international affiliates and associates of the NAI.

Activities:

NAI Central coordinated 11 meetings of the EC in 2005. Three of the meetings were in-person and hosted by an NAI team. September '04 was at the University of Rhode Island, December '04 was in San Francisco, California, and April's meeting was in Boulder, Colorado. The NAI Directors, Rose Grymes and Bruce Runnegar, and the Assistant Director for Communication and Technology, Krisstina Wilmoth, prepare the agendas and chair the meetings. Technical support for videoconferencing is provided by Mike Fitzjarrell and Diane Hawks. Technical support for online meetings and real-time meeting coordination is provided by Estelle Dodson. Logisitics for onsite meetings are supported by Jeni Joiner. Webpage materials are posted and maintained by Marco Boldt. Minutes for 2005 meetings were kept by Karen Bradford*.

Mission Statement Goals

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Focus Groups

Project Investigator: Edward Goolish

Project Progress

During this past year the following Focus Groups were on tenure with the NAI: Early Earth, Evogenomics, Europa, Titan, Virus, Mars (transitioning to new Chair), Impacts, Astronomy, and Astrobiotechnology. Ed Goolish continued to be responsible for all of the administative aspects of the Focus Groups including their review, approval, and funding. Julie Fletcher collected reports for the NAI Annual Report and Marco Boldt managed their pages on the NAI website (http://nai.arc.nasa.gov/about/focus_groups.cfm). NAI Central organized breakout sessions of nearly all the Focus Groups at the NAI 2005 biennial meeting of the Institute. These miniworkshops were a popular and important element of the conference. Throughout the year, NAI Central received requests from the current Focus Groups for funding to support workshops and other activities. These requests for activities received prompt attention and rapid turnaround. As in previous years, every effort was made to meet the schedule needs of the organizers.

Of particular note during this past year was a workshop and field expedition organized by the Virus Focus Group in the Summer of 2004. Sixteen researchers gathered in Mammoth Lakes, California for a 'NAIVIFOG' workshop, followed by concerted and collaborative sample collection at hot springs in the Long Valley Caldera and on Paoha Island in Mono Lake. The results of this meeting, and subsequent analyses, were published in the August 2005 issue of the journal Astrobiology.

This past year also saw another in a series of NAI 'virtual' workshops, sponsored by the NAI Astronomy Focus Group. Entitled, *Atmospheric Biomarker Signatures*, this meeting was organized by Co-chairs: Sara Seager and Victoria Meadows (December 1-2 2004, Carnegie DTM). The important goal of this workshop was to determine global-scale biomarkers from past and present Earth, and their detectability in disk-averaged planetary spectra. The outcome of this working meeting is directly applicable to the definition of requirements for NASA's planned Terrestrial Planet Finder (TPF), and similar missions. This workshop was held at the Carnegie Institution of Washington (hosted by NAI Carnegie) and at Caltech (hosted by NAI VPL). These two nodes were linked by point-to-point videocon and WebEx to successful bring together NAI Members from across the U.S.

Other significant activities of the NAI Focus Groups during this past year, made possible by the efforts of NAI Central, were:

- Impacts Focus Group Field Trip, to acquire materials from the Permian-Triassic (P/T) boundary in Meishan, China (October, 2004)

- Astrobiotechnology Focus Group workshop on Mars Astrobiology Technology (September 8-10, 2004; Carnegie Institution of Washington)

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Interdisciplinary Exploration Science (IES) Preproposal Workshop Webcast

Project Investigator: Estelle Dodson

Project Progress

On April 19th 2005 NAI webcast the NASA IES Preproposal Conference Workshop from Washington DC. Estelle Dodson coordinated the entire webcast from inception to implementation and was the sole producer of the live event including the networking, computer, camera and sound set-up and the audio/video and multimedia mixing of the live content feed. This enabled researchers to watch the meeting and use the information for writing grant proposals without the time and cost of traveling to the meeting location. Researchers were able to connect from their desktop and watch the meeting using high-resolution real-time streaming video, with close-ups of the presenters, slides and overhead projector images and hear high fidelity sound taken directly from the individual microphones. The webcast was four hours in duration and had over forty viewers connected, representing a potential savings of thousands of dollars in travel costs and valuable work time.

Mission Statement Goals

- **Goal:** exploring new approaches using modern information technology to conduct interdisciplinary and collaborative research amongst widely-distributed investigators

Josep Comas i Sola International Summer School in Astrobiology

Project Investigator: Krisstina Wilmoth

Project Progress

In partnership with the Centro de Astrobiología (CAB,) NAI Central has established an interdisciplinary summer school. The school is intended to bring together students and researchers from Europe and the U.S. to experience a focused workshop type environment on topics relevant to astrobiology. The school is held at the *Universidad Internacional Menéndez Pelayo* campus in Santander, Spain. The topics vary each year and are chosen to engage the participants in timely issues in astrobiology. NAI Central provides travel support for the American faculty and travel and logistics for NAI students to participate.

The third year of the school was entitled "Titan, Pre-biotic Chemistry, and the Origin of Life," and featured five special lecturers: Athéna Coustenis, Observatoire de Paris; Jesús Martínez Frías, Centro de Astrobiología; Robert Hazen, Carnegie Institution of Washington; Jonathan Lunine, University of Arizona; and John C. Zarnecki, Open University, U.K. Thirty-seven participants attended this year. There was also a field trip led by Jesús Martínez Frías and Bruce Runnegar. Information regarding future courses will be available on the NAI website.

2005 Josep Comas i Solà International Summer School Participants

Field trip discussion

Mission Statement Goals

- **Goal:** training the next generation of astrobiology researchers
- **Goal:** providing scientific and technical leadership on astrobiology investigations for current and future space missions
- **Goal:** supporting outreach by providing scientific content for K-12 education programs, teaching undergraduate classes, and communicating directly with the public

Methane on Mars Virtual Workshop

Project Investigator: Krisstina Wilmoth

Project Progress

Beginning with a Director's Seminar in March 2005, NAI organized a series of activities to discuss the issues and ideas behind the recent findings of methane on Mars. Coordinated by a four person planning committee, a virtual workshop was held on May 18, 2005. Mark Allen of Jet Propulsion Lab, Jim Lyons of University of California Los Angeles, Mike Mumma of Goddard Space Flight Center, and Bruce Runnegar of NAI devised an agenda and an invitation list of experts in a broad range of relevant scientific areas. Scientists participated from four locations around the globe. Ames Research Center (ARC) hosted west coast participants. Participants from the eastern part of the U.S. attended from Goddard Space Flight Center (GSFC.) There were also participants at the Centro de Astrobiologia in Madrid and at the Australian Centre for Astrobiology in Sydney.

Activities: In addition to coordination of the agenda by the Project Lead and Science Director, Bruce Runnegar, NAI Central's Collaborations Manager, Estelle Dodson, supported videoconferencing between the sites and coordinated an online meeting to allow for presentations from both ARC and GSFC. Darlene Gadd also organized travel support for six participants to attend at the location closest to them.

Evaluation: Participants indicated the meeting was a useful and timely discussion of the topic and included an appropriately broad range of expertise from many disciplines. The virtual nature of the workshop was lauded as a good way to minimize the time and travel required while still maintaining focus on the topic. One shortcoming of the workshop was the lack of participation from members of the European team who first published findings of methane in conjunction with the Mars Express mission. Although they were invited to participate, members of Vittorio Formisano's research team declined to join the workshop. Formal outcomes will include a white paper, led by Mark Allen, which will be disseminated later this year. The workshop and white paper may lead to a follow-up in person workshop sometime in 2006.

Mission Statement Goals

- **Goal:** carrying out, supporting and catalyzing collaborative interdisciplinary research
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Minority Institution Research Sabbaticals

Project Investigator: Edward Goolish

Project Progress

The Minority Institution Research Sabbatical was designed to support researchers from Minority Institutions, as defined by the U.S. Department of Education, to gain experience in and familiarity with the field of astrobiology. The program has supported four participants in past years. Participants have gone from the sabbatical opportunity to become, in some cases, co-investigators on NAI teams.

Activities: In 2005, the NAI received and funded an unsolicited proposal from Tennessee State University (TSU) to run the MIRS program. TSU will begin offering sabbaticals in the summer of 2006.

Evaluation: There were no participants in 2005.

Mission Statement Goals

- **Goal:** carrying out, supporting and catalyzing collaborative interdisciplinary research

NAI 2005, the Biennial Meeting of the NASA Astrobiology Institute

Project Investigator: Edward Goolish

Project Progress

The NAI 2005 meeting, hosted by the NAI University of Colorado Team, attracted nearly 500 attendees and was by all measures a wonderful success for the NAI and astrobiology. The twin objectives of the meeting were to learn about the latest science being accomplished by NAI members and to encourage contacts between individuals and teams that will pay off in future collaborations. One outstanding attribute of this meeting was the large number of young scientists attending. The scientific meeting itself – both the 50 oral presentations and the more than 250 posters – was organized according to scientific themes. In a departure from earlier meetings, the papers on education and public outreach were not placed in a separate session but were distributed throughout the program. Abstracts of all the papers and posters were published in the journal Astrobiology (Volume 5, No. 2, April 2005), which was distributed to all attendees. Other events in this fast-paced meeting included four public lectures, a banquet with talks by NASA officials, daily press briefings, a special invited presentation by Jonathan Lunine (Univ.of Arizona) on the latest news from Titan, smaller group meetings of several NAI Focus Groups and of working groups on education and communications, and two get-togethers of the graduate students and postdoctoral fellows at the conference.

NAI Central provided comprehensive planning and administrative support for NAI 2005 including all logistical aspects such as mailings, updating address lists, keeping the POC list updated, tracking registrations, assuring all VIPs were registered, defining and assembling required supplies, compiling staff folders, contacting participants and distributing or communicating information as required. The creation of the NAI 2005 website was a collaborative effort involving NAI Central (Marco Boldt, Karen Bradford, and Shige Abe) and the NAI 2005 local organizing committee. The website served as an entry point to the web based registration and abstract submission systems. In addition to general meeting information, the website contained pages about logistics, registration, abstract/poster submission, and press information. A comprehensive agenda was posted, and all meeting abstracts were made available for download. During the meeting the NAI Central administrative team (Jeni Joiner and Darlene Gadd) helped to coordinate the many ongoing activities, assured materials and equipment were available, procured any unplanned items when necessary, and supported the preparation of all documentation such as the materials distributed to all of the attendees.

NAI also coordinated the support for the sponsored students, contacting the 16 NAI teams to sponsor eight students and organizing the student logistics to assure their attendance at the meeting. Jeni Joiner and Darlene Gadd coordinated and supported the NAI Focus Groups and the Astrobiology Primer Sessions – i.e. reserved rooms, assured required materials and equipment were there, stayed in contact with the NASA meeting coordinator, and contacted the Focus Group Chairs. In addition, Janet Morrison* fully implemented the NAI Student Poster Competition, which required detailed instructions for the judges, providing a poster abstract submission website, and logistics planning. Janet Morrison* and Julie Fletcher coordinated the daily poster sessions, the student presenters, the poster judges, the poster signage (poster numbers and poster lists), prepared the award certificate and the poster winner's award check. This year's competition winner was Abhishek Tripathi from UCLA, Department of Earth and Space Sciences. His poster was titled "Comparison of Ancient and Modern Cyanobacteria in Three Dimensions Using Confocal Laser Scanning Microscopy." (Abstract #855 - Page 269 in Astrobiology - the NAI 2005 Meeting Abstract Book) The poster was co-authored by J. William Schopf from UCLA.

Finally, Julie Fletcher created the graphical look for the meeting (including the meeting poster, powerpoint template, signage, fliers, pocket agenda and design of the website). Shige Abe coordinated the publication of the 300 meeting abstracts in the journal *Astrobiology*, and developed the wireless networks used throughout the meeting. Janet Morrison* carried out an evaluation based on responses to a questionnaire from 115 participants (about 26% of total attendees. This evaluation is expected to lead to improvements in the way in which future NAI General Meetings are organized.

Mission Statement Goals

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NAI Annual Report

Project Investigator: Julie Fletcher

Project Progress

This year, we set out to develop a completely new way of displaying the Annual Report data by providing greater access to the wealth of information collected each year from the NAI Teams. In the past the Annual Report was presented as it's own website for that year only without the ability to access previous year's data. This year we have incorporated the Annual Report data into new "Team Pages" on the NAI website making it possible to access current and previous year's data all in one place. The new design incorporates tab-navigation, breadcrumbs and robust search functions for additional ease-of-use. The Team Pages have met with overwhelming support from the team PI's.

Required by the Cooperative Agreement Notice (CAN) each Team must submit an annual report for each funded year. The Report consists of an executive summary written by the team PI, project reports of their various science projects, reports of all EPO activities, NASA Mission involvement, field expeditions, team member lists and related publication bibliographies. Julie Fletcher managed the overall project, coordinating schedules and data collection, supporting the teams through the process, and developing the concept for the new team pages. The report is database driven and the NIMS database was developed and maintained by Shige Abe. Shige also designed the team pages. Marco Boldt developed the web-based submission site and managed the output into html for web presentation. NAI Central coordinated the collection of these reports from 16 teams, 11 Focus Groups and 5 International Partners.

Mission Statement Goals

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NAI Information Management System (NIMS)

Project Investigator: Shige Abe

Project Progress

The primary purpose of the NAI Information Management System (NIMS) is to serve as the data repository for information collected from Teams. The bulk of this information is collected once a year in the form of submissions to the Annual Report. This is set to gradually change, however, with plans to collect some information such as citations on a continuous basis.

The usefulness of NIMS is directly proportional to the quality of the submitted data. Towards this end, the NAI is placing high priority on refining the ease-of-use of the NAI Annual Report submission site as well as demonstrating the importance of collecting information from the Teams.

Previously, the primary product of the NIMS was the NAI Annual Report website. For 2005, the NAI will debute the new Team Pages on the NAI Website. This major overhaul strives to integrate the previously separate Annual Report website in with the NAI website. The annual report data has been repackaged and together with NAI directory merged with each team's overview information to form a coherent and integrated resource. In addition to making this information much more readily accessible, navigation between reporting years is also much easier. All these changes, culminates in a more useful presentation of information that better showcases the NAI's work for a variety of audiences from scientists to the general public.

In addition to the new Team Pages, NIMS is used to generate reports and statistics that form an important component of many presentations produced by the Institute. Examples of NIMS reports include statistics on NAI publications, NAI Membership breakdown studies, E&PO reports, and Information Technology accomplishments reports.

Moreover, extensions can be added that leverage the preexisting data to carry out special tasks. One such usage was modifications to give support to the processing of abstracts for NAI 2005. Specifically, the NIMS information on its members were cross-referenced with information collected with abstracts in order to create customized email messages specificially informes each participant such information as their

presentation status (oral or poster), which specific session the abstract was placed in, the specific day the poster was to be put up and the times to stand with the poster to answer questions. In the past, emails had to be written for a whole group of participants that often pointed to a listing of abstracts on our website which could have been misinterpreted. The extra effort to provide personalized emails seemed to have paid off as there was very little reported confusion despite the fact that posters sessions at NAI 2005 was unusually complex.

The NIMS is based on MySQL, which is a general-purpose, free, SQL-based database. As such, the database is often tapped for novel projects such as organizing the structure of the NAI 2005 abstract book for the journal Astrobiology. Even more extensive usage of the database and NIMS is anticipated for the coming year.

Mission Statement Goals

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NAI Newsletter

Project Investigator: Julie Fletcher

Project Progress

The NAI Newsletter was restructured this year into sections or categories of the most common types of articles that we publish. The sections are, NAI News; Recently Published Research from the NAI; Awards; Astrobiology EPO, Undergrads, Grads, Postdocs; and Courses & Conferences. This has made it easier for readers to locate important information and for this information to be linked in specific areas of the NAI website. The NAI community has responded with very positive feedback and contributions from this community have increased significantly.

The NAI Newsletter is a web-based source for current NAI related activities. It is emailed out every three to four weeks to NAI members and additional subscribers. In this reporting year, 15 Newsletters were published with each edition emailed to over 1,000 recipients. Julie Fletcher is the newsletter editor and Marco Boldt posts it on the NAI website (http://nai.arc.nasa.gov/newsletter/index.cfm) and emails it to the recipients.

Mission Statement Goals

- **Goal:** training the next generation of astrobiology researchers
- **Goal:** exploring new approaches using modern information technology to conduct interdisciplinary and collaborative research amongst widely-distributed investigators
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NAI Research Archive

Project Investigator: Daniella Scalice

Project Progress

The 16 Teams of the NASA Astrobiology Institute are home to researchers of the highest caliber; naturally, their publications are prolific and appear in top journals such as *Science* and *Nature*. In 2005, NAI Central has made an effort to collect information from its members about these publications as they happen, and has worked to showcase this cutting edge research to different audiences prominently on our website.

Since March 2005, NAI Central has highlighted 8 *Science* papers, 4 *Nature* papers, and 13 papers in various other journals including *PNAS* and *Astrobiology*. News of them is broadcast monthly to the NAI Newsletter's ~1000 subscribers. When there is sufficient notice, NAI Central has been able to coordinate with or generate press releases that inform news media of the research. Finally, NAI Central has notified its informal education/ public outreach partners of upcoming or recent publications, resulting in popular stories in various media venues such as the Are We Alone? radio show from the SETI Institute, Science Bulletins from the American Museum of Natural History, www.astrobio.net, and NASA's Earth Observatory website.

Daniella Scalice coordinated the content for the Research Archive, posted information on the NAI Website, and liaised with press release and other outreach personnel. Marco Boldt supported the NAI website functionality for this project.

Mission Statement Goals

- **Goal:** carrying out, supporting and catalyzing collaborative interdisciplinary research

NAI Research Scholarship Program

Project Investigators: Shige Abe, Edward Goolish

Project Progress

The NAI Research Scholarship (NRS) Program offered stipends and research-related travel expenses to allow students (graduate or postdoctoral) to conduct collaborative research amongst two or more of the Teams, including all of the participating institutions of the NAI. The program also supported travel to field-sites when required for the progress of the student's research.

During this reporting period, three cycles of the NRS were completed. The quality of applications has remained very high and number of applications received have allowed the NAI to easily meet its target of awarding eight scholarships per year.

Next year will see a major change to the NRS, where scholarships for field work will no longer be awarded. Instead, applications for field work will be handled by the "Lewis and Clark Fund for Exploration and Field Research in Astrobiology." This is a joint project with the American Philosophical Society.

Additional details on this change will be available on the NAI website in the funding section.

Mission Statement Goals

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NAI Seminar Series

Project Investigator: Estelle Dodson

Project Progress

The NAI virtual seminars have become a consistently popular way for scientists, staff, and graduate students to come together and bridge both distances and disciplines. In the words of one researcher, “the seminars have lowered to barriers to collaboration” by providing an easy way for scientists to learn about current research in areas in and out of their specialty and to engage in a dialog with other interested participant. The seminars provide an opportunity to harness the assortment of expertise in the audience and has a synergistic effect.

The NAI seminars are held twice a month and connect members of the community from their local institution using videoconferencing and WebEx real-time meeting software for a 50 minute presentation followed by ten minutes of questions, answers and discussions. The virtual nature of the seminars allows researchers to interact real-time without having to travel and devote days to attending a discipline specific conference. It also facilitates interaction within the researchers institutions by bringing people together on a regular basis who share an interest in the seminar; often leading to follow-up discussions between colleagues. The Director’s Seminar is held on the forth Monday of each month at 11:00am PT and features an invited speaker established in their field. The FAR seminar is held on the second Monday of each month at 1:00pm PT and features one to three researchers who are early in their careers and performing interesting and notable research. Technical support for all videoconferencing is provided by Mike Fitzjarrell and Diane Hawks. The FAR seminars provide an opportunity for the presenters to network within the community, get valuable feedback from knowledgeable sources about their research and refine their skills in explaining and discussing their work. Attendees have said the seminars lower the barrier to collaborations, making it easier to connect with researchers outside of their sub-discipline.

Upon its inception the seminars drew 4-6 sites and did not include slides. They now regularly draw 10-16 sites and provide high resolution slide sharing with a virtual laser pointer, allowing presenters to refer to specific areas of their pictures and graphs. The real-time nature of the Polycom videoconferencing tools easily provides high fidelity, face to face, immediate interaction which strengthens communication and community building. NAI also provides audio from the seminars on a NASA conference telephone number, allowing people without Polycom systems to connect and hear the talk. When combined with WebEx, any member can experience the full range of audio, video and slides. Additionally, the seminars are streamed and archived for later viewing on the internet using Realmedia player. Highlights of the last year include Jonathan Lunine’s talk, "Titan: A personal View after Cassini’s First Six Months in Saturn’s Orbit" with over 18 sites connecting and Margret Turnbull’s talk, "Remote Sensing of Life and Habitable Worlds: Habstars, Earthshine, and the Challenge of TPF".

NAI Summer Student Seminar Series Due to overwhelming popularity of the FAR seminars and requests from teams for summer students to have the opportunity to present at a seminar, NAI produced a two part seminar series specifically for summer student presenters. The seminars were 90 minutes long and held on two consecutive Friday’s at noon to allow maximum attendance across time zones from Hawaii to the east coast. 16 students from seven NAI sites gave ten-minute presentations with two minutes for questions and answers. The seminars were produced using the same technical set-up as the Directors and FAR seminars and were attended by 8-10 sites with large local audiences. A number of individuals also connected using the telephone and webcasting technologies. Students were primarily undergraduates with the exception of one high-school student and one master’s student. Topics included water production on comets, searching for extrasolar planets, Europa, subseafloor sediments, Mars, and many more. Audience members commented on the high quality and advanced level of the research and the professionally delivered presentations.

Mission Statement Goals

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NAI Team Visits

Project Investigator: Krisstina Wilmoth

Project Progress

Team Visits are onsite meetings of the NAI Central Senior Staff with members of a hosting team. The Team Visits are aimed at building a better sense of membership and participation in the NAI while also conveying to NAI management more intimate knowledge of the Team's research and other activities. While all teams have the opportunity to host a team visit, they are not required to do so. The visits are typically in conjunction with team meetings where current work of the individual members is presented along with the work of students and Education and Public Outreach projects. Team Visits also frequently include meetings with appropriate University management where both the NAI and the University become more familiar with each other's organizations. Finally, NAI Central also presents the various projects and opportunities available to the team for their information. In this way, there is two-way exchange of information, critical to the understanding of all aspects of the Institute.

Activities:

In the 2005 reporting period, team visits occurred at URI, MSU, PSU and GSFC, and UH. Each Team Visit included participation by the Scientific Director and often the Executive Director as well, along with at least one other member of the senior staff. The UH team visit also included participation from the SI, URI, and UW teams. The Project Lead coordinated the scheduling of the visits and assisted with developing the agendas. The Project Lead and Scientific Director also developed presentations to be given at each team.

Evaluation:

Several positives have come out of the team visits that have occurred so far. An intimacy and familiarity has developed between the NAI Central senior staff and the visited teams making the senior staff feel better informed of how to serve those specific teams. During these visits there has also been a strengthening or creation of a "team feeling" at some of the sites that might not have been there before. Also, by making personal connections during the visits, the senior staff has been able to recommend members of other teams as sources for collaboration.

Mission Statement Goals

- **Goal:** carrying out, supporting and catalyzing collaborative interdisciplinary research

NAI Website

Project Investigator: Marco Boldt

Project Progress

The NAI website is the primary source of information about the NAI, for it's members, the larger astrobiology community and the general public. The website's growth and evolution over the past year has focused on delivering relevant information quickly and efficiently to our varied audiences. This year our site usage averaged 600,000 to 1 million hits a month!

This year the NAI website underwent a major redesign to comply with NASA standards for webpage design.

Member Portal: One of the key features of the redesign was the "Member Portal." The member portal highlights funding opportunities, especially those with upcoming deadlines and profiles members' recent publications. A "Research Archive" highlights current research being carried out by NAI members. The portal also features the NAI Newsletter, upcoming seminars, courses, and workshops. 13 "Research Archive" entries were published in this reporting period.

Public Portal: With the release of the "Member Portal", the public website was reorganized to better serve the non-member audience. The most popular sections of the website are now easily accessible from the front page. These include "Ask an Astrobiologist" "For Teachers" and "Feature Stories." Information about funding, events, NAI teams and other NAI information is also easily accessible. 27 feature stories were published during this reporting period.

Other accomplishments include the creation of a website for the NAI 2005 meeting, and the creation of the Shared Resouces Database. More information about these projects can be found in other reports.

Several members of the NAI Administrative Office contribute to the success of the NAI website. Krisstina Wilmoth provides general NASA oversight for the website, and is an editor of the NAI Research Archive. Daniella Scalice provides content for the NAI Research Archive, For Teachers and For Students sections of the website. David Morrison provides content for the NAI Feature Stories, and answers "Ask an Astrobiologist" questions. Ed Goolish maintains the funding and focus group webpages. Shige Abe maintains the funding pages and the NIMS database. Estelle Dodson maintains the seminar series webpages. Janet Morrison maintains the NAI History website, the NAI Library and the Shared Resources Database. Julie Fletcher is the editor of the NAI Newsletter and maintains the Events page. To visit the NAI website go to (http://nai.arc.nasa.gov).

Mission Statement Goals

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NAI / NRC Postdoctoral Fellowship Program

Project Investigator: Julie Fletcher

Project Progress

The NAI is committed to training future generations of astrobiology researchers. A major component of the NAI's investment towards this objective has been the NAI/NRC Postdoctoral Fellowship Program. Administered in cooperation with the National Research Council, of the National Academy of Sciences, the NAI/NRC Postdoctoral Fellowship Program has now supported 33 NAI Fellows, at 18 different host institutions. Our program continues to support two review cycles per year; with application due dates of February 1 and August 1.

NRC Associates selected through the NAI/NRC Program become full members of the NAI, and, as such, are included in the NAI database and online directory, invited to attend and submit abstracts for NAI General Meetings, given access to NAI collaborative tools, and are eligible for additional NAI funding opportunities. NAI/NRC Fellows have, therefore, a wide spectrum of opportunities for further collaboration with NAI researchers, as well as the broader scientific community. In this role, NAI Fellows act as 'Ambassadors' amongst and between the NAI Teams and the broader scientific community, helping to define and lead the new discipline of astrobiology. Go to the "Postdoc Reports" tab in the Team Pages to read about the projects these Fellows have worked on in this and previous years.

Mission Statement Goals

- **Goal:** training the next generation of astrobiology researchers

Shared Resources Database

Project Investigators: Janet Morrison, Shige Abe, Marco Boldt

Project Progress

NAI teams are encouraged to share significant and unique research facilities across the Institute and throughout the astrobiology community. The Shared Resources Database was created to foster collaboration, augment individual research capability, and accelerate overall research advancement in astrobiology. Janet Morrison researched and collected all the data that went into the database and Shige Abe developed the database. This database was finalized and will be made available on the NAI website in October 2005.

The database is searchable by keyword(s), NAI Team, category, and science discipline. Resource category types are: (1) major centralized facilities (including a variety of resources supporting one type of research); (2) state-of-the-art instruments and equipment; (3) models, databases, and sample collections; (4) environmental simulation facilities; (5) astronomical observatories; and (6) computational facilities. Availability of individual resources and conditions for their use are negotiated between the prospective user and the individual or institution responsible for the resource.

Mission Statement Goals

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Student Council

Project Investigator: Julie Fletcher

Project Progress

The NAI Central Student Council was formed this year to be an advisory group for NAI Central "student" projects at the undergraduate, graduate – postdoctoral, and early career levels. The Council reviewed and evaluated all NAI student projects and discussed in detail the effort vs. benefit of each one. We agreed that the purpose of these student projects are to provide support with funding, provide exposure and networking opportunities that enhance student experiences and hopefully to help lead students into a career in astrobiology. Julie Fletcher prepared the agendas, scheduled and participated in the meetings, and Krisstina Wilmoth, Ed Goolish, David Morrison, Estelle Dodson and Shige Abe presented, reviewed and evaluated the projects.

Several key projects emerged from the efforts and coordination of the student council, the Astrobiology Primer and AbGradCon 2005.

The NAI provided funding for the development of the **Astrobiology Primer**, a short reference for Astrobiologists to use in preparing for and understanding conference presentations outside their area of primary expertise. It is also intended to help graduate students and others entering Astrobiology to conceptualize the broad sweep of basic knowledge. NAI helped develop and distribute a questionnaire to determine relevant topics for the primer, develop the production and editing timeline, support travel of the author to the NAI General Meeting in Colorado, assist with graphics production, reviewed and edited drafts of the primer and produced the hardcopy version for review by contributers, experts in the field and NAI Staff.

NAI provided supporting coordination for **AbGradCon 2005**, an astrobiology science conference organized by and for graduate students. We determined dates for the meeting, assisted in meeting organization, budget projections, provided a student email list and promoted the conference within the NAI community, researched additional funding support and mechanisms for dispersal of funds to vendors. NAI Collaboration Technologies manager attended the conference, gave an overview of NAI and the collaborative technologies and projects available through the institute and led a panel session followed by a discussion on facilitating interdisciplinary communication and strengthening the early career astrobiology community. A direct result of AbSciCon was the formation of an online community using a NASA/NAI tool called Secure Workgroups.

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EPO Reports: NAI Central

Please see the project report "Education and Public Outreach"

Publications: NAI Central

No Publications were found.

Team Members: NAI Central

18 members found.

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

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Projects | Publications | Update Profile

Name:Krisstina Wilmoth
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Projects | Publications | Update Profile