# *"Living Links Through Time and Space: Meeting the Challenges of Interdisciplinary Science"*

# Program Organizing Committee

**Jack Farmer, Co-Chair**
Arizona State University

**Robert Blankenship, Co-Chair**
Arizona State University

**Carlton Allen**
Johnson Space Center

**Linda Amaral**
Marine Biological Laboratory

**Michael Arthur**
Pennsylvania State University

**John Baross**
University of Washington

**Jay Brandes**
University of Texas

**Wendy Dolci**
NASA Astrobiology Institute

**Eric Gaucher**
University of Florida

**Edward Goolish**
NASA Astrobiology Institute

**Monika Kress**
University of Washington

**David Lubman**
University of Michigan

**Kevin McKeegan**
University of California, Los Angeles

**Victoria Meadows**
Jet Propulsion Laboratory

**Michelle Minitti**
Arizona State University

**Norm Pace**
University of Colorado

**Alex Pavlov**
University of Colorado

**Jean Schneider**
Paris Observatory

**Yanan Shen**
Harvard University

**Marguerite Syvertson**
Jet Propulsion Laboratory

**Catherine Tsairides**
Ames Research Center

**Leslee Unser**
Arizona State University

**Malcolm Walter**
Australian Centre for Astrobiology

# Letter from the Director

This year, and this meeting, are both marks in the series of transitions that characterize the plasticity and maturation of the Institute. As we conclude the final award year of the original participating Lead Teams, we simultaneously welcome our third Director, Dr. Bruce Runnegar, as we meet together, hosted by Arizona State University. Just before our last meeting, we added four new Lead Teams to our membership. Since then, we've been joined by two additional international Affiliates, the Groupe de Recherche en Exobiologie and the European Exo/Astrobiology Network Association. This year marks the largest, most comprehensive, gathering of the NAI's community.

Over the past five years, the research accomplishments of the Institute's science teams have been interwoven with the linking efforts of our collaborative technologies and outreach activities. In this General Meeting, the Program Organizing Committee has mirrored our science content and our cooperative aspirations to create an agenda reflective of our priorities and interests. We gather to reinforce our personal interactions, our friendships, and to learn the latest from our colleagues—those familiar to us and those we will come to know over the next few days. There are opportunities to participate in the growth of NAI's initiatives in Focus Groups and other topical areas, and to contribute to the future strategy of the Institute's development through a Town Hall Meeting discussion.

This biennial event provides an important counterweight in the delicate balancing act between our structure as a distributed, virtual Institute and our nature as a community. As I bridge the transition between Directors, a delicate balancing act in itself, I appreciate the generous support I've received from all the Institute's members. Many of you have become friends, and I know that many more will.

Welcome to your meeting. Your contributions, as individuals and as living links in a wider community, have created and defined the character of the NAI.

**Rosalind A. Grymes**
**Director (Acting)**
**NASA Astrobiology Institute**

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# Lead Teams, Principal Investigators, and Executive Council

**Ames Research Center**
PI: David Des Marais

**Arizona State University**
PI: Jack Farmer

**Carnegie Institution of Washington**
PI: Sean Solomon

**Harvard University**
PI: Andrew Knoll

**Jet Propulsion Laboratory 1**
PI: Kenneth Nealson

**Jet Propulsion Laboratory 2**
PI: Victoria Meadows

**Johnson Space Center**
PI: David McKay

**Marine Biological Laboratory**
PI: Mitchell Sogin

**Michigan State University**
PI: Michael Thomashow

**Pennsylvania State University**
PI: Hiroshi Ohmoto

**Scripps Research Institute**
PI: Reza Ghadiri

**University of California, Los Angeles**
PI: Bruce Runnegar

**University of Colorado**
PI: Bruce Jakosky

**University of Rhode Island**
PI: Steven D'Hondt

**University of Washington**
PI: Peter Ward

# International Partners

***Associate Members:***

**Centro de Astrobiología (CAB)**
Director: Juan Perez-Mercader

**Australian Centre for Astrobiology**
Lead: Malcolm Walter

***Affiliate Members:***

**United Kingdom Astrobiology Forum and Network**
Chair: Charles Cockell

**Groupe de Recherche en Exobiologie**
Lead: François Raulin

**European Exo/Astrobiology Network Association (EANA)**
President: André Brack

# Focus Groups

**Mars Focus Group**
Chair: Jack Farmer

**Ecogenomics Focus Group**
Chairs: Mitch Sogin and David Des Marais

**Mission to Early Earth Focus Group**
Chairs: Ariel Anbar and Stephen Mojzsis

**Evogenomics Focus Group**
Chairs: S. Blair Hedges and James Lake

**Europa Focus Group**
Chair: Ronald Greeley

**Astromaterials Focus Group**
Chair: David McKay

**Titan Focus Group**
Chair: Jonathan Lunine

**Virus Focus Group**
Chairs: Baruch Blumberg and David Smith

**Biological Consequences of Impacts Focus Group**
Chairs: Peter Ward and Frank Kyte

# The NAI: Opening Doors

# NAI International Partners

NAI has initiated a program of partnership with other international astrobiology organizations to provide collaborative opportunities for its researchers with the global science community. Foreign astrobiology organizations can propose to become either Associate or Affiliate Members of the NAI. Associate Membership entails a formal agreement between NASA and the foreign government. International requests which do not elect to pursue formal agreements are considered Affiliate Members.

***Associate Members:***

**Centro de Astrobiología (CAB)** (Director: Juan Perez-Mercader)
http://www.cab.inta.es/page/home_cab_e.htm

The CAB was the first astrobiology center outside the USA to be associated with the NAI. It's membership in the NAI was formalized in the year 2000. Application of the scientific method to astrobiology requires the combination of theory, simulation, observation, and experiment. This application is the most important goal for the Centro de Astrobiologia (CAB). The multidisciplinary setting provided by CAB allows engineers to interact with experimental, theoretical, and observational scientists from various fields: astronomy, fluid dynamics, geology, biogeochemistry, biology, genetics, remote sensing, bio-informatics, ecology, computer science, physics, robotics, and communications engineering. CAB research relates to the systematization of the chain of events that took place between the Big Bang, the self organization of interstellar gas, and the origin and evolution of life.

**Australian Centre for Astrobiology (ACA)** (Lead: Malcolm Walter)
http://aca.mq.edu.au

The Australian Centre for Astrobiology became an Affiliate Member of the NASA Astrobiology Institute in January 2001 and became an Associate Member in November 2002. It is located at Macquarie University in Sydney, Australia.

The Australian Centre for Astrobiology is building its membership, with increasing involvement in astrobiology research and education. Its members include university faculty and research scientists.

Subject disciplines of its members include: Microbiology, geochemistry, and planetary science.

Their research areas include: Origins of life on Earth, the search for life elsewhere, geochemistry and life (e.g., biogenic/nonbiogenic origin of proterozoic iron accumulations on Earth), and extreme environments for microorganisms.

***Affiliate Members:***

**United Kingdom Astrobiology Network (UKAF)** (Chair: Charles Cockell)
http://astrobiology.rl.ac.uk/

The UK Astrobiology Forum (UKAF) is a committee of the British National Space Centre, established as a central group to encourage and promote the science of astrobiology within the UK. Members of this group are astrobiology researchers. The UKAF became an Affiliate Member of the NAI in October 2000.

The UK Astrobiology Network (the second component of this combination) is an informal network of astrobiologists in various fields to promote communication among those involved in the science of astrobiology in the UK.

Astrobiology itself is a very active and rapidly growing field. Astrobiology-related research in the UK is developing rapidly, with several groups explicitly doing research in astrobiology.

**Groupe de Recherche en Exobiologie (GdRenE)** (Chair, Scientific Council GDR Exobiologie: François Raulin)
http://www.lisa.univ-paris12.fr/GDRexobio/exobio.html

The Groupe de Recherche en Exobiologie (GdRenE), created by the Centre National de la Recherche Scientifique (CNRS) in 1999, is a French federation of research laboratories working in Exo/Astrobiology. It is currently supported by CNRS, and CNES, the French Space Agency. It is composed of about 50 laboratories and includes a Scientific Council with 16 scientists from different fields of research.

Five main research topics are emphasized:

1) Terrestrial life as a reference (the primitive Earth environment; the first terrestrial living systems)

2) The origins of life on Earth (sources of organics on the primitive Earth; prebiotic chemistry; RNA world and other models of life)

3) Exobiology in the Solar System and the interstellar medium (search for life on Mars, on Europa, prebiotic chemistry on Titan, comets, meteorites and micro-meteorites; the chemistry of the interstellar medium traced back to the protostellar nebula)

4) Life in the universe (planetary diversity; criteria of habitability; spectral signatures of life)

5) The epistemological aspects of astrobiology are also included in these topics

The main goals of the GdRE are to promote Exo/Astrobiology in France, as well as at the international level, by helping and coordinating scientific research programs in selected domains of this field, optimizing the existing collaborations and inducing new ones.

**European Exo/Astrobiology Network Association (EANA)** (President: André Brack)
http://www.graz-astrobiology.oeaw.ac.at/eana.html

The European Exo/Astrobiology Network Association (EANA) was established as an Affiliate Member of the NASA Astrobiology Institute in early 2002, with the signature of formal affiliation taking place in Graz, Austria on September 19th at the Second European Workshop of Exo/Astrobiology. EANA itself was created in 2001 to co-ordinate the different European centers of excellence in exo/astrobiology, and the related fields previously organized in paleontology, geology, atmospheric physics, planetary physics and stellar physics.

EANA is administered by an Executive Council consisting of national members representing 12 European nations active in the field: Austria, Belgium, Denmark, France, Germany, Italy, Portugal, Spain, Sweden, Switzerland, The Netherlands, and The United Kingdom

# How to Propose an International Partnership

- International proposals to the NAI are requested to outline:
  - the organizational nature of the entity (i.e. government agency, private, non-profit, etc.)
  - the themes of the scientific work being undertaken/proposed and potential synergy with NAI objectives
  - the specific areas where near-term exchanges/partnerships will be productive and areas for long-term cultivation of interactions

- An NAI Partnerships Committee is internally appointed to comment on submissions

- The Director requests the Partnerships Committee to comment on:
  - the relevance of the scientific work being undertaken to the Astrobiology Roadmap and its synergy with the NAI
  - the nature of funding/endorsement from sponsor(s)
  - the specific areas where near-term exchanges/partnerships will be productive, and areas for long-term cultivation of interactions
  - any other issues which the reviewers may deem relevant

Depending on the nature and/or preference of the proposers, an international submission may lead to a formal agreement between NASA and the foreign entity's host government. There are two such international agreements as Associate Members. International requests which do not elect to pursue formal agreements are considered Affiliate Members of the NAI.

Inquiries should be directed to:

**Rosalind A. Grymes, Ph.D.**
**Deputy Director, NASA Astrobiology Institute**
**MS 240-1, NASA Ames Research Center**
**Moffett Field, CA 94035**
**Rosalind.A.Grymes@nasa.gov**

# NAI Focus Groups

The purpose of the NAI Focus Group initiative is to mobilize expertise from across the Institute and the wider scientific community towards the rapid advancement of a defined area of research, mission planning, or other activity of particular importance to astrobiology. Although significant representation by members of the NAI is expected, both the general membership and the position of Chair are open to individuals not associated with the Institute.

## Mars Focus Group

Chair: Jack Farmer, *Arizona State University* jfarmer@asu.edu

The Mars Focus Group was chartered to provide a forum within the NAI for discussing the scientific goals, objectives and measurement requirements for ongoing and future Mars missions involved with the exploration for past or present Martian life, and/or pre-biotic chemistry. The products of this focus group are basic science recommendations and advice on implementation of astrobiology missions provided to mission planning groups.

## Ecogenomics Focus Group

Co-Chairs: Mitch Sogin, *Marine Biological Laboratory* sogin@mbl.edu
David Des Marais, *NASA Ames Research Center* ddesmarais@mail.arc.nasa.gov

The over-arching objective of the EcoGenomics Focus Group is to define the relationship between microbial diversity, complex gene expression patterns, and biogeochemical processes that shape planetary environments. Using the hyper-saline cyanobacterial mats of Guerrero Negro, Baja California, Mexico as a field site, this inter-team effort is characterizing biogeochemical patterns in the microbial mats with special emphasis on gradient location and shape.

## Mission to Early Earth Focus Group

Co-Chairs: Ariel Anbar, *University of Rochester* anbar@earth.rochester.edu
Stephen Mojzsis, *University of Colorado* stephen.mojzsis@colorado.edu

The rational search for life beyond Earth requires some concept of the conditions under which life originates and begins to evolve, and of the environmental "fingerprints" of primitive biospheres. This concept must be informed by a solid understanding of the only planet on which life is known to exist- the Earth. Hence, study of life and the environment on the early Earth is a critical component in developing mission plans for astrobiology space missions. This is the underlying rationale of the Mission to Early Earth Focus Group.

## Evogenomics Focus Group

Co-Chairs: S. Blair Hedges, *Pennsylvania State University* sbh1@psu.edu
James A. Lake, *University of California, Los Angeles* lake@mbi.ucla.edu

The purpose of the EvoGenomics Focus Group is to coordinate, combine, and enhance research efforts involving evolutionary genomics across the multiple disciplines and institutions represented in the astrobiology community. Evolutionary analysis of the complete genomes of organisms has greatly advanced our understanding of how life originated, adapted to diverse environments, and increased in complexity on this planet, and in turn, these studies will lead to a better understanding of life elsewhere in the Universe.

## Europa Focus Group

Chair: Ronald Greeley, *Arizona State University* greeley@dione.la.asu.edu

The objective of the Europa Focus Group is to foster scientific studies and joint investigations of Europa and related research in order to understand the exobiological potential of this satellite of Jupiter. This goal is to be met through various video conferences, workshops, and information exchanges sponsored by the NAI. The study of Europa requires a multidisciplinary approach using spacecraft data analyses, laboratory

simulations, terrestrial analog studies, and other techniques to understand the complex history and present environments on and in Europa.

## Astromaterials Focus Group

Chair: David McKay, *NASA Johnson Space Center* david.s.mckay1@jsc.nasa.gov

Astromaterials include lunar samples, meteorites, interplanetary dust particles, and any sample returned to Earth by a space mission. The objective of the Astromaterials Focus Group is to coordinate and facilitate astrobiological investigations of Mars meteorites, terrestrial analogs of potential Mars samples, and sample acquisition and collection technology and procedures; and in general to advance the development of instruments and techniques for examining all astromaterials for evidence of past or present Life.

## Titan Focus Group

Chair: Jonathan Lunine, *University of Arizona* jlunine@lpl.arizona.edu

Titan is of interest from the perspective of astrobiology because it is known to generate suites of hydrocarbons and nitriles in its stratosphere, which then fall to the surface and are protected from damaging particle and UV radiation by a thick atmosphere. Further chemistry, including that in the presence of transient and localized areas of liquid water, may proceed on the surface in staccato fashion over geologic time. Titan, therefore, provides us with a planet-sized laboratory for testing the synthesis of organic compounds in a nearly neutral redox environment, over large spatial scales, both with and without liquid water. An initial high-priority objective of the Titan Focus Group is to ensure the conceptualization and initial study of appropriate techniques for advanced organic analysis on Titan, after the Cassini-Huygens mission.

## Virus Focus Group

Co-Chairs: Baruch Blumberg, *NASA Astrobiology Institute* bblumberg@mail.arc.nasa.gov
David Smith, *University of Rhode Island* dcsmith@gso.uri.edu

The Virus Focus Group (VFG) has been initiated to bring together researchers from different disciplines and perspectives to advance the study of viruses from an astrobiological perspective. Topics of interest to be addressed by the VFG include; the origin and evolution of viruses, viruses in extreme environments, virus detection methods, preservation and fossilization of viruses, survival of viruses outside of their hosts, the role of viruses in gene transfer, and viruses as self-assembling molecules. This new NAI Focus Group begins with a roster of 40 potential members whose research interests span the breadth of astrobiology. The VFG is expecting to develop and integrate new approaches and technologies towards the study of viruses and astrobiology.

## Biological Consequences of Impacts Focus Group

Co-Chairs: Peter Ward, *University of Washington* argo@u.washington.edu
Frank Kyte, *University of California, Los Angeles* kyte@igpp.ucla.edu

The Impacts Focus Group (IFG) has been established to examine how impacts of asteroids, comets, and other materials have influenced the origin, evolution, and extinction of life on Earth. A major goal of the Impacts Focus Group is to accumulate samples from a wide variety of temporal and geographical research locales, and then to coordinate the geochemical and paleontological analysis of these samples. Impacts, as a geological process, have affected landscapes of every rocky or icy planet in the solar system. If life does or ever existed on extraterrestrial bodies of astrobiological interest such as Mars or Europa, then impacts have likely affected the biota on these bodies as well.

# POSTDOCTORAL FELLOWSHIPS in the NASA ASTROBIOLOGY INSTITUTE

The NASA Astrobiology Institute (NAI) has established a program to support a highly select group of Institute-wide postdoctoral fellows. These fellows have a home research base at one of the NAI member institutions, but are encouraged to interact across the entire Institute. They have an opportunity to help define the interdisciplinary field of astrobiology.

The NASA Astrobiology Institute postdoctoral appointments are made on behalf of NASA by the National Research Council (NASA/NRC) Research Associateship program. The NRC is a part of the National Academy of Sciences and the National Academy of Engineering.

The selected awardees are outstanding researchers from all scientific disciplines that contribute to the astrobiology research program. Each applicant is required to indicate in their application one of the approved participating institutions as the primary research base and host institution, as well as the prospective Research Adviser (mentor).

It is expected that applicants propose a significant and innovative research topic of their own choosing. However, consultation with the prospective mentor and host institution is required.

**There are two review cycles per year, with application deadlines of February 1 and August 1.**

## The 15 Lead Member Institutions of the NAI are:

### Ames Research Center, Moffett Field, CA

*P.I.: Dr. David Des Marais, ddesmarais@mail.arc.nasa.gov*
Chemical building blocks of life; Habitable planets; Protocellular processes; Early microbial ecosystems; Rapid rates of ecological change; Cold-adapted cyanobacteria and potential for life on Mars

### Arizona State University, Tempe, AZ

*P.I.: Dr. Jack Farmer, jfarmer@asu.edu*
Origins, Evolution and Distribution of Life in the Solar System; Prebiotic chemistry of meteorites; Role of planetary hydrothermal systems; Role of photosynthesis; Fossil record of early microbial life; Exploration for life on Mars and Europa

### Carnegie Institution of Washington, Washington, DC

*P.I.: Dr. Sean C. Solomon, scs@dtm.ciw.edu*
The physical, chemical, and biological evolution of hydrothermal systems, including vent complexes associated with ocean ridges , deep aquifers, and other subsurface aqueous environments both on Earth and on other Solar System and extrasolar bodies

## Harvard University, Cambridge, MA

*P.I.: Dr. Andrew Knoll, aknoll@oeb.harvard.edu*
Planetary context of biological evolution: A Combined effort in microbiology, paleontology, stratigraphy, geology and geochemistry to understand the coevolution of life and environments in Earth history

## Jet Propulsion Laboratory 1, Pasadena, CA

*P.I.: Dr. Kenneth Nealson, kenneth.h.nealson@jpl.nasa.gov*
Coevolution of Planets and Biospheres; Lessons from Earth and Mars; Definition and development of biosignatures; Life in extreme environments on Earth; Study of Mars as a habitat for life

## Jet Propulsion Laboratory 2, Pasadena, CA

*P.I.: Dr. Victoria Meadows, Victoria.S.Meadows@jpl.nasa.gov*
Understanding the plausible range of atmospheric and surface compositions for terrestrial planets; recognizing the presence of life on extrasolar terrestrial planets by identifying signatures of life in their spectra

## Johnson Space Center, Houston, TX

*P.I.: Dr. David McKay, david.mckay@jsc.nasa.gov*
Institute for the Study of Biomarkers; Evidence of past biologic activity in terrestrial and planetary samples; Biomarkers in biominerals; Fractionation; Morphologic features and specific organic molecules

## Marine Biological Laboratory, Woods Hole, MA

*P.I.: Dr. Mitchell L. Sogin, sogin@mbl.edu*
Environmental Genomes and the Evolution of Complex Systems in Simple Organisms: Eukaryote origins; Thermophillic prokaryotes; Protein and genome evolution

## Michigan State University, East Lansing, MI

*P.I.: Dr. Michael Thomashow, thomash6@msu.edu*
Genome expression under conditions of low temperature and dehydration; the identification of genes adaptive to such conditions; the development of possible molecular "signatures" for the presence of life in cold environments, on Earth as well as on other bodies such as Mars and Europa

## The Pennsylvania State University, University Park, PA

*P.I.: Dr. Hiroshi Ohmoto, ohmoto@geosc.psu.edu*
Environment of prebiotic Earth and origin of life; Biochemistry of Archea-roles of metals in the origin and evolution of life; Timescale for the early evolution of life on Earth; Evolution of atmospheric oxygen, climate and terrestrial biosphere; Diversification and extinction of metazoans

## The Scripps Research Institute, La Jolla, CA

*P.I.: Dr. M. Reza Ghadiri, ghadiri@scripps.edu*
Self-Reproducing Molecular systems and Darwinian Chemistry: Single biopolymer and protein-based origins of life; Self-sustained nucleic acid replicators in RNA world; Properties necessary for molecular self-replication

## University of California, Los Angeles, CA

*P.I.: Dr. Bruce Runnegar, runnegar@ucla.edu*
Extrasolar planetary systems; Early Earth and Mars; Earth's earliest life; Genomics and the tree of life; Celestial connections; Solar system exploration

## University of Colorado, Boulder, CO

*P.I.: Dr. Bruce Jakosky, jakosky@argyre.colorado.edu*
Formation of stars and planets; Habitability of planets; Origin of life and the RNA world; RNA chemistry and the history of life on Earth; Evolution of life on Earth

## University of Rhode Island, Narragansett, RI

*P.I.: Dr. Steven D'Hondt, dhondt@gso.uri.edu*
The subsurface microbial ecosystems of marine sediments, their role in Earth's biogeochemical cycles, and their relevance to the search for life on other planets

## University of Washington, Seattle, WA

*P.I.: Dr. Peter Ward, argo@u.washington.edu*
The characteristics of planets that can evolve complex organisms, the distribution of such planets in the universe, how biological complexity might evolve on such planets, and how it might end

The following NAI Teams are currently hosting NAI/NRC Postdoctoral Fellows; Arizona State University, Carnegie Institution of Washington, Harvard University, Marine Biological Laboratory, NASA Ames Research Center, NASA Johnson Space Center, Scripps Research Institute, University of California - Los Angeles, University of Colorado - Boulder, University of Washington.

**For program information see http://www.national-academies.org/rap or contact:**

Dr. Robert Manka, Associate Director or
Ms. Sally Lytch, Program Coordinator
National Research Council
Associateship Programs (TJ2114/NAI)
2101 Constitution Ave NW
Washington, DC 20418

E-mail: astrobio@nas.edu
Internet: http://national-academies.org/rap
Tel: (202) 334-2760

Dr. Edward Goolish, Sponsored Programs
NASA Astrobiology Institute
MS 240-1
NASA Ames Research Center
Moffett Field, CA 94035-1000

E-mail: egoolish@mail.arc.nasa.gov
Internet: http://nai.arc.nasa.gov
Tel: (650) 604-1961

**Qualified applicants will be reviewed without regard to race, creed, color, age, sex or national origin.**

# NAI Minority Institution Program

The NASA Astrobiology Institute (NAI) Minority Institution Involvement Program (MIIP) launched in Summer 2002 with the introduction of a Minority Institution faculty sabbatical. The sabbatical provides opportunities for Minority Institution faculty researchers to collaborate with NAI Lead Team researchers. The sabbatical is for a period of 8 weeks and it includes the following:

- A stipend of $1K per week sent directly to the selected applicant
- Travel reimbursement for one round trip travel fare to the host site
- Paid registration and travel reimbursement (within 1 year of the sabbatical completion) for the faculty member and up to 2 of the faculty member's students to attend the NAI General Meeting or the NASA Astrobiology Science Conference
- Up to $3K for institutional fees, lab and office set-up for the faculty participant

The program is viewed in three phases. The implementation of the sabbatical is phase one of the program. The second phase is the feedback/information from the participating host site PI's and faculty participants. The third phase is the attendance and participation of the MI faculty and students at either the NAI General Meeting or NASA Astrobiology Science Conference.

The first NAI Minority Institution faculty sabbatical participants were:

*Dr. Todd Gary*
**Tennessee State University**
Host: University of California, Los Angeles
PI: Jim Lake

*Dr. M. F. Mahmood*
**Howard University**
Host: Carnegie Institution of Washington
PI: Andrew Steele

In October of 2002, a third sabbatical participant was selected:

*Dr. Lekan Latinwo*
**Florida A&M University**
Host: Michigan State University
PI: Michael Thomashow

The program is developing with further outreach into the MI community planned for Year 5 and an internal review to ensure the program is continuing on a beneficial collaborative path for both the NAI and the MI communities.

Inquires should be directed to:

**Karen Bradford**
**Minority Institutions, NASA Astrobiology Institute**
**MS240-1, NASA Ames Research Center**
**Moffett Field, CA 94035 650-604-0809**
**Karen.C.Bradford@nasa.gov**

# Virtual Institute: Resources and Opportunities

The NAI is envisioned as a virtual institute that provides meeting venues and information tools and technologies to support exchange and collaboration among a geographically distributed community. To further this vision during the past year, the Collaborative Research Support Group at NAI Central has instituted two video seminar series and has made WebEx, a real-time meeting tool, available for use by NAI members.

- NAI VIDEO SEMINAR SERIES
  - Director's Science Seminar Series - 3rd Monday of the month at 11:00 PST - presentations by senior scientists

  - Astrobiology Research Video Forum – 1st Monday of the month, times vary - presentations by graduate students and Post Doctoral Fellows

These seminars are broadcast to the NAI videoconferencing rooms at lead institutional sites and are also webcast live to any interested viewer. Presentations are followed by Q & A sessions accessible to all participants, either though the videoconference rooms or a moderated chat room. Seminars are also archived for later viewing. Information on all seminars and on connection instructions is available at : <http://nai.arc.nasa.gov/seminars>

- NAI COLLABORATIVE TOOLS
  - WebEx – Web-based browser-accessible real-time meeting tool enabling application and file sharing, whiteboard with drawing tools, chat, polling during meetings, passing of presentation functions from one participant to another, and viewing of presenter's live video image. Based on NAI member input, WebEx was selected for piloting and is available for use by any interested NAI member. More information can be found at: <http://nai.arc.nasa.gov/institute/member_services>

Your feedback, your recommendations for future virtual institute developments and your specific requests for support in setting up virtual collaborations with your colleagues are welcomed.

For further information please contact

**Dr. Lisa Faithorn,**
**NAI Manager of Collaborative Research**
**650-604-6505**
**lfaithorn@mail.arc.nasa.gov**

# The Gerald A. Soffen Award

The Best Student Poster Presentation at each NASA Astrobiology Institute General Meeting is selected to receive the Gerald A. Soffen Award. The purpose of the Gerald Soffen Award is to provide encouragement, motivation, and recognition to our most outstanding future astrobiologists. There will be a single award of $1,000. The winner will be announced at the meeting.

- Eligibility Requirements
  - The award is intended primarily for students at the graduate level
  - However, individuals at the undergraduate level are also eligible to compete
  - The student must be enrolled in a degree program at the time of abstract submission
  - Postdoctoral students are not eligible
  - Eligibility is open to both U.S. citizens and non-U.S. citizens
  - Students must register for the competition at the time of abstract submission.
- Abstract Requirements
  - Only one abstract per student will be considered for the award
  - The student must be the senior author of the abstract, the major contributor to the material presented, and the person presenting the poster
  - The majority of the material should not have been previously presented at another meeting
- The Criteria for Selection are
  - Originality of the research
  - Quality of the execution
  - Impact to the field
  - Organization and clarity of presentation

# Complete Abstracts Listing

# Complete Abstracts Listing

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# Public Lecture
# & Concluding Lecture Abstracts

# Abstract # 13090 - **Astrobiology and the Emergence of Life on Earth**

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Long before the idea of spontaneous generation was incorporated into evolutionary theory at the turn of the 19th century by Lamarck, the possibility that other planets were inhabited had been discussed, sometimes in considerable detail, by scientists and philosophers alike. More often than not, these were speculations that rested on the idea of a uniform Universe, but with little or no empirical basis. Thanks to the development of the new field of astrobiology, our approaches to the issue of life in the Universe have changed dramatically and are studied within a multidisciplinary framework. In the astrobiology framework, neither the formation of stars and planets or the origin of life is seen as the result of miracles or inscrutable random events, but rather as natural outcomes of evolutionary events. The interconnection between these two processes is evident: understanding the formation of planets has major implications for our understanding of the early terrestrial environment, and therefore for the origin of living systems.
Although the recognition of the oldest traces of life on Earth is a contentious issue, it is generally agreed that life emerged very rapidly and quickly took hold. Unfortunately, it is unlikely that data on how the first living systems appeared will be provided by the geological record. There is no direct evidence of the environmental conditions on the Earth at the time of the origin of life, nor any fossil register of the evolutionary processes that precede the appearance of the first cells. This has led to a wide variety of theories, but it will be argued that astronomical evidence, laboratory simulations and other types of evidence strongly support the idea of a heterotrophic origin of life from a primordial soup formed by organic compounds of both endogenous and extraterrestrial origin.

# Abstract # 13092 - **Our Evolutionary Journey: From Darkest Africa into Darkest Space**

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Human beings seem to be inordinately captivated by their origins and their destiny. We are the only known species in the universe to have the curiosity and ability to discover and evaluate the evidence for our evolutionary origins. The most ancient evidence for humans comes from Africa and subsequently all important landmarks that define us as a unique species are first recorded in African strata. The origin of all humankind lies in Africa--we are united by this past--the evidence is overwhelming.

Where we go as a species is best left in the hands of those who ponder the future, but how interesting that two watershed events in human history are recorded in footprints. The 3.6 million-year-old footprints left in Africa's Great Rift Valley symbolize the moment when our ancestors first stood up and initiated the human career. The other, floating high above the Great Rift Valley are the lunar footprints that testify to the success of the first species to leave planet Earth, and symbolize the rise of modern technology and forecast the future of the species.

# Plenary Sessions Abstracts

# Abstract # 13091 - **Life Beyond the Solar System: If, Where, When, and How?**

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The Origins Theme of NASA Space Science is building an ambitious program to find solar systems like our own and wet, warm worlds like Earth. If these can be found in the Sun's neighborhood of the Milky Way Galaxy, we should be able to build space telescopes that will be able, through remote sensing, to characterize the physical conditions of these Earth-like worlds.

Even more exciting, however, is the possibility of searching for signs of life, such as the presence of oxygen or other disequilibrium gases in a planet's atmosphere. Planning is already underway at the Jet Propulsion Laboratory for the first space telescope to have a chance to do so --- the Terrestrial Planet Finder. TPF might fly as early as 2015, but this is just the beginning of what could grow to be a central focus of 21st century astronomy. By mid-century, we could see constellations of giant space telescopes ---working in concert --- dedicated to searching for a diversity of life among tens of thousands of neighboring worlds.

# Abstract # 13071 - **Prospects for Life in our Solar System and Intelligent Life Elsewhere**

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What is life? There is no broadly accepted definition, and even the popular "Darwinian definition" faces counter-examples. The philosopher Carol Cleland and I (Origins of Life 32, 387-393, 2002) have recently argued that defining 'life' poses a dilemma analogous to that faced by those hoping to define 'water' before the existence of molecular theory. In the absence of an analogous theory of the nature of living systems, interminable controversy over the definition is inescapable, as was the problem of defining water prior to the elucidation of the theoretical context that allows one to identify water with $H_2O$.

In the absence of a definition, the search for life will rely on tentative criteria that serve to focus attention on suspicious physical systems. In the case of the Viking spacecraft's search for life on Mars, these criteria amounted to signs of metabolism (the biology package) and the presence of organic molecules (the GCMS).

An analogous approach is taken in the search for environments in our Solar System or beyond that could prove suitable for life. Attention is focused on those environments that permit the key criteria for life as we know it: liquid water, so-called "biogenic" elements, and a sufficient source of free energy. Rapidly this leads one to focus on Mars and Europa in our own Solar System, although other worlds may provide environments that are analogs in some sense to putative ancient terrestrial environments possibly relevant to the origin of life on Earth.

Mars is currently the focus of systematic exploration, with exobiology as one of its goals. There is, however, currently no mission planned to explore Europa. Therefore this talk will focus more on Europa than on Mars, and review what is known, what is likely, and what is speculative about Europa's habitability for life. Europa almost certainly harbors a second liquid water ocean whose volume is about twice that of Earth's ocean; it is very difficult to avoid the conclusion that Europa should have a substantial inventory of biogenic elements, and sources of free energy that can be used by terrestrial organisms may already be proposed (see Chyba and Phillips, Origins of Life 32, 47-68, 2002 for a review). We have emphasized that habitability for extant life is distinct from suitability for the origin of life, and recent laboratory work (Monnard et al., Astrobiology, in press) suggests that some models for Europa's ocean imply salt concentrations that may be problematic for certain important prebiotic processes (Goldman and Chyba, in preparation).

What is intelligent life? There is also no decisive answer to this question. From the point of view of the scientific search for intelligent life, operational criteria are employed, such as the ability to transmit electromagnetic signals of a bandwidth more narrow than any known natural source. With the construction of the Allen Telescope Array, we should be able to search the ~106 nearest Sun-like stars for artificial electromagnetic signals by 2020 (see Ekers et al., eds., SETI 2020, SETI Press, 2002, 549pp). So far, well under 1000 such stars have been searched by Project Phoenix, too few in a galaxy of hundreds of billions of stars to provide statistically useful results.

Whether the evolution of intelligence is common or rare will only be determined empirically; SETI searches are one approach but there are a surprising number of empirical investigations that can be, but to date have not been, conducted with the terrestrial fossil record that will provide insight into this question. One reproducible criterion that may be used as a measure of 'intelligence' is encephalization, a measure of an organism's brain to body mass. The SETI Institute is currently funding a small pilot project as a demonstration of the type of statistical, objective investigations that can be performed to address these questions of the evolution of intelligence (McShea and Marino, "Trends in Encephalization", paper given at the Bioastronomy Conference, Hamilton Island, 2002). We have just begun to scratch the surface of scientific, reproducible investigations into the astrobiological question of "are we alone?"

# Abstract # 13062 - **Self-Assembly and Energy Flow through Molecular Systems**

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A clue to understanding the origin of life is that certain kinds of molecules have physical and chemical properties which allow them to self-assemble into orderly structures. A second clue is that even the simplest forms of life have the ability to capture energy. For this reason, we are investigating self-assembled systems of molecules that can extract energy from the environment and use it to drive biosynthetic chemical reactions. One such system incorporates catalytic and replicating macromolecules encapsulated by a boundary membrane composed of amphiphilic compounds. What sources of amphiphiles might have been available on the early Earth? One possible source is organic material delivered during late accretion (1), and earlier work has demonstrated that amphiphilic substances present in carbonaceous meteorites can in fact assemble into membranous vesicles (2). The amphiphilic compounds that are present include monocarboxylic acids 8 - 12 carbons long. Monocarboxylic acids and alcohols are also produced by geochemical Fischer-Tropsch type reactions (3, 4) so it is reasonable to assume that such compounds were likely to have been have been available on the prebiotic Earth, either by delivery or synthesis.

We are investigating the physical properties of simple amphiphiles, particularly with respect to their self-assembly and ability to capture energy from the environment. Significantly, recent work has shown that ionic solutes such as magnesium, calcium and ferrous iron markedly inhibit membrane formation by amphiphiles by binding to anionic head groups of the amphiphiles (5). These ions are present in sea water, which suggests that the self-assembly of membrane structures may have required a fresh water environment. However, other simple amphiphiles such as monoglycerides can undergo self-assembly in the presence of divalent cations, so there may be a way to resolve this issue.

A second concern is that a membrane enclosure limits access to external sources of nutrients and energy. The measured permeability coefficients of liposome membranes to phosphate and amino acids are in the range of $10^{-11}$ - $10^{-12}$ cm $s^{-1}$ (6). From these figures one can estimate that if a primitive microorganism depended on passive transport across a lipid bilayer composed of a modern phospholipid, it would require several years to accumulate phosphate sufficient to double its DNA content, or pass through one cell cycle. If solutes like amino acids and phosphate are so impermeable, how could primitive cells have had access to these essential nutrients? Modern lipids are highly evolved products of several billion years of evolution, and typically contain hydrocarbon chains 16 to 18 carbons in length. These chains provide an interior "oily" portion of the lipid bilayer that represents a nearly impermeable barrier to the free diffusion of ions. One

possible solution to this conundrum is that permeability is strongly dependent on chain length (7). The reason is that thinner membranes have increasing numbers of transient defects that open and close on nanosecond time scales, so that ionic solutes can get from one side of the membrane to the other without dissolving in the oily interior phase of the bilayer. On the early Earth, shorter chains would have been much more common than longer chain amhiphiles, suggesting that the first cell membranes were sufficiently leaky so that ionic and polar nutrients could enter, while larger polymeric molecules were maintained in the encapsulated volume.

These results provide a useful perspective on the most primitive forms of cellular life. In the early Earth environment, a variety of amphiphilic hydrocarbon derivatives could self-assemble into bilayer boundary structures and encapsulate polymers that were being synthesized by a separate process. The vesicle membranes would have been sufficiently permeable to allow passage of smaller ionic substrates required for metabolism and biosynthesis, yet maintain larger molecules within a boundary. Encapsulated catalysts and information-bearing molecules would thus have access to nutrients required for growth. Furthermore, specific groupings of macromolecules would be maintained, which would allow true selection of such groupings to occur, a process that could not as easily take place in mixtures of molecules free in solution. Certain encapsulated molecular systems were likely to have properties that allowed them to capture free energy and nutrients from their environment to support growth by polymerization. At some point, the growth would become catalyzed by the encapsulated polymers, and then begin to be directed by a primitive genetic process. Such structures would be on the evolutionary path to the first forms of cellular life (8, 9, 10).

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# Abstract # 13058 - **What is a Biosignature? What makes a Planet Habitable? Matching Darwinian Chemistry to Solar System Habitats**

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Most organic molecules can suffer spontaneous chemical transformation, or "mutation". Many can template nanoscopic to macroscopic structure, if only through the formation of crystals. A growing number of organic systems are known to guide the assembly of replicates of themselves. But only one class of molecule, nucleic acids, is known to display rule based molecular recognition that survives mutation without disrupting properties that are essential for replication.

As a consequence, nearly all efforts to search for life in the solar system have focused on environments compatible with the physical properties and chemical stability of nucleic acids. These include water as a solvent, temperatures between 273 and 373 K, and pH values near neutral.

But any chemical system that combines the capacities of directing its own replication, suffering mutation, and allowing mutant structures to themselves be heritable should undergo natural selection, evolving in structure to replicate faster through more efficient use of available molecular resources and energy. Molecular systems capable of Darwinian chemistry should generate the same structural and chemical behaviors that characterize life on Earth.

Can we conceive of self-sustaining chemical systems capable of Darwinian evolution that do not operate in water near neutral pH between 273 and 373 K? Easily. Many non-aqueous solvents appear to support chemical templating. Chemical transformations that might support energy and chemical metabolisms are known in environments as acidic as the aerosols in the atmosphere of Venus, or as basic as the atmosphere of Jupiter. Laboratory experiments with analogs of the nucleic acids, proteins, sugars, and lipids found in terrean life also show that these particular molecular structures need not be found in life forms having a genesis independent of life on Earth, even in water near neutral pH. Indeed, water creates its own problems, destroying biological macromolecules from terrean life, rapidly for nucleic acids, and slowly for proteins.

As NASA directs missions towards the exploration of the solar system, the number of locales holding terrean like habitable environments is small and generally inaccessible (subsurface Mars, sub-ice Europa). The number of environments providing environments for non-equilibrium chemical processing (the minimum for life), including the presence of organic molecules, the presence of energy, and the presence of solvent, is larger. Some are more accessible, even for sample return, such as the atmosphere of Venus.

One goal of Chemical Astrobiology, therefore, is to use chemical insight and experiment to match potential Darwinian chemistry with the inventory of environments present in the solar system, and then to use general chemical understanding to help guide the design of missions to locations within the solar system. Here, habitability is defined within the context of the kinds of Darwinian chemistry a particular environment might support. Possible biosignatures are then suggested based on the kinds of outcomes expected from Darwinian evolution in that environment.

In part, the challenge is to avoid being trapped into "Earth-o-centric" thinking based on familiar terrean biochemistry, without at the same time being lured into fanciful "Star Trek Chemistry", fun to imagine but lacking any chance of reality. To do so requires drawing on every piece of information known in chemistry, and then some, to enforce the discipline needed to ensure reality.

This talk will outline experimental and conceptual approaches to defining habitability, biosignatures, and the search for life in the solar system via robotic missions and in situ analysis. We will ask whether constraints can be imposed based on information about chemicals generated in the interstellar medium, chemicals delivered to a planet via meteoritic infall, and chemical generated endogenously on a planet. We will also ask whether details of terrean biochemistry can provide clues about what features of biochemistry are universal for life regardless of genesis, and regardless of habitat.

# Abstract # 13038 - **The Early Evolution of Life as Reflected in the Molecular Record**

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Darwin's work on the origin of species and the neo-Darwinian synthesis suggested that over long periods of time evolution could be described as a steadily bifurcating tree. The introduction of ribosomal RNA as a tool in microbial taxonomy by Carl Woese and George Fox let many microbiologist to assume that the concepts of animal and plant taxonomy could be extended to the realm of prokaryotes. The metaphor for organismal evolution that underlies a natural taxonomic system is a steadily bifurcating species tree, also known as the tree of life. A decade ago ribosomal RNA promised that one day it might be possible to place every extant organism on a universal tree of life, and the hope was that more genomic sequences would make this placement more accurate. However, the analyses of completely sequenced genomes initiated a reassessment of concepts in microbial evolution. While some molecular markers were found to agree with one another, others do not. Transfer of genetic information between divergent organisms has turned the tree of life into a net or web, and genomes into mosaics. Different parts of genomes have different histories, and representing the history of genome evolution as a single tree appears inconsistent with the data. However, the exchange of genetic information is not so rampant as to have obliterated all signals. Horizontal gene transfer is not random, neither with respect to donors and recipients nor with respect to the type of genes that are transferred.

The talk will address the following questions:
What is the role of horizontal gene transfer in the microbial evolution?
Is there a core of little transferred genes that can be used to trace organismal evolution?
What biological processes gave rise to the recognizable taxonomic groups?
How did enzymes with new properties and new biochemical pathways emerge?

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# Abstract # 13065 - **Biomarkers: Molecular Signatures for Early Life**

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Molecular methods are providing new windows through which we can observe microbiologically-driven processes in the geological past. DNA cloned from living organisms has given us the well known 'tree of life' and a depiction of the genetic distances between all living organisms. The tree also encodes a sense of their evolutionary relationships. The inheritance and expression of lipid biosynthetic pathways follows a comparable pattern, whereby a range of diagnostic chemical structures in membrane lipids are largely confined to the domain level or higher. We also have an excellent molecular fossil record of these structures that tells us that many of these biosynthetic pathways are highly conserved and can be seen evolving through geological time. For example, molecular markers for 'recently' evolved taxa, diatoms for example, can be observed to increase in rocks and oils through the Cainozoic. Molecular markers for vascular plants also show secular variation that is consistent with the records of pollen and other visible remains. Evidence from excellently preserved rocks in the 1.64 Ga McArthur Basin tells us that the biosynthetic pathways to acyclic isoprenoids, bacterial triterpenoids, steroids and even some pigments were extant. Very similar assemblages of compounds can be found in rocks of Late Archean age, suggesting that these biosynthetic pathways are indeed highly conserved.

These observations show that it is feasible to search deeper in time for a molecular fossil record of major taxa. However, there are a number of obstacles. We have a very fragmentary, and occasionally flawed, knowledge of the lipids of extant organisms, especially those that have been recognized by their DNA but have not been brought into culture. Many of the diagnostic structures that are known have minimal potential for preservation. We have no knowledge about the types of lipids that may have been synthesised by extinct taxa. Most importantly, the rock record is incomplete and often compromised by the affects of contamination, thermal metamorphism and biodegradation.

This presentation examines some of the ways that we might overcome these obstacles and the potential for extending the molecular fossil record into older strata. It also examines the systematics of how lipids are constructed from simple precursors and ways of testing for the biogenicity of organic compounds that can be applied to extraterrestrial samples.

# Special Session I Abstracts

## Astrobiological Perspectives in Exploring the Solar System

# Abstract # 12627 - **Sub-Freezing Activity of Microorganisms and the Potential Habitability of Mars' Polar Regions**

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The martian subsurface today is generally thought to meet the environmental requirements to be able to support life. Liquid water likely is the limiting factor, and it can occur at depths of 100s of meters to kilometers where temperatures are warmer than at the surface. Geochemical energy is available there through reactions of the water with the surrounding rock or by mixing in hydrothermal systems. Terrestrial organisms, at least, are able to take advantage of these sources of energy to support metabolism. While the deep subsurface is, therefore, a likely place to find life, it is not readily accessible. We examine whether surface temperatures in the polar regions might allow the presence of liquid water and the ability to support microorganisms during periods of high tilt of the polar axis. The tilt, or obliquity, varies on timescales longer than $10^5$ years, and can reach values as high as about 60º. At these high values, solar heating of the polar regions increases, and surface temperatures can rise to near or above 0º C, allowing either thin films of liquid water or near-surface melting. Thin films of liquid water can exist at temperatures as low as -20º C, and psychrotolerant microbes isolated from Siberian permafrost can grow at temperatures as cold as -10º C and can metabolize at -20º C. Thus, Mars in recent epochs had conditions that overlap the coldest conditions on Earth able to support life, and therefore the martian surface is on the edge of being habitable by microorganisms.

In order to determine whether Mars polar conditions at high obliquity overlap those in which life could exist, we consider (i) the minimum temperatures at which liquid water

can exist in soil and ice, (ii) the minimum temperatures at which microorganisms can either grow or metabolize, (iii) the range of obliquity values that can occur and the surface and subsurface temperatures that result, (iv) the distribution of polar ice and ground ice on Mars that could provide a source of melt water, and (v) the general ability of microorganisms to survive and grow in such an environment. We draw on prior analyses in each area, along with new measurements showing the abundance of liquid water in soils at sub-zero temperatures and the growth and metabolism of microorganisms at temperatures as low as -20ºC.

Our results suggest that Mars today appears to be right at the edge of being habitable by microorganisms. An increase in obliquity to high values would allow sufficient liquid water to exist at the surface or within the top meter on the polar cap and at high latitudes that microorganisms could live. While life might have a more difficult time surviving in these regions compared to deep-subsurface habitats, the polar regions are much more accessible. A spacecraft mission to search for dormant organisms, spores, or organic detritus from prior epochs, or for geochemical evidence for liquid water having been present, would not need to land at a specific location determined by the local geology, for example, but could be directed toward a more geographically distributed region. Also, rather than having to drill down 100s of meters or more to access regions where liquid water had been present, access to the topmost meter would suffice. Both of these are within our present-day abilities.

# Abstract # 13047 - **Carbon on Mars: Reservoirs, Processes, and Implications for Biosignatures**

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We have undertaken in situ carbon isotope studies of selected phases in martian (SNC) meteorites in order to address the broad-scale carbon isotope composition of various martian carbon reservoirs. Knowledge of the isotope abundances in such reservoirs, and the nature of the processes that affect them, are necessary if C isotope composition is to be used as an indicator of biogenicity, as is done on the Earth for isotopically light carbon.

In order to constrain the isotopic composition of magmatic carbon on Mars, we have analyzed the C isotope composition of magmatic phosphates in two martian basalts, Los Angeles and Zagami. This required development of a new in-situ approach for analysis of trace C in phosphates with the ion microprobe because the phosphate minerals are small and rare, and conventional C extraction by heating from these C-carriers is extremely difficult and unreliable. The results for two types of phosphate (apatite and whitlockite) for both meteorites show a consistent value of $\delta^{13}C_{PDB}$ of +15 ± 5 ‰. This value should be considered a lower limit on the true magmatic value, as processes such as degassing or decarbonation would tend to lower the $\delta^{13}C$ value preserved in the phosphates. The measured $\delta^{13}C$ value is higher than previous estimates of magmatic carbon isotope composition of between –20 and –30 ‰. These previous estimates are based on bulk extraction of carbon from martian meteorites above 700°C, and suggest that these bulk heating experiments may have been compromised by refractory terrestrial contamination. Our measured value is lower than the terrestrial mantle C isotope composition of ~-5 ‰, but isotopically consistent with the bulk of organic matter in carbonaceous meteorites, the likely source of C on the Mars. This could support the idea that martian magmatic C accurately reflects the planet's accretion history due to the lack of tectonic recycling on Mars.

Near-surface processes are recorded by carbonates in ALH84001. The environment of formation of these carbonates has remained enigmatic despite extensive chemical and mineralogical characterization and abundant in situ O isotope studies. These previous

studies show that the ALH84001 carbonates are strongly zoned in chemical composition (from Mg-ankerite to nearly pure magnesite) and O isotopes (with $\delta^{18}O_{SMOW}$ from ~+3 to +25 ‰, correlated with mineral chemistry). Previous conventional C isotope studies are suggestive of C isotope heterogeneity as well, with $\delta^{13}C$ values typically ranging from ~+32 to +42 ‰. We report the first extensive in situ C isotope analyses of the carbonates. The $\delta^{13}C$ values are highly zoned, ranging from ~+30 ‰ for the Ca-rich carbonates to +60 ‰ for the magnesite compositions. These data were collected using two very different ion probe techniques and encompass the range of previous conventional analyses, giving high confidence in the results.

The ALH84001 data provide new constraints on the formation of the ALH84001 carbonates, which have now been shown to have large, correlated variations in mineral chemistry, oxygen isotope composition, and carbon isotope composition. Specifically, if the C and O isotope variations are the result of a single process, we can firmly rule out several previous models of carbonate formation, including those invoking temperature change and those involving a limited amount of $CO_2$-rich fluid, as neither of these models can account for the large C isotope variation observed. Possible models for carbonate formation that account for the large isotopic variation include fluid mixing, a coupled evaporation/$CO_2$ degassing model, and formation from high pH fluids. Especially the latter two models are consistent with environmental expectations on Mars, and suggest that production of large, abiotic isotopic variations may be common on Mars. In any case, the data confirm the idea that martian atmospheric $CO_2$ was $^{13}C$ enriched, even very early in Martian history, with values as high as +60 ‰. Such isotopic enrichment, probably caused by preferential atmospheric loss of the lighter C isotope, has implications for the history of the martian magnetic field.

In summary, the history of C on Mars is complex in space and time due to atmospheric evolution, the probable lack of long-lived oceans, and lack of plate tectonics. In addition, martian surface conditions are conducive to production of large abiotic C isotope effects. Even with limited samples from Mars, the range of C isotope values observed is 2-3 times larger than typical on Earth, suggesting careful context will be necessary if C isotopes are to be used as a martian biosignature.

# Abstract # 13033 - **Delivery of Water to the Terrestrial Planets**

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Morbidelli et al. (2000) demonstrated on dynamical and chemical grounds that more than an Earth's oceans worth of water could have been delivered by large "planetary embryos" which grew in the asteroid belt during terrestrial planet formation. The source is consistent with current understanding of the water content of the asteroid belt as informed by the chondritic meteorite record, and with the role of the giant planets in clearing the primordial asteroid belt. It is also consistent with the isotopic record of D/H and the oxygen isotopes in Earth and chondritic meteorites, with the latter capping the amount of water that could be delivered in this fashion (Drake and Righter 2002). Alternative distal sources of Earth's water, that is, comets, are ruled out on isotopic or dynamical grounds. A local (1 AU, astronomical unit) source of water for the Earth would require very low nebular temperatures and seems to contradict the meteoritic evidence suggesting that material inward of 2 AU-3 AU was too dry to supply an ocean or more of water.

An asteroidal source for the origin of Earth's water must have implications for the total amount of water that Mars acquired during its formation. At first glance, one might imagine that Mars should gain more water since it is closer to the asteroid belt that is the Earth. However, the stochastic nature of planetary growth implies that this facile inference is incorrect. By analyzing the results of published dynamical simulations, we infer that Mars acquired less water than did the Earth, about 0.05 of an Earth's ocean (1 Earth ocean ~ $1.5 \times 10^{21}$ kg), and the original D/H value for this material was 1.6 SMOW (SMOW = standard mean ocean water, 156 ppm). We then compare these numbers to constraints on the early inventory of Martian water, and the D/H value inferred from SNC meteorites. Finally, we show that the initial abundance and D/H value are consistent with the current D/H value for the Martian atmosphere derived through escape.

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# Abstract # 13048 - **Titan and Prebiotic Chemistry**

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The surface of Titan has always been an enigma, both physically and chemically, because it is for the most part concealed from view by the global aerosol haze. Most of the organic chemistry on Titan that could be relevant to the origin of life, however, must go on at or near the surface, since the atmosphere is lacking any significant source of oxygen, and most prebiotically-interesting compounds contain oxygen. Thus, in order to fully evaluate the relevance of Titan as a natural prebiotic chemistry laboratory, we must better understand the interactions between organic material produced in the upper atmosphere and surface materials that may include transient liquid water. Laboratory analogs of the aerosol material are available from experiments involving irradiation of nitrogen/methane gas mixtures, and the structure and chemistry of these analogs is being investigated. The degree to which these analogs resemble the actual Titan haze will become clearer when the Huygens probe performs pyrolysis/GCMS on the haze in 2005. Huygens will also characterize to some extent the nature of the surface, allowing us to better explore in the laboratory the possible interactions between haze particles and surface materials. This combination of observations and experimental data will also help us plan follow-on missions to Cassini/Huygens for the astrobiological exploration of Titan.

# Abstract # 12891 - **Convective Transport Within Europa**

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**Introduction:** Understanding the potential habitability of Europa requires understanding its history of deformation, including: the origin of its surface features, possible changes in its geological style over time, and the means of material exchange between the surface and interior. We have embarked on a study that integrates these themes. The present study addresses convective transport within Europa, with important implications for the formation of surface features (lenticulae, chaos, and bands), as well as for the potential to transport organisms from the interior ocean to the surface, oxidants from the surface to the ocean, and spacecraft-born contaminants (including terrestrial organisms) from the surface to the ocean.

**Morphological Constraints:** Europa's surface is peppered by pits, domes, and spots that show a peak in their size distribution near 10 km and which tend to have a regular spacing, suggesting an origin through convective diapirism [Pappalardo et al., 1998]. In this model, domes are formed by intrusive diapirism, spots are formed by diapiric extrusion, and pits are formed by drainage of melt to the subsurface. Larger chaos regions might also be accounted for by diapiric processes, potentially related to intra-shell melting or concentrations of low mleting point salts within the ice [Collins et al., 2000; Head and Pappalardo, 2000].

**Method and Previous Work:** We have modified a numerical convection model that was developed to study mantle convection in Earth (Citcom) [Zhong et al., 2000] to study convective motions of ice within Euopa's icy shell. The viscosity of ice as measured in laboratory experiments is strongly dependent on temperature and strain rate [Goldsby and Kohlstedt 2001]. The high viscosity ice at the ~100 K surface temperature of Europa prevents convective motions from reaching the surface, and motion is confined to the low-viscosity sub-layer beneath a stagnant lid.

In past work [Barr et al., 2002] we have explored a range of rheologies of ice considering the acceptable range of Newtonian flow laws and the Newtonian approximations to non-linear rheologies, finding that the stagnant lid thickness varies from 2 to 9 km. Convective velocities in the viscous sub-layer in the shell are on the order 0.1 to 10 cm/yr, implying that the convective portion of the ice shell can be recycled on a time scale of $10^4$ to $10^6$ yr.

**New Results:** We have recently completed modifications of Citcom to take into account the stress-dependent rheology of ice, thereby incorporating the tidal strain rate of $\sim 10^{-10}$ $s^{-1}$ [Ojakangas and Stevenson, 1989]. We present the results of a model which mimcs the

behavior of grain boundary sliding which has a stress exponent $n$=1.8 and activation energy $Q^*$= 60 kJ/mol; we are currently incorporating the full deformation map of ice [Goldsby and Kohlstedt, 2001]. The resultant stagnant lid thickness for this model is 4 km and the brittle/ductile tranistion (BDT) is 2 km, significantly thinner than the 9 km stagnant lid thickness and 5 km BDT predicted by a Newtonian model with a similar activation energy. Sub-layer convective velocities in the non-Newtonian model are larger as well, averaging 4 cm/yr, with local velocities in the smaller-scale convective upwellings reaching 100 cm/yr.

The results of our new model have interesting implications for the potential habitibility of Europa's ocean and for our ability to detect ocean chemistry, life and/or its chemical signature on the surface. Although we are still dependent on resurfacing events to erupt material to the surface where it can be detected, in the non-Newtonian model solid-state convection can deliver material to within 4 km of the surface, which is 5 km closer than previous estimates. Additionally, the brittle/ductile transition of 2 km predicted by the non-Newtonian model well matches the geologically inferred value of 2 km [Pappalardo et al., 1999].

**Future Work:** The current model produces vigorous convection and a shallow brittle/ductile transition depth, even without inclusion of tidal heating. We will next link a convective model of Europa with a visco-elastic deformation model of Europa to characterize tidal heating due to viscous dissipation within Europa's ice (rather than simply as a function of viscosity). We plan to incorporate Byerlee's law in this model to link sub-surface ice motions with surface deformation on Europa. We are also incorporating variations in local strain rate as a function of geographic location on Europa in response to tidal forcing, as such variations may be important in understanding the evolution of any specific location on Europa with time as nonsynchronous rotation occurs.

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# Abstract # 13057 - **Deuterium and the Interstellar Contribution to the Inventory of Solar System Organic Materials**

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A question of key interest in the fields of meteoritics and planetary system formation is the extent to which interstellar materials survive incorporation into forming planetary systems. In the field of astrobiology, there is a particular interest in understanding what interstellar organic compounds survive the transition from interstellar space to planetary surfaces since such compounds could potentially play a role in the origin of life.

In general, the best evidence that interstellar materials survive incorporation into forming stellar/planetary systems is their identification in meteoritic materials through detection of isotopic anomalies. In the case of organic compounds, the chief isotopic tracers are the enrichment of D and $^{15}N$, both of which are seen in carbonaceous chondrites and interplanetary dust particles (IDPs). Thus, these isotopes can serve as key probes of the linkages that exist between interstellar and protostellar/planetary processes.

Various organic materials are currently known to exist in the interstellar medium (ISM). These materials, the environments in which they are found, and the astrochemical processes that are responsible for their creation and alteration will be briefly discussed. Emphasis will be placed on the chemistry occurring in dense molecular clouds, the environments in which new planetary systems form. The principal chemical processes responsible for the creation/alteration of interstellar organics will then be examined in light of the D/H signatures (if any) imposed on their products. The processes that will be considered are ion-molecule, unimolecular photodissociation, gas-grain, and ice irradiation reactions. Each of these chemical processes is expected to lead to significant D enrichments in their products. Furthermore, each process is expected to generate a different isotopic "signature" in its resultant products. Aromatic compounds will be discussed as a specific example of this point.

The talk will then focus on reviewing the isotopic evidence (primarily associated with deuterium) suggesting that some of these interstellar materials have survived incorporation into bodies within our Solar System when it formed. Emphasis will be placed on the survival of organic species of astrobiological relevance.

The talk will end with a brief discussion of the types of future studies that will be required if additional progress is to be made in understanding the interstellar/planetary connection. This includes astronomical (telescopic), laboratory simulation, and meteoritic studies.

# Special Session II Abstracts

## Evolutionary Genomics

# Abstract # 13052 - **Prokaryotic Phylogeny: Lateral Gene Transfer and Long Branch Attraction**

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The phylogeny of prokaryotes is mainly based on the comparison of the 16S ribosomal RNA sequences. In Bacteria, this tree suggests an early emergence of hyperthermophilic organisms followed by an unresolved bush, which is often interpreted as a radiation. Since hyperthermophilic Archaea also emerge early, this has lead to the hypothesis of a hyperthermophilic last universal common ancestor, and even a hot origin of life. Yet, genome sequencing reveals that lateral gene transfers (LGTs) are quite frequent. Indeed, phylogenies based on various proteins are generally incongruent with the rRNA one as well as between themselves. Because of the high frequency of LGTs, some authors have questioned the very existence of a prokaryotic phylogeny. We analyzed all the proteins involved in translation for 45 eubacterial species. Through the use of a newly developed method, we showed that a core of 46 genes shared the same evolutionary history. Interestingly, the phylogeny inferred from their concatenation was very similar to the one based on ribosomal RNA. This suggests that, despite the high frequency of LGTs, it is possible to infer the prokaryotic phylogeny from a core of genes that are not (or extremely rarely) transferred. Similar results were obtained for Archaebacteria. Another major problem that impedes the inference of prokaryotic phylogeny is the existence of tree reconstruction artifacts. For example, in our phylogeny based on 46 genes, the GC content of the genome has some influence on the inference. More importantly, using the Slow-Fast method, we showed that long branch attraction was responsible for the early emergence of hyperthermophilic Eubacteria (Aquificales and Thermotogales). This strongly rejects the hypothesis of an hyperthermophilic last universal common ancestor. Interestingly, our phylogeny indicated planctomycetales as the first branching bacterial group. This little studied phylum is a major division of Bacteria, whose members share several original features such as the lack of peptidoglycan in their cell walls or a budding mode of reproduction. The most intriguing feature is the existence of either a single or a double membrane around the bacterial chromosome in *Gemmata* and *Pirellula* species, which has been compared to the eukaryotic nuclear envelope. Yet, evolutionary homology with the eukaryotic nucleus has not been proved. If the early emergence of Planctomycetales is confirmed by a careful phylogenetic analysis of genome sequences from several representatives of putatively early branching Bacteria, the origin of this domain should be seriously reconsidered.

# Abstract # 12982 - **Interactions between Horizontal Gene Transfer and the Environment**

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Horizontal gene transfer (HGT) is a process through which disparate prokaryotic groups can obtain foreign genetic material in response to a changing environment. It is an ancient process that has altered genomes since, at least, the last common ancestor of life, and it is influenced by abiotic factors such as temperature and pH. HGT is selective and preferentially favors the exchange of some gene types. Operational genes (mostly housekeeping genes) are readily incorporated through HGT, but informational genes (translation, transcription, and other genes) are less readily incorporated through this mechanism. HGT is also influenced by abiotic factors such as temperature and pH. It has been suggested that the collection of organisms that exchange genes can be thought of as a global organism, having an immense population size and a correspondingly great potential for evolving novel genes. Here we ask whether the organisms which share genes truly share them on a global scale, or whether environmental factors can affect its scale. In other words, can geography and environment, or abiotic and biotic parameters, influence genetic exchange by HGT? Our analyses of some 20,000 genes in eight complete genomes show that environmental factors can significantly alter horizontal transfer among prokaryotes.

# Abstract # 12796 - **Defining Prebiotic Ancestral Peptides and Proteins**

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The earliest proteins on Earth would have arisen before cellular life (as we know it) was formed. Many of the early proteins and fragments of proteins must have been ancestors of the complex protein world that exists today. To generate a cell, a process similar to duplication and subsequent divergence must have transpired before the time that a modern-type cell (metabolically capable and self replicating) could arise. Without assumptions about the process of duplication and divergence at those early times, we can nevertheless ask the question "How many and what kinds of ancestral proteins would have been required to generate all the basic life processes found in all free-living organisms today?"

We have approached this question of enumerating and describing protein ancestors by collecting modern proteins into families of similar sequence, and we have further collected these into larger families of similar three-dimensional structure. Examples of large families will be shown. In the category of enzymes, there are many families such as alcohol dehydrogenase families containing a variety of enzymes reactivities, enzymes acting on CoA derivatives, aldolases, transaminases and the like. Many such families contain enzymes having a spectrum of functions. Within each family, even though the reactions may seem different, they are carried out by basically similar chemistries. One presumes that single ancestral proteins could have given rise to the multiplicity of reactions found within any one family. Not only enzymes, but also other protein types, can be gathered into large families. We have also collected large families of regulators and large families of transporters that also could have descended from single ancestral proteins. Each family could represent one early ancestral protein. Thus we believe we have identified some of the types of ancestor proteins that could have generated the massive diversity we find today.

One can also look within proteins for elements of ancestry. Many proteins contain smaller domains that serve (for instance) as necessary for proper folding of the protein, or are required for binding substrates and cofactors, or are required for interaction between proteins. We may assume that the most invariant and widespread of the features of modern proteins were present at early times. We have collected the domains in all E. coli proteins and determined the most numerous classes and the most frequent partners when

more than one domain is present in one protein. These are compared with data for all sequenced proteins from all organisms. With respect to astrobiology, the most prevalent domains in earth's proteins could be used as a basis for probing other planets for presence of proteins or peptides with comparable features.

# Abstract # 12821 - **Evidence for an Ancient Operon of Redox Biochemistry**

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Microbial genome analysis has revealed that the architecture of the genome is quite fluid and dynamic. Limited operonic structures are found intact between closely related organisms. In fact, in spanning the phylogenetic breadth between Archaea and Bacteria less than 20 putative operons are found in common, the majority of these related to ribosomal function. The driving force behind the lack of conserved genome structure is likely to be horizontal gene transfer. This transfer of genetic material can be in pieces that may or may not include portions of genes, single genes, multiple genes, or operons. The presence and frequency of transfer is being indicted as a major reason for phylogenetic incongruity and the lack of confidence in single gene trees.

We report the conservation of a unique putative operon whose phylogenetic history indicates multiple duplication events as well as a robust inclination to spread throughout the bacterial kingdom. The only consistent exceptions to this phenomenon are the absence of the operon in Archaea or cyanobacteria unless they have the capacity to fix nitrogen. This operon is composed of two genes, nifS and nifU, which are involved with iron-sulfur cluster formation. As iron-sulfur cluster formation is integral to the enzymes of many core metabolic functions of both Archaea and Bacteria, the first occurrence of this operon and its subsequent evolution are important.

We report the phylogenetic reconstruction and whole genome analysis for 60 microbial genomes with respect to the following genes: NifS (2 paralogues), NifU, IscA, and CobT. We report the timing of two separate versions of this operon and discuss the likely evolutionary scenario that may have led to their phyletic distribution today.

# Abstract # 12742 - **Bacterial Tubulin: Evidence and Evolutionary Implications**

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Tubulins, the protein constituents of the microtubule cytoskeleton, are present in all known eukaryotes, but until now they have never been reported in prokaryotes. We have found two tubulin-like genes (btuba and btubb) in bacteria of the genus Prosthecobacter (Division Verrucomicrobia). The btuba and btubb genes are arranged as adjacent loci along with a light-chain kinesin gene homolog within the genome. Reverse transcriptase PCR (RT-PCR) experiments indicate that btuba and btubb and the kinesin-like gene are co-transcribed and a probable promoter was identified upstream of btuba. Based on comparative modeling data, we predict that the Prosthecobacter tubulins are monomeric, unlike eukaryotic ( and ( tubulins, which form dimers and microtubules.

Several different hypotheses are possible regarding the phylogenetic implications of finding tubulin genes in bacteria. They could be the result of a horizontal gene transfer event from a eukaryotic organism to these bacteria. However, phylogenetic analyses indicate the bacterial tubulin genes are quite divergent from eukaryotic tubulins, so this does not support a recent horizontal transfer (Figure 1). Alternatively they could represent an ancient horizontal gene transfer event, either from an early eukaryote to the Verrucomicrobia or from an early member of the Verrucomicrobia to a proto-eukaryote. Another hypothesis is that an early member of the Verrucomicrobia gave rise to the eukaryotic lineage. The evidence for these various hypotheses will be discussed along with genomic information that provides further insight into the evolutionary origin of tubulin genes.

# Abstract # 13032 - **Temporal Constraints on the Origin of Complex Multicellular Life**

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Microbial life probably evolved early on Earth, and some believe that microbial life is common in the Universe. Multicellularity also arose early, because diverse living and fossil prokaryotes can occur as filaments or other simple aggregates of cells, usually involving only one or two different cell types. However, multicellularity in eukaryotes can involve as many as 250 cell types and includes elaborate developmental pathways and rapid cell-to-cell signaling. It is of great interest to know how and when complex multicellular life evolved on Earth in order to gain insight into the relative ease or frequency at which we should expect to encounter complex life elsewhere. If complexity evolved relatively late on Earth, and required a series of rare events, then the probability of finding complex extraterrestrial life will be low. Conversely, if complex life appeared earlier and did not involve a series of rare events, that probability would be higher.

The fossil record documents that animals, fungi, and plants are not much older than the Phanerozoic (<0.5 Giga years ago, Ga), which spans the last 10% of Earth's history (i.e., late). However, molecular clocks using large numbers of genes have estimated the divergences of these three groups to as early as 1.5 Ga (Wang et al., 1999; Heckman et

al., 2001), which is the last one-third of the history of Earth (i.e., not quite so late). The origin of cyanobacteria and the symbiotic events involved in the origin of eukaryotes provide other temporal constraints (Hedges et al., 2001). The common ancestor of animals, fungi, and plants was probably single-celled; therefore, the rate at which complexity increased in the three lineages, following their divergence, bears directly on our understanding of the evolution of complex multicellular life. To more clearly understand the problem, we need better phylogenetic trees and greater precision of molecular time estimates.

Nucleotide and protein sequence data from genome projects are increasing rapidly in public databases. We have used all such available data, and have also collected new sequence data for some lineages, to address the phylogenetic and chronological questions concerning the origin of complexity. As with previous molecular clock studies, ancient divergences were found, implying large gaps in the fossil record. In addition, the use of different global and local clock methods gave concordant time estimates. A synthesis of information from diverse areas leads to a new perspective on the rise of complex life and insights into possible mechanisms.

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# Special Session III Abstracts

## Searching for Life Outside the Solar System

# Abstract # 13060 - **How Unusual are Stars with Planets?**

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The frequency of extrasolar planetary systems is clearly a key issue for astrobiology. The first extrasolar planetary system was discovered in 1995. In the few succeeding years, over one hundred planetary-mass companions have been discovered around nearby stars, including several multi-planet systems. With a sample of this size, it becomes possible to examine the statistical properties of the parent stars, with a view to searching for characteristics which set those stars apart from the average field star. A crucial step in this process is constructing an unbiased reference sample, a step rendered possible by the Hipparcos astrometric survey, which allows the identification of every solar-type star within 25-parsecs of the Sun. Those stars provide an unbiased picture of the properties of the local Galactic disk. Comparative analysis of the planetary host stars and the nearby disk dwarfs shows a strong trend for increasing frequency with increasing heavy element abundance. However, at least 5% of solar-metallicity stars have detectable planetary-mass companions and, given current observational selection effects, this must represent a lower limit to the true frequency of planetary systems. Stars with planets are not particularly unusual – at least in the Solar neighbourhood.

# Abstract # 13094 - **The Formation of Earth-like Planets in Extrasolar Systems**

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Current observational techniques permit the detection of giant planets in orbit around nearby Sun-like stars, and roughly 100 of these planets have been found to date. At present, it is not possible to detect extrasolar planets with masses comparable to Earth, although a number of ground-based and space-based observing programmes are being developed with this goal in mind. In many cases, it will prove valuable to know ahead of time which stars are likely to contain Earth-like planets, since this will make it possible to focus the observing effort on these candidates. Here I will investigate to what extent we can make such predictions.

Recently, it has become apparent that the formation and survival of Earth-like planets is controlled largely by the presence of giant planets orbiting the same star. In the Solar System, the giant planets orbit beyond 5 AU from the Sun, and terrestrial planets located between the orbits of the giants are unstable. Many orbits in the asteroid belt and Kuiper belt are stable, but gravitational perturbations from the giant planets prevented smaller planets from accreting in these regions. Only in the region interior to 2 AU were the gravitational effects of the giant planets small enough to permit terrestrial planets to form and survive. Not coincidentally, this region encompasses the Sun's habitable zone, in which Earth-like planets are able to maintain liquid-water surface temperatures.

One of the most surprising results of the search programmes that have detected extrasolar planets is the great diversity in their orbits and masses. Essentially, these objects have a range of masses, orbital periods, and orbital eccentricities that fills the portion of phase space that has been searched to date. In many of these systems, terrestrial planets are likely to form in different locations than in the Solar System, due to differences in the perturbations of the giant planets. In a number of cases, terrestrial planets may not form at all. The planetary system of 47 UMA, which currently represents the best analogue of the Solar System, provides a good example. This system contains 2 Jupiter-mass planets with roughly circular orbits lying very roughly 2 and 4 AU from the star. Numerical simulations show that stable orbits exist in the habitable zone of 47 UMa, but that the giant planets would have frustrated the accretion of any habitable planets.

In many other systems, one can determine immediately that any terrestrial planets in the habitable zone would be unstable. However, as the 47 Uma system shows, the presence of stable orbits in the habitable zone does not automatically imply that habitable planets would have formed. I will present results of a wider study of terrestrial-planet formation and survival in extrasolar systems, examining both observed systems and artificially-generated systems of giant planets. These simulations show a clear correlation between the characteristics of the giant planets in a system, and the formation locations and formation efficiency of terrestrial planets. In addition, it is possible to address the question of whether these terrestrial planets will contain materials such as water, carbon and nitrogen, that are likely precursors of life.

# Abstract # 13041 - **What Compounds Do Micrometeorites Contribute to the Atmospheres of Habitable Planets?**

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Over four billion years after its formation, the Earth still accumulates about 40 million kilograms of extraterrestrial material yearly, mostly in the form of micrometeorites ~100 micrometers in size. The flux of micrometeorites would have been much higher when the Earth was much younger; thus, particles in this size range potentially supplied the inchoate biosphere with organic compounds. However, micrometeorites suffer extreme flash-heating to tempeatures in excess of 1500 K upon atmospheric entry. Such high temperatures have been thought to destroy the organic content of micrometeorites, and so these particles have been underappreciated as important sources of extraterrestrial organics.

To address this issue, we are conducting experiments to quantify what products evolve from micrometeorites upon atmospheric entry. Particles in the 100-300 micron size range are subjected to conditions similar to those experienced during entry into the Earth's early atmosphere (e.g., low pressure, low oxygen levels, heating rates up to 500 K/sec). Our results indicate that many aromatic compounds are released under these conditions, including numerous alkylbenzenes, alkylnapthalenes, benzene nitrile, styrene, various alkyl thiophenes, and small polycyclic aromatics. Methane, carbon dioxide and water are also important compounds that may be released from these particles, and we are measuring the release of these compounds as well.

Our results strongly suggest that micrometeorites were potentially important sources of carbon in the atmosphere of the early Earth, and by extension, young habitable planets. Aromatic compounds are excellent absorbers of UV radiation and may have served this purpose before the ozone layer formed. Because the flux of micrometeorites may indeed be quite high in the first few hundred million years of a habitable planet's life, it is important to get an inventory of these volatiles because of their roles as greenhouse gases and UV absorbers. Because the presence of life on terrestrial planets will be inferred from the presence of compounds in chemical disequilibrium with one another, it is particularly important to understand and quantity the flux of compounds from endogenous as well as exogenous sources.

# Abstract # 13068 - **Environmental Consequences of an Emerging Biosphere**

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It seems feasible to detect biological signatures ("biosignatures") in other planetary systems using the tools of astronomy. There are at least two types of biosignatures: (1) spectral and/or polarization features created by biological products; and (2) electromagnetic signals created by technology. The latter example of a biosignature requires SETI-like searches. This presentation addresses only spectral signatures of biological products and properties of habitable planets. Spectral biosignatures are indeed promising targets for near-term exploration. They can arise from organic constituents (e.g., vegetation) and/or inorganic products (e.g., atmospheric $O_2$). Features originating from a planet's surface are likely to be localized in specific regions, whereas gaseous biosignatures can become globally distributed by atmospheric circulation.

Biosignatures should be most abundant within environments that are, or once were, habitable. We currently believe that habitable environments necessarily provide liquid water and biochemically useful energy. However, we do not yet fully comprehend the diversity of features that might arise within these environments that are non-biological in origin, yet mimic biosignatures. For example, atmospheres reflect the events leading to their origins as well as a host of ongoing planetary processes that might include biological activity. We are persuaded that abundant atmospheric oxygen in an environment with abundant liquid water constitutes definitive evidence of life. However, our own early biosphere thrived for more than a billion years in the absence of abundant atmospheric oxygen. The production of other, more reduced, gaseous biomarkers of "young" and/or anaerobic biospheres has not been systematically studied. Biological gas production is strongly controlled by the structure and function of microbial ecosystems. Investigations of microbial ecosystems that are close analogs of ancient communities offer multiple benefits. Such studies can interpret the production of the most important biomarker gases, while simultaneously helping us to understand the formidable array of ecological processes that guided the early biological evolution. Astrobiologists must recognize those aspects of biosignatures that truly reflect the most fundamental, and therefore universal, properties of life. We must learn how the environment can modify biosignatures, and how technology can enable an array of biosignatures to be detected remotely within realistic budgetary constraints.

**REFERENCE:** Des Marais, D. J., Harwit, M., Jucks, K., Kasting, J. F., Lunine, J. I., Lin, D., Seager, S., Schneider, J., Traub, W., Woolf, N. (2002) Remote sensing of planetary properties and biosignatures on extrasolar terrestrial planets. *Astrobiology*, Vol. 2, No. 2, 153-181.

# Abstract # 13070 - **Characterizing Extrasolar Terrestrial Planets Using Remote Sensing**

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Once an extrasolar terrestrial planet has been detected and resolved from its parent star, a combination of remote-sensing techniques will be needed to characterize its environment and potential for habitability. The photometric and spectroscopic techniques, which have been developed for studies of the Earth and its planetary neighbors, will provide an excellent starting point for these investigations. However, great care will be needed to retrieve unambiguous results from disk-averaged observations like those anticipated from the first generation instruments, like those being considered for the Terrestrial Planet Finder. Here, we summarize the information content of commonly used remote sensing methods and their implications for the design and operation of future observing systems.

***Photometry and Photometric Variability:*** Time-resolved, disk-averaged photometric observations have provided a wealth of information about planets and small bodies in our solar system and may yield some of the first clues about the environments of extrasolar terrestrial planets. For example, the intensity of the radiation that is reflected and emitted by a planet provides constraints on its effective temperature. However, the size of the body must be known to retrieve quantitative information from such data. In principle, that information could be retrieved from time-resolved photometric observations acquired as the planet occults field stars. This approach would also help to determine whether the planet has an atmosphere, and it could provide constraints on its vertical structure. On longer time scales, time-resolved photometric observations collected as the planet rotates and moves along its orbit track might reveal brightness or color changes associated with the surface or atmosphere, providing additional clues to its environment (e.g., ice caps, clouds, continents, oceans; Ford, Seager and Turner, Nature, 2001, 412, p885).

Temperature estimates derived form photometric measurements collected over a limited spectral range must be interpreted with caution by astrobiologists because planets with atmospheres adequate to support life can have albedos and emissivities that vary dramatically with wavelength. Photometric measurements obtained at a few visible, near-infrared (IR) or thermal IR wavelengths could address this concern. Multi-spectral photometric observations would also reveal the planet's "color", which could provide additional clues to the composition of its surface and/or atmosphere.

***Spectroscopic Techniques:*** Spectra of the Earth and other planets in our solar system have yielded a great deal of information about their atmospheres surfaces. For example, moderate resolution ($100 < \lambda/\Delta\lambda < 600$) thermal IR spectra have provided the best available global constraints on the thermal structure of the atmospheres of Venus, Earth,

Mars, and Jupiter, and the only available constrains on the atmospheres of Saturn, Uranus, and Neptune. These spectra have been combined with ultraviolet (UV), visible, and near IR spectra to derive the ambient atmospheric pressure of the effective reflecting or emitting layer (surface or cloud top) and the trace gas composition above that level. These spectroscopic remote sensing techniques should also be ideal for studying the environment of extrasolar terrestrial planets. They are also needed to search for classical chemical disequilibrium biosignatures, such as the simultaneous presence of highly oxidized (e.g., $O_2$, $O_3$) and reduced ($CH_4$, $NH_3$, OCS, $H_2S$) species.

A cursory inspection of a low-resolution ($\lambda/\Delta\lambda < 100$) IR spectrum will establish whether the planet has a substantial atmosphere. If it does, a more thorough analysis of the spectrum will identify its primary absorbing gases. If, as on Earth, the primary atmospheric constituent ($N_2$) has few identifiable spectral features, its presence and total mass can still be inferred from moderate to high resolution ($500 < \lambda/\Delta\lambda < 1000$) spectra, because of its pressure broadening effects on the IR absorption lines of other gases. If the atmosphere is sufficiently transparent that radiation can escape from the surface, (e.g., Earth, or Mars), the total atmospheric mass can be derived from spectroscopic data. For cloudy atmospheres, (i.e., Venus or the Jovian planets), this will yield constraints on the cloud top pressure. In many such cases, observations at UV, visible, and IR wavelengths will indicate different effective pressures (and surface temperatures). While such results may initially cause confusion, a more complete analysis of the spectrum should yield additional insight into the vertical structure of the atmosphere.

Once the primary absorbing gases and the pressure of the emitting/reflecting surface of an extrasolar planet have been estimated, the surface temperature and atmospheric thermal structure can be derived from thermal emission spectra using conventional remote sensing retrieval techniques. Global-scale constraints on the atmospheric thermal structure would be of great value in studies of the planet's climate and chemical equilibrium. Estimates of the globally averaged surface temperature are also needed to determine whether liquid water is stable on the surface.

Time-resolved spectroscopic observations may reveal variations in surface and atmospheric composition that are linked to diurnal or seasonal variations, and may also be produced by the presence of life. For example, time-resolved spectroscopic observations of the Earth would reveal temporal variations in the atmospheric $CO_2$ and $CH_4$ abundance that are correlated with seasonal variations in the respiration and photosynthesis of land plants. Such periodic observation on an extrasolar planet would provide compelling evidence for an active biosphere.

Each of these spectroscopic and photometric objectives places specific requirements on the spectral range and resolving power, sampling rate, signal-to-noise ratio of future instruments. Specific examples from our solar system will be used to derive and motivate each requirement.

# Abstract # 13061 - **NASA's Terrestrial Planet Finder**

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NASA has made the search for life (both inside and beyond our solar system) a focus of its space science program. The goal of the Terrestrial Planet Finder (TPF) is to search for Earth-like planets.

Recently completed architecture studies suggest that both infrared and visible light techniques offer plausible solutions to the daunting observational problems this goal presents. I will summarize NASA's program, the results of recent studies, and the prospects for international collaboration on TPF.

# Special Session IV Abstracts

## Life in Extreme Environments

# Abstract # 13093 - **Stochastic Astronomical Radiation and the Limits of Life**

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Earth or any exoplanet will be exposed to a stochastic bath of UV and ionizing radiation from astronomical sources ranging from flares on the host star to supernovae. This radiation can induce polymer formation, create or repair mutations, provide an environment where radiation repair mechanisms and associated biological processes like lateral gene transfer and meiosis evolve, disturb a planet's atmospheric chemistry, and, under extreme circumstances, partiallly sterilize a planetary surface. We have evaluated the probability of exposure to certain of these stochastic sources, stellar flares on timescales of days to centuries depending on the host star and several hundred biologically significant supernova per Gyr. We have also computed, using a Monte Carlo radiative transfer code, the biologically-effective doses after transmission through model planetary atmospheres of various thicknesses. We find that while a thick atmosphere like that of the Earth provides protection from direct exposure to incident ionizing radiation, a significant fraction, about 1%, of incident hard radiation can reach the ground by auroral processes that convert the incident energy to biologically-active UV flux.

# Abstract # 12881 - **Diversity of Rock-Hosted Microbial Communities from High pH Hydrothermal Vents at the Lost City Field**

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Most of the well-characterized mid-ocean ridge hydrothermal systems are driven by volcanic and tectonic activity associated with basaltic oceanic crust and often result in the production of reducing, low-pH, metal laden hydrothermal fluids. However in some areas of the seafloor ultramafic mantle rock (peridotite), rich in Fe- and Mg- bearing minerals, has been exposed due to tectonic uplift. In such environments, exothermic reactions involving the serpentization of iron-bearing minerals (i.e. olivine + $H_2O$ ±C (or $CO_2$) → serpentine + magnetite + brucite ±$CH_4$ ±$H_2$) in the susbseafloor provides an additional source of heat and drives hydrothermal circulation. The conditions created by such reactions, which include significant quantities of dissolved methane and hydrogen, may favor microbial communities specifically adapted to this unusual vent environment.

In this regard, a novel peridotite-hosted hydrothermal environment was discovered in December 2000 at 30ºN near the Mid-Atlantic Ridge (see also Kelley, et al.). This site, named the Lost City Field (LCF), contains multiple large (up to 60 m), carbonate chimneys venting high pH (9-10), moderate temperature (45-75ºC) fluids. The LCF is unusual in that it is located on 1.5 my-old oceanic crust, 15 km from the nearest

spreading axis. Ultramafic, reducing hydrothermal environments like the LCF may be analogous to geologic settings present on the early Earth, which have been suggested to be important for the emergence of life. Additionally, the existence of hydrothermal environments far away from an active spreading center expands the range of potential life-supporting environments elsewhere in the solar system.

The abundance and diversity of microbial communities inhabiting carbonate chimney structures from LCF was analyzed by culturing, microscopic, and molecular methods. Enrichment culturing from chimney material yielded microorganisms in media designed for methanogenesis, methane-oxidation, and heterotrophy at mesophilic and thermophilic temperature regimes. Cell abundances between $10^5$ and $10^7$ cells/g were observed within samples collected from the various chimneys. A subset of the microbial population in direct contact with vent fluids fluoresced with Flavin-420, a key coenzyme involved in methanogenesis. In situ hybridization analysis of microorganisms from LCF revealed that Archaea and Eubacteria are important parts of the cell populations. 16S rDNA clone libraries show that diverse microbial communities, including autotrophic microorganisms and macrofaunal symbionts, are contained within the vent structures. These results indicate that abundant and varied microbial communities inhabit different regions of the chimney structures and may be specifically adapted to the reducing, volatile-rich fluids percolating through the chimneys.

In addition to expanding the range of known deep-sea ecosystems, the microbial ecology of carbonate structures associated with hydrothermal venting at the LCF may provide key insights into the microbiology of subsurface environments near this site. Studying the microbial communities within these systems will enable us to better understand geo-microbial processes associated with serpentinite environments and perhaps allow us to expand our search for life elsewhere in the universe.

# Abstract # 12704 - **Combining High-Pressure Physics with Biology**

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By applying the experimental tools and techniques from high-pressure physics to biology, we have monitored physiological and metabolic activity of Shewanella oneidensis strain MR1 and Escherichia coli strain MG1655 at extreme pressures. Enclosing the microbes within a diamond anvil cell, we measured biological formate oxidation rates to 1 GPa (10 kbar) pressures. At pressures of 1200 to 2200 MPa, living bacteria were observed to reside within fluid inclusions in high density ice phases and continued to be viable upon subsequent release to ambient pressures. Evidence of microbial viability and activity at these extreme pressures raises important questions regarding the adaptability, survivability and viability of life in extreme environments. Besides providing a direct observation approach to experimentation on microbial life at extreme conditions, our observations expand by an order of magnitude the range of conditions representing the habitable zone in the solar system.

# Abstract # 13040 - **A New Photosynthetic Green Sulfur Bacterium Isolated from Deep-Sea Hydrothermal Vents**

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Photosynthetic organisms are usually restricted to environments where sufficient light is available to sustain cellular functions. This includes the surface of the land and the photic zone of aquatic systems. The photic zone of the ocean extends from the surface to about 250 meters below the surface. Below this depth, there is insufficient light available to sustain photosynthesis.

A possible exception to this rule is in the vicinity of deep-sea hydrothermal vents. These vents are at depths (~2000-2500 meters) where no surface light can penetrate. However, the vents are sufficiently hot that they produce a weak light emission. This vent light has been measured and found to be of sufficient intensity such that photosynthesis in this environment could be possible.

In December 2001, a team of scientists explored the deep sea hydrothermal vents off the coast of Puntarenas, Costa Rica at the 9°N dive site along the East Pacific Rise. Samples were collected both at the vents and at control sites away from the vents. The samples were subsequently cultured on a variety of media in an attempt to establish laboratory cultures of any vent phototrophs. A number of isolates were cultured from these samples, including an isolate that shows spectral characteristics of a photosynthetic green sulfur bacterium. Phylogenetic analysis of both 16S rRNA and the FMO antenna complex confirms that this isolate is grouped with the genus *Prosthecochloris* within the subset of green sulfur bacteria. Further characterization of this isolate is underway.

# Abstract #12629 - **Ultramafic-Hosted Hydrothermal Systems: The Lost City Field as a Possible Guide for Early Life**

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Ultramafic-hosted hydrothermal systems must have been common during early Earth-ocean formation, prior to the development of an extensive crustal sequence. Such environments would have been characterized by the production of warm alkaline fluids, which may have been a requirement for the emergence of life on/within the seafloor. Model calculations based on thermodynamic considerations and experimental studies suggest that synthesis of numerous organic compounds is favored during mixing of warm, serpentinite-derived, high-pH, reducing fluids with cool, oxygenated seawater (Shock and Schulte, 1998). Dissolved hydrogen, present in hydrothermal fluids due to reaction of olivine and other iron-bearing minerals, provides the reduction potential and the thermodynamic drive for organic synthesis. Significant quantities of methane and hydrogen produced during serpentinization reactions may have provided nutrients critical for the establishment of early microbial communities.

The peridotite-hosted Lost City Field (LCF), discovered in December of 2000, may represent our closest analogue to hydrothermal systems operative during early Earth. This recent discovery raises the possibility that such systems are prevalent not only on Earth, but that similar systems may have existed or currently exist elsewhere in the solar system. The LCF, which rests atop the Atlantis massif at 30°N on the Mid-Atlantic Ridge, is unlike any previously known hydrothermal field in that: 1) it is located on 1.5 my-old crust, nearly 15 km west of the spreading axis; 2) it hosts at least 30 active and inactive carbonate-brucite chimneys that tower up to 60 m above the seafloor; 3) the venting pinnacles appear to be the surface expression of warm (40-75°C), high pH (9-10) fluids emanating from fault zones that tap a region of active serpentinization in the underlying peridotites; and 5) hydrothermal flow is driven by exothermic serpentinization reactions at depth.

The LCF rests on a terrace at a water depth of 700-800 m and is underlain by a diverse suite of mafic and ultramafic basement rocks that crop-out on the cliffs immediately below the edge of the scarp. The field extends for at least 300 m across the terrace and hosts at least 30 active and inactive structures. Just to the south, cliffs composed of basement material show extensive areas of active and inactive white hydrothermal

precipitates. These deposits fill fractures and form hundreds of large flanges that protrude as much as 2 m from the cliff face. Within the field, active and inactive vents form spires, mounds, pinnacles, and flanges. Large isolated pinnacles are commonly 10-30 m tall. But, the most spectacular of the pinnacles is a giant edifice (Poseidon) that rises 60 m above the seafloor, making it the tallest hydrothermal deposit yet discovered. The top of this composite structure is actively venting 75°C fluid. On this and other large pinnacles, flanges exhibit concave-down forms, which trap highly reflective pools of 40°C-55°C vent fluid.

Active structures within the LCF are typically awash in buoyantly rising mixtures of warm vent fluid and cooler seawater. The diffuse vents support dense microbial communities that commonly form white to light grey colored filamentous strands several centimeters in length. Preliminary investigations of microbial communities show extensive biofilm development on mineral surfaces from within the carbonate structures that contain filaments, rods and cocci. Cell counts from active samples reach $>10^7$ cells/gm. Enrichment culturing of chimney material in aerobic and anaerobic media yielded microorganisms in the hyperthermophilic (90°C), thermophilic (50°C, 70°C) and mesophilic (25°C) temperature regimes in media designed for methanogenesis, $CH_4$-oxidation, and heterotrophy.

Many of the carbonate veined serpentinites (ophicalcites) and breccias that underlie the LCF are similar to those known from ancient ophiolites, including Archean (>3000 m.y. old) examples. These types of assemblages may represent a linkage to hydrothermal and possibly biological activity at the time of the oldest known life on Earth. The warm, organic- and volatile-enriched environment present within the porous interior of ancient hydrothermal deposits may have been extremely suitable habitats for the emergence of thermophilic or hyperthermophilic anaerobic organisms capable of utilizing methane and hydrogen.

The discovery of the LCF serves as a vivid reminder that there is much left to be discovered about mid-ocean ridges and the life that they support. Although there is strong evidence that serpentinite-hosted systems similar to the LCF are widespread in slow-spreading environments, Lost City is the only such field visited to date. We do not yet know what the chemical impacts are of such off-axis systems on the oceans, or what types of microbial communities are supported by serpentinization. If high pH, reducing, ultramafic systems are the closest analogue to early Earth environments, Lost City may provide important new insights into ancient microbial ecosystems.

# Abstract # 13012 - **Yellowstone National Park Offers Public Access to Astrobiology**

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Yellowstone National Park (YNP) provides insights into the origin and evolution of life and the potential for life to exist beyond Earth. Biochemical clues hint that our early ancestors might have lived in high-temperature environments, including hot springs. Ancient spring alcoves on the flanks of Martian volcanoes invite comparisons with YNP, whose fossil-rich sinter spring deposits might, in turn, resemble deposits on Mars. A new visitor center is planned at Old Faithful, and interest in astrobiology is rising among the three million visitors of all ages that experience YNP each year. Thus the time has come to initiate a focused outreach project that highlights both astrobiology and the work of the NASA Astrobiology Institute (NAI) in the Park. The Ames NAI Team, its partners, and YNP staff are creating trailside signs to exhibit astrobiology throughout YNP. This integrated team is also developing chapters on astrobiology and microbiology for the Yellowstone Resources and Issues Guide, a training manual for the interpretive research staff. Knowledge of Park resources and accurate information are fundamental elements of the interpretative equation. This team effort will help the general public to enhance their knowledge and skills and to access NASA research in astrobiology, including geology, microbiology and space missions.

# Special Session V Abstracts

## Advances in Ecological Genomics

# Abstract # 13067 - **Development of Specific and Sensitive Microarray-Based Technology for Detecting Microorganisms in Environmental Samples**

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Using oligonucleotide microarray hybridization for detecting 16S rRNA genes is a great challenge due to their secondary structure. To determine whether single mismatch discrimination can be achieved with microarray hybridization for 16S genes, a model oligonucleotide microarray was designed and fabricated containing probes derived from 3 different regions of 16S genes, with *nir*S and *amo*A genes as a control. These probes have 1-5 mismaches at various positions. Five target templates of 50 bp were also synthesized. The hybridization conditions for optimal discrimination of single-base differences were optimized using different buffer compositions. Our results indicated that the position of mismatch, type of mismatch and the concentration of hybridization additives such as formamide and tetramethylammonium chloride (TAMCl) significantly affected the discrimination power and signal intensity. The hybridization signal intensity of the probes with a single-base mismatch is about 10-30% of the signal intensity with the perfect-match probes, depending on the type of nucleotides. The signal intensity of the probes with two-base mismatches is about 5-25% compared to the perfect match probes. Probes with three or four base pair mismatches gave very low signal intensity, which are less than 5% of the perfect match probes. Maximum discrimination and signal intensity were achieved with the probe length of 19 bp. These results indicated that single-base discrimination for 16S rRNA genes can be achieved with array-based hybridization. We have also developed a novel amplification system to improve microarray detection sensitivity. With this system, as low as 10 fg DNA can be detected. Such a system could be very useful for detecting microorganisms in spaceship samples.

# Abstract # 13059 - **A Community Genomics Study of Microorganisms Associated with Acid Mine Drainage Generation**

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Acid mine drainage (AMD) is a biologically-mediated process that is intrinsically linked to environmental geochemistry. Biologically-mediated metal sulfide dissolution produces solutions that are extremely acidic (pH <1.0), have very high ionic concentrations (arsenic, copper and zinc), and are moderately hot (30 to 50˚C). All AMD microbial communities investigated to date comprise only a handful of phylogenetically distinct organisms, typically dominated by the iron-oxidizing members of the *Nitrospira* and *Thermoplasma* lineages. Also, AMD communities are chemoautotrophic and isolated from external sources of fixed carbon and nitrogen. Hence, they provide an ideal opportunity to explore microbial community structure and function at the level of pathways and to examine evolution and genome heterogeneity. We are investigating AMD communities growing in a pyrite-dominated metal sulfide deposit at the Richmond mine at Iron Mountain, CA.

We have undertaken a community genomics analysis of a pink subaerial biofilm collected from the Richmond Mine in March 2002. This biofilm community comprises six phylogenetically distinct populations; ~75% *Leptospirillum* group II (closely related to *Leptospirillum ferriphilum*), ~10% *Leptospirillum* group III, <1% *Sulfobacillus*, and ~10% Archaea that fall into three distinct groups within the *Thermoplasmatales* order (*Ferroplasma* sp., for which genome data is already available, "A-plasma" and "E-plasma"). High throughput sequencing of two 16S rDNA clone libraries (384 clones sequenced from both ends) confirmed the low species-level diversity in this community and suggested that the extent of microheterogeneity within each of the six populations was limited. 17 unique *Leptospirillum* group II 16S rDNA phylotypes (defined by one or more base changes) were resolved, with ~85% belonging to one phylotype. The remaining ~15% were very similar in sequence identity, only diverging by 1.2% in total. Similarly, 14 unique *Leptospirillum* group III phylotypes formed a tight cluster with ≤

0.8% sequence divergence. The limited intra-population, and significant inter-population sequence variation in the community should allow determination of the gene content and metabolic pathways of the majority of community members (especially *Leptospirillum* spp.), permit evaluation of the genomic heterogeneity within each species population, and potentially enable reconstruction of genome fragments and whole genomes.

We have constructed a small (3-4 Kb shotgun) and large-insert (40 Kb fosmid) library from the target community genomic DNA. The Joint Genome Institute (JGI) has initially sequenced 2 Mb from the small insert library. Surprisingly, when the data was assembled using Phredphrap, almost a quarter of the sequence reads formed contigs. Using the Lander-Waterman equation we predicted that the size of the community genome being sampled is only marginally larger than the estimated size of the community based on the genome sizes of pure culture representatives of each population, 8.3 Mb, excluding *Sulfobacillus* which is a minor component of the community (<1%) and unlikely to be adequately sampled in the community genome libraries. This suggests that each population is dominated by a single genome-type and that reassembly of the AMD community genome may be more tractable than initially thought. The largest contigs in the community genome assembly were all chimeric artifacts consisting of conserved transposases in multiple genomic contexts. In particular, low stringency assemblies rapidly targeted especially successful (multiple copy) transposases within the populations. After removal of chimeric contigs, the community genome size is estimated to be 9.1 Mb. We have designed the major phase of the sequencing so that we maximize the chances of recovery of large genome fragments, potentially permitting genome reconstruction.

Similarity searches of the initial 2 Mb of sequence data revealed many genes, consistent with the chemoautotrophic lifestyle of the community. These include $C0_2$ fixation genes (RuBisCo, RuBisCo transcriptional regulator), nitrogen fixation genes (nifA, nifS, nifU, nif-specific regulator), and many electron transport chain components. None of the $CO_2$ an $N_2$-fixation genes identified in the community genome data had close matches to the *Ferroplasma* genome, suggesting that they may all come from the *Leptospirillum* genomes. Organism-resolved metabolic pathway information will be used to develop methods to monitor microbial activity in the environment. Ultimately, our goal is to develop a predictive analytical ecological model that resolves the linkages, feedbacks, and controlling variables that underpin acid mine drainage generation.

# Abstract # 12660 - **Expression Profiling of the Microbial Mat Organism: *Microcoleus chthonoplastes***

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Consortia of microorganisms that can adapt to extreme conditions will most likely be the dominant life forms in habitable zones beyond Earth. The microbial mats of Guerrero Negro in Baja California (Mexico) resemble structured communities that could have existed during the early development of life on this planet. While a number of studies have helped catalog the microbial diversity found in these mats, we have little understanding of the specific mechanisms enabling the organisms to withstand such extreme environmental stresses as a threefold increase in salinity as compared to open ocean.

To address this question at the genomic level, we have constructed a microarray-based system to study cyanobacterial expression patterns in these mats. Our array consists of approximately 1100 unique *Microcoleus chthonoplastes* cDNA clones that will be used to monitor cyanobacterial gene expression in response to a number of environmental conditions. In order to study specific adaptations to extreme environments, we are comparing axenic cultures from the hyper saline Guerrero Negro region with a strain found in the more typical environment of Sippewisset Marsh (Massachusetts). These two strains show significant variation in the intergenic spacer region of 16S ribosomal RNA. This suggests the two are sufficiently divergent to warrant individual examination for possible adaptations in response to the unusual Guerrero Negro conditions. While these experiments focus specifically on *Microcoleus*, ultimately we will apply this approach to examining global expression patterns of the entire interrelated mat community. Here we present preliminary results from a comparison of these two *Microcoleus* strains.

# Abstract # 13066 - **Transcriptome Dynamics of Deinococcus radiodurans Recovery from Ionizing Radiation**

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Deinococcus radiodurans (DEIRA) is a bacterium best known for its extreme resistance to the lethal effects of ionizing radiation, but the molecular mechanisms underlying this phenotype remain poorly understood. To define the repertoire of DEIRA genes responding to acute irradiation (15 kGy), transcriptome dynamics were examined in cells representing early, middle, and late phases of recovery using DNA microarrays covering 94% of its predicted genes. At least at one time point during DEIRA recovery, 832 genes (28% of the total predicted genes) were induced and 451 genes (15%) were repressed two-fold or greater. The expression patterns of the majority of the induced genes resemble the previously characterized expression profile of recA following irradiation. DEIRA recA, which is central to genomic restoration following irradiation, is substantially up-regulated upon DNA damage (early phase) and down-regulated before the onset of exponential growth (late phase). Many other genes were expressed later in recovery, displaying a growth-related pattern of induction. Genes induced during the early phase of recovery included those involved in DNA replication, repair, recombination, cell wall metabolism, cellular transport, and many encoding uncharacterized proteins. Most striking was the observation that metabolic functions, in particular, appear to play crucial roles in DEIRAís recovery from acute radiation. Collectively, the microarray data suggest that DEIRA cells efficiently coordinate their recovery by a complex network that involves the regulation of multiple cellular functions. Components of this network include: (1) a predicted novel ATP-dependent DNA ligase, which appears to functionally replace the repressed NAD-dependent DNA ligase; and (2) metabolic pathway switching that could prevent additional genomic damage elicited by metabolism-induced free radicals.

# Abstract # 13046 - **Genome-Based Tree Building Applied to 55 Ecological Bacteria, Archaea, and Eukarya**

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We constructed genomic trees based on the presence and absence of families of protein-encoding genes observed in 55 prokaryotic and 5 eukaryotic genomes. There are features of the genomic trees that are not congruent with typical rRNA phylogenetic trees. In the bacteria, for example, *Deinococcus radiodurans* falls within the gram-positive bacteria, as a sister group to the low GC gram positives, a result which is also seen in most other phylogenetic studies using whole genome data.

In the Archaea, the methanogens form a united clade and the Euryarchaeota are divided with the two *Thermoplasma* genomes and *Halobacterium* sp. falling below the Crenarchaeota. While the former appears to be an accurate representation of methanogen-relatedness, the misplacement of *Halobacterium* may be an artifact of parsimony.

These results imply the last common ancestor of the Archaea was not a methanogen, leaving sulfur reduction as the most geochemically plausible metabolism for the base of the archaeal crown group. It also suggests that methanogens were not a component of the Earth's earliest biosphere and that their origin probably occurred sometime during the Archean.

In the Eukarya, the parsimony analysis of five Eukaryotes using the Crenarchaeota as an outgroup seems to counter the Ecdysozoa hypothesis, placing *Caenorhabditis elegans* (Nematoda) below the common ancestor of *Drosophila melanogaster* (Arthropoda) and *Homo sapiens* (Chordata) even when efforts are made to counter the possible effects of a faster rate of sequence evolution for the *C. elegans* genome. Further analysis, however, suggests that the gene loss of "animal" genes is highest in *C. elegans* and is obscuring the relationships of these organisms.

# Abstract # 12545 - **A Liquid Proteomics Analysis of Survival Mechanisms in Bacteria**

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The work described herein involves the development of new technology for screening the protein content of bacterial cells. These methods will be applied to the study of bacterial response to temperature adaptation, especially to mechanisms for survival under low temperature conditions. Although DNA serves as the blueprint of the cells, it is the proteins that perform the functions and dynamic processes that ultimately determine cell phenotype and its response. This is especially important in bacterial cells where small changes in protein expression may be responsible for changes in the phenotype of the cell which allow for survival under extreme conditions. These protein expression differences for bacterial cells grown under different conditions are monitored using a 2-D liquid phase separation, which provides a map of the protein content of the cells. The map formed will be analogous to the 2-D gel concept for imaging proteins from cells, but it will use a liquid-based technology which can be adapted to other technologies for protein analysis.

The protein separation in our work is performed using a liquid phase pI-based fractionation in the first dimension and reversed-phase HPLC in the second dimension. The first dimension utilizes chromatofocusing, which is a column-based method for separating proteins using pH. This method can provide a separation of proteins between pH 4-9 and allows for fractionation of proteins in intervals of <0.2 pI. The narrow range fractionation allows for separation and detection of large numbers of proteins that may otherwise remain unresolved in gelñbased separations. In addition, the method allows the loading of >5 mg of sample so that substantial amounts of protein are available for

further analysis. In the second dimension, nonporous silica (NPS) reversed phase HPLC is used to separate large numbers of intact proteins. This method provides a means for rapid separation of large proteins with high recovery of protein in the liquid phase. The proteins can be detected by UV absorption so that a 2-D liquid map of the protein content of a cell can be detected. Of great significance to these studies is that isolated proteins in the liquid phase are collected for peptide mapping studies using MALDI-mass spectrometry. In addition, the liquid eluent can be interfaced directly to a mass spectrometer for analysis of intact proteins for their molecular weight using electrospray mass spectrometry. Using this method the intact molecular weight of each protein can be used to generate a mass map with MW values accurate to 150 ppm. The mass maps provide a means of studying changes in profiles between bacterial cell proteins grown under different conditions. The mass maps from bacterial samples will be compared using software developed in our lab to search for these differences in protein production. Proteins identified as being differentially expressed will be identified using peptide mapping techniques and tandem mass spectrometry against available databases.

Initial work with this 2-D mapping technique has been used to study changes in E. coli that have evolved under different growth conditions. Six lines of E. coli that have adapted to 20(C and their two ancestors have been studied using Sigmagenesis microarrays (DNA on DNA). Deletions of portions of the ancestral genotype have been identified in 3 of the 6 lines. All six lines have approximately the same fitness at 20 (C, but their fitness is different at higher temperature (40(C). The 3 lines with the deletions are all lower in fitness than those with no detectable deletions. The +2 strain, one of 3 lines with the deletions, has dramatically decreased fitness. In this project, the +2 strain and its ancestor will be studied using the 2-D mapping technique after being grown at 20(C. The 2-D map of evolved cell lines will be compared to the 2-D map of the ancestor strain to identify the major differences that exist on the protein level and which proteins are involved in the +2 cell line being a specialist for 20(C. In addition, the proteins that are differentially expressed or not expressed in the +2 cell lines (which may be involved in preventing the +2 cell line from being a generalist in adapting to a wide range of temperatures) will also be explored. Identification of the proteins of interest will be performed by mass spectrometric techniques combined with database searching to explore their metabolic functions in E. coli survival.

# Special Session VI Abstracts

## Early Biosphere Evolution

# Abstract # 12677 - **Using the Great Oxidation Event and Whole Genome Sequences to Establish Upper Age Constraints for Multiple Archaeal Groups**

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The sudden appearance of oxygen in the biosphere at about 2.25 billion years ago (Ga) likely had a profound impact on the energy structure of microbial communities as well as a marked influence on global biogeochemical cycles. For example, oxygenation of the atmosphere allowed the independent origins of sulfide oxidation in the Archaeal domain, Low G+C Gram Positive, Nitrospira, and Proteobacterial divisions in the Bacterial domain. The advent of microbial sulfide oxidation would have significantly increased the rate of oxidative weathering on continents, resulting in an increase of sulfate concentration in the oceans.

While age constraints are beginning to emerge for major groups in the Bacterial domain, at present there are no age constraints for any major Archaeal groups. No fossil record exists for any Archaeal group, and biomarkers are lacking or poorly constrained. On the other hand, it is clear that oxidative metabolism arose independently several times in the Archaeal tree. For example, *Sulfolobus* and *Aeropyrum* in the Crenarchaeaota, and *Thermoplasma*, *Halobacterium*, and possibly *Palaeococcus* (Amend *et al.,* submitted) in the Euryarchaeota use oxygen as a terminal electron acceptor. Because oxygen arose suddenly at about 2.25 Ga (possibly due to the origination of Cyanobacteria between 2.4-2.3 Ga; Blank, submitted), we can use the acquisition of oxidative metabolism to constrain the origination dates of these clades, as well as others that do not exhibit oxidative metabolism.

In order to date these origination events, we used a cladistic approach. First, a robust tree topology was generated. Most phylogenetic analyses of the Archaeal domain with small subunit ribosomal RNA are poorly resolved, likely due to multiple long branch attraction artifacts and insufficient characters. Therefore, whole genome sequences were used to construct a well-resolved phylogenetic tree, where several (i.e., 18) of the most highly conserved genes were used to construct a backbone tree topology. Additional taxa were added to the tree using small subunit ribosomal RNA sequences and the genome tree as a constraint tree. Next, the ability to use a wide range of electron acceptors was coded as characters for each organism (where 1=ability to metabolize that particular compound

and 0=inability). These metabolic characters were mapped onto the tree using MacClade and ancestral metabolic characters were inferred using maximum Parsimony. Clades were identified where oxidative metabolism was present in the last common ancestor, and were assigned a maximum origination date of 2.25 Ga. Maximum age dates were also assigned to non-oxygen metabolizing sister groups using the Principle of Equal Age of Sister Groups. It should be noted that this procedure will work regardless of whether the ability to metabolize oxygen was acquired via convergent evolution or lateral gene transfer. This approach may be beneficial in interpreting the energy structure and metabolic composition of Archean age microbial communities, as well as aiding in the interpretation of the Archean and Paleoproterozoic carbon isotopic records.

# Abstract # 12593 - **The Archaean: Crucible of Creation or Cauldron of Crud, Data from Western Australia**

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The Archaean stratigraphic succession of Western Australia consists of five unconformity bound megasequences that formed as a volcaniclastic carapace above the intruding Archaean granitoid complex that underlies the Pilbara protocontinent[i]. The 10-15 km thick Warrawoona Group, which accumulated at ca. 3.4 Ga, occurs close to the base of this ancient succession[ii]. Stromatolitic structures in the Strelley Pool Chert, which forms part of the Warrawoona Group, have been interpreted as evidence for some of the earliest life on Earth[iii]. We have carried out detailed mapping and sampling of the Strelley Pool Chert at three well exposed localities and conclude that the sedimentary succession is hydrothermal and formed in at least moderately deep water.

The Strelley Pool Chert consists of iron-rich carbonate or silicified carbonate interbedded with units of mega-quartz after barite(?) with laminated black and white chert and finally, at the top of the formation, grey green chert which is locally stained green by copper. The carbonate and silicified carbonate intervals are generally laminated with the laminae being either parallel or swaly. Stromatolitic structures are found at well-defined intervals in these units. In cross section the laminae preserved in the structures are strongly isopachous with occasional evidence of erosion around the base of some of the steeper domes. The mega-quartz interbedded with the carbonate/chert units may be massive or contain botryoidal structures. Delicate fans of pseudomorph crystals, often highly acicular, occur in most of the mega-quartz units and are often associated with a pronounced zone of "chicken-wire textures"[iv] at times overlain and infilled by black

chert, suggesting that the mega-quartz is a replacement after barite(?). Primary chert always occurs toward the top of the formation. The stratigraphically earlier cherts are finely laminated black and white intervals whilst the later cherts are generally grey green and either massive or finely laminated and locally stained blue green by copper.

The Coucal Formation, which consists largely of tholeiitic basalts, disconformably underlies the Strelly Pool Group in the study area. Cross-cutting the steeply dipping formation is a dyke complex that extends for ca. 1.7 km beneath the Strelley Pool Chert. Cavity fill lithologies within the dyke provide a record of the hydrothermal activity through the dyke system. All of the lithologies identified in the overlying Strelley Pool Chert can be identified within the cavity fill preserved in the dyke, and they follow the same general sequence as the stratigraphy of the formation. Mega-quartz after barite occurs throughout the dyke system, black, massive chert begins at a depth of ca. 1.5 km, small amounts of carbonate appear at 1.1 km, but the main carbonate cavity fill appears at a depth of 700 m. Small gossans after sulphides first appear at depths of 1.25 km in the dykes. Cu staining in the grey-green cherts at the top of the section suggests that the sulphides are a late stage phase.

The Strelley Pool Chert, rather than being a shallow-water evaporitic unit, is a complex hydrothermal deposit that accumulated around a series of hydrothermal vents. The regional setting indicates that the iron-rich carbonates of the Strelley Pool Chert are simply part of a hydrothermal succession that began to precipitate from solutions well below the seafloor. Consequently, large volumes of very fine-grained abiotic carbonate issued directly into the marine environment. The stromatolitic structures were generated by direct precipitation of carbonate from hydrothermal fluids in a relatively deep marine setting. We find no direct evidence of biogenic mediation in their construction. They appear to be sedimentary structures. This, along with our earlier work on the Apex chert[v] implies that photosynthesis may not have become a significant oxygen producing mechanism until after 2.8 Ga when the first large continents assembled and energy release from the earth began to drive plate tectonics. This, in turn, resulted in the formation of broad shallow intracratonic basins that provided an ideal environment for the rapid expansion of photosynthesising organisms and active plate margins that allowed sequestration of carbon-rich sediments in the upper mantle[vi].

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# Abstract # 12599 - **Diversity and Complexity of Early Eukaryotic Cells**

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Using molecular sequence data, biologists can generate hypotheses of protistan phylogeny and divergence times. Fossils however provide our only direct constraints on the timing and environmental context of early eukaryotic diversification. The combined protein eukaryotic tree (Baldauf et al., 2000, *Science*) supports a rapid radiation of major taxa. What happened before this radiation is much debated, as some taxa originally interpreted as early-branching groups (including microsporidia, slime molds, and pelobionts) now fall within main cluster of branches (Bapteste et al., 2002, *PNAS*).

Chronological calibration of the tree by eukaryotic fossils of known affinities suggests that the early Mesoproterozoic was a crucial time of eukaryotic diversification. Much before these fossil records, biomarkers in 2.7 Ga kerogens of the Fortescue Group, Australia (Brocks et al., 1999, *Science*) indicate the presence of cells able to synthesize sterols, a characteristic of eukaryotes. Between the late Archean biomarkers and the earliest fossils that can be placed with confidence into an extant clade, 1.2 Ga bangiophyte red algae, lies a rich record of microfossils that are possibly eukaryotic. Criteria can be developed to identify eukaryotic cells and distinguish them from prokaryotes in the early fossil record. The presence of processes and/or other surface ornamentation, of excystment structures and wall structure might show a degree of complexity unknown in prokaryotes. TEM observations of microfossil wall ultrastructure and their comparison with modern protist ultrastructure may provide evidence for eukaryotic affinities and, perhaps, relationship to a specific clade within the domain. Analysis of the wall chemistry by laser micropyrolysis might similarly reveal chemical signatures of eukaryotes or of specific groups.

Our study of early Mesoproterozoic organic-walled microfossils from the 1.5 Ga Roper Group of Australia and the >1.2 Ga Ruyang Group of China reveals an exceptional

preservation of early eukaryotes at the structural and ultrastructural level. Leiospherids (simple spheres) arbitrarily separated at the species level on the basis of their size and wall thickness on the basis of light microscopic observations, show very different wall ultrastructures, implying either different stages of a protistan life cycle or a level of taxonomic diversity undetected by light microscopy. Other early Mesoproterozoic microfossils, including *Valeria lophostriata, Satka favosa, Satka squamifera, Tappania plana*, large longitudinally striated tubes, and *Shuiyouspharidium macroreticulatum* also show distinctive wall ultrastructures, implying diverse biological affinities. These microfossils have a worldwide distribution in various early Mesoproterozoic rocks (1.5-1.4 Ga Roper Group, northern Australia; >1.2 Ga Ruyang Group, China; 1.3 Ga Totta Fm, Siberia; and 1.3-1.6 Ga Sanda Fm, Ganga Basin, India), confirming the widespread participation of eukaryotes in the early Mesoproterozoic biosphere.

Morphological complexity shown by taxa with processes, and/or with walls made of polygonal plates, imply cytological complexity in the early Mesoproterozoic and the evolution of a eukaryotic cell with nucleus, cytoskeleton, and Golgi apparatus involved in secretion and self-assembly of wall components. In previous studies (Javaux et al., 2001, *Nature*), we have shown that microfossil assemblages were distributed along an environmental gradient in the Roper Group, demonstrating ecological heterogeneity. Thus, ecological and cytological complexity and diversity of early eukaryotes characterizes the early Mesoproterozoic biosphere, implying a preceding period of early eukaryote evolution and diversification.

In combination with molecular phylogeny, biochemistry, geology, and paleoecology, detailed studies of organic-walled microfossils focusing on wall morphology, ultrastructure, and chemistry will help us to understand patterns of protist evolution and diversification on the Proterozoic Earth.

# Abstract # 13045 - **Geochronological Constraints on Terminal Neoproterozoic Events and the Rise of Metazoans**

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Neoproterozoic history has been plagued by a lack of precise geochronological constraints. In particular the correlation and duration of global or "Snowball" glaciations has relied on litho and chemostratigraphy, which has given rise to much debate about the number, magnitude, and duration of glacial deposits. New U-Pb constraints on the age of the Gaskiers glacial deposits in Newfoundland coupled with an age for the oldest Ediacaran fossils have important implications for global correlation and the rise of Metazoans.

In the central and eastern parts of the Avalon Peninsula, southeastern Newfoundland, the oldest rocks are arc-related tuffs, agglomerates, and flows of the Harbour Main Group (>1.5 km thick) which have published dates from 606-630 Ma. These are overlain by marine siliciclastic rocks of the Conception Group a thick (ca. 7.5 km) upward-shoaling succession with minor volcanic tuffs. Over 2,300 m of deep-sea deposits of the Mall Bay and Drook formations are separated by the regionally extensive glacial diamictite of the Gaskiers Formation (up to 300 m-thick). This unit is often described as a Varanger-age glaciomarine deposit and is locally overlain by a thin cap carbonate bed with a highly negative C isotopic signature. Interbedding of classical turbidites with diamictite facies within the Gaskiers Formation, as well as basic facies analysis, have been interpreted to indicate deposition of the glaciogenic deposits on a submarine fan or slope setting.

This (1-15 cm) silicic ash beds are found interlayered with turbidites just below and above the glacial deposits and the glacial deposits locally contain volcanic bombs, pyroclastic debris, and lavas. U-Pb geochronology of zircons separated from ash-beds below, within, and above the glacial deposits indicates that they are 580 Ma and accumulated in less than 1 Ma. This is considerably younger than previous estimates and calls into question many of the global correlations with similar rocks.

An ash-bed within the overlying Drook formation is preserved in depositional contact with spectacular surfaces exposing Ediacaran fossils. Zircons separated from it yield an age of 575 Ma making these the oldest well-dated Metazoan fossils that are less than 5

Ma younger than the glacial deposits. Of particular interest is whether these fossils are correlative or younger than the fossil embryos of the Doushantuo of south China that also immediately overlie glacial deposits.

The short duration of the Gaskiers glaciation is difficult to reconcile with a full snowball earth scenario as currently modeled. Thus, either the Gaskiers is not the result of a snowball glaciation or the duration of these dramatic climatic events has been overestimated.

# Abstract # 13072 - **Estimating Metazoan Divergence Times with a Molecular Clock**

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Accurate dating of when the first bilaterally-symmetrical animals arose is crucial to our understanding of early animal evolution. The fossil record suggests that bilaterians arose ~555 mya. However, previous molecular-clock analyses, which were calibrated against the vertebrate fossil record, estimate that they arose 900-1,200 mya. Because of this pronounced discrepancy, we sought to develop estimates from molecular data using invertebrate calibration dates. Our analysis gives dates that are consistent with the fossil record. We estimate that bilaterians arose ~560 mya, and metazoans ~660 mya. We further show that the rate of molecular evolution in vertebrates is significantly slower than that of invertebrates, which accounts for the spuriously deep estimates of bilaterian origination in previous analyses. We argue that the origin of metazoans and then bilaterians straddle one of the most extreme environmental episodes in the history of life.

# Abstract # 12999 - **Partnership for Curriculum Innovation: Scientists and The Voyages Through Time Project**

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Scientists have much to offer to K-12 education - knowledge of science and the scientific process, access to cutting-edge data and research, plus windows to real world explorations and discoveries. There are many different ways for scientists to make valuable contributions to education, and many different levels of possible involvement. One very effective way for scientists to share their expertise with a large number of students and teachers is to work with curriculum developers on new science materials for classrooms nationwide and to contribute to the professional development of teachers so they can effectively use these materials. This presentation describes how scientists helped build the *Voyages Through Time* curriculum and presents a model for the different ways scientists can contribute to the development of K-12 science curricula.

*Voyages Through Time (VTT)* is a unique year-long integrated science curriculum for high school based on the overarching theme of evolution and delivered on CD-ROM. *VTT* provides inquiry and hands-on approaches to the study of astronomy, earth sciences, biology, anthropology, and technology in a cross-disciplinary framework that is the essence of astrobiology. This curriculum is the result of five years of vision and work on the part of a core group of scientists, science educators, and curriculum developers, aided by over thirty-four scientists from many different fields and institutions and by teachers and students across the nation. *VTT* was developed with the continuous involvement of scientists over the entire project – from first ideas through building specific lessons, activities, and media through reviews and revisions to final product. Scientists played an active role providing ideas; consulting and advising; presenting their science via video clips, images, simulations, and database activities; writing articles; and reviewing and contributing to final revisions. And together they helped produce a very high-quality, comprehensive, scientifically accurate, and classroom-effective curriculum.

What motivated the investigators and other scientists to contribute their time and expertise to a large, complex curriculum such as *VTT*? Many saw this as a chance

to formally share their research interests and their excitement about science with a large number of students and teachers; to provide content knowledge and classroom applications of that content; and to serve as role models for future generations. As astrophysicist Yvonne Pendleton, *VTT* co-investigator from NASA Ames, says: "This was a great opportunity. My research on the evolution of organic material in space and its delivery to the early Earth prompted my involvement with an education curriculum where that insight could be incorporated. The interdisciplinary aspect of the *Voyages Through Time* project allowed us to tie together big concepts that teachers and students were unlikely to find elsewhere."

The results of these partnerships with scientists for curriculum development are high-quality and well-received teaching materials. *VTT* was tested nationally in twenty-eight states during the 2001-2002 school year. Teachers appreciated the accuracy, richness, level of detail, and flexibility of the material, and found that it a very engaging, cohesive, and effective curriculum. The students enjoyed the variety of short video clips of scientists talking about their research, the student reader articles about scientific explorations, and the powerful images, database activities, and simulations that bring up-to-date science into their classrooms.

To quote from a *VTT* student: "This year's science class was really challenging and interesting at the same time. And it got me interested in science, because I never liked it before. The way the curriculum is planned showed me that there's a lot that no one really knows, and a lot I can find out about."

The *Voyages Through Time* curriculum was developed by the SETI Institute, NASA Ames Research Center, California Academy of Sciences, and San Francisco State University, and funded by the NSF (IMD #9730693), with support from Combined Federated Charities, the Foundation for Microbiology, Hewlett-Packard Company, the NASA Astrobiology Institute, the NASA Fundamental Biology Program, and the SETI Institute.

# Education and Public Outreach Abstracts

# Abstract # 12582 - **An Online Astrobiology for Teachers Course**

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A continuing challenge for scientists is to keep K-12 teachers informed about new scientific developments. Over the past few years, this challenge has increased with new research findings coming from the field of astrobiology. In addition to trying to keep abreast of these new discoveries, K-12 teachers must also face the demands of the content and pedagogical goals imposed by state and national science education standards. Furthermore, many teachers lack the scientific content knowledge or training in current teaching methods to either create their own activities or to appropriately implement new teaching materials that are designed to meet the standards. There is a clear need for special courses designed to increase the scientific knowledge of K-12 science teachers.

This astrobiology education project was initiated to improve the quality and quantity of astrobiology concepts taught in middle and high schools and to meet the desire of teachers wanting to capitalize on student interest resulting from recent science discoveries in this field. One response to this need would be to create some classroom lesson plans with posters and do several brief workshops for teachers. However, the authors recognized that this approach, although common, is clearly insufficient. In response to this need, the authors developed a suite of innovative, classroom-ready, lessons for grades 5-12 that emphasize an active-engagement instructional strategy and focus on the recent discoveries in the field of astrobiology. They further created a graduate-level, Internet-based, distance learning course for teachers to help them become familiar with these astrobiology concepts and gain first hand experience with the NSES-based instructional strategies. Teachers need both classroom-ready curriculum materials aligned with the *National Science Education Standards* and comprehensive professional development programs to affect real change at the student level. This project's developed lessons are unique because they focus on real scientific data, promote the research emphasis of astrobiology, and are completely classroom-ready curriculum supplements. At the same time this project has addressed the need for teacher professional development by creating credit-bearing university courses designed both to improve science understanding and to help teachers bring that understanding to the classroom.
Work supported in part by the NASA HQ Grant, #NAG5-4576 and by NAI Central.

# Abstract # 12694 - **SETI and Astrobiology: Contact – An International Youth Perspective**

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The search for extraterrestrial life was discussed at the Space Generation Forum (SGF) at UNISPACE-III. The Search For Extraterrestrial Intelligence (SETI) and astrobiology have been a main area of activity for students and young professionals in recent years. Ideas, recommendations, and visions for astrobiology and SETI are being further developed at the Space Generation Summit (SGS), an event at the 2002 World Space Congress (WSC) that will unite international students and young professionals to develop a youth vision and strategy for the peaceful uses of space. SGS, endorsed by the United Nations, took place from October 11th to 13th, 2002. The 200 SGS delegates addressed a variety of technical, economic, and political space issues with the goal of devising new recommendations according to the theme, 'Accelerating Our Pace in Space' to bring

forward to the International Space Policy Summit and the United Nations. The abstract presented here will highlight the findings of the vision document created by the SGS delegates who served on the SETI and Astrobiology Focus Group and introduce an international opportunity to unite young professionals in SETI and astrobiology communities.

The SETI and Astrobiology Focus Group at SGS discussed the need to increase public awareness of the search for life initiative (SFL) on a global scale. The search for life has little relevance on the day-to-day activities of individual people all over the world. People often feel alienated from this subject because they feel the lack of knowledge or technical background to form an opinion, or they may have a strong opinion based on little scientific knowledge about the subject. In order to increase public support for international research on the search for life activities, the public must have access to new information regarding current research. We must take the current research and make it more accessible to the global public in order to "Accelerate Our Pace In Space".

The vision statement created by the delegates is this: "To unite and motivate the global community in the effort to seek evidence for extraterrestrial life, by understanding the social and cultural importance of this endeavor." The key recommendation of the SGS working group was to create a Humanics Implementation Group within the Space Generation Advisory Council (SGAC). The aim of this group would be to research public awareness, understand enthusiasm regarding the SFL initiative, and to work upon the means to improve both.

To be successful in this enormous task, the Humanics Implementation Working Group will need to seek participation, endorsements, and support from the existing SFL scientific communities all over the world.

# Abstract # 12698 - **Graduate/Senior Course in "Alien Cultures: Dialog Between Astrobiology, Science, and Society"**

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Astrobiology and the potential for life elsewhere generate widespread interest with the public. They also represent one of the intellectual drivers of NASA's solar system exploration program, as outlined in the recent NRC decadal report. We have the opportunity to take advantage of this interest by using astrobiology as a hook through which we can educate the public on the meaning of science, the value of basic research and exploration, and the broader roles of science in our society today. However, these topics are usually not discussed within the science community or in the teaching of future scientists at either the undergraduate or graduate levels, so that astrobiologists are not well positioned to take on this task. We have attempted to fill this gap with a graduate and senior-level course on the nature of science and society, intended for science majors and incipient scientists.

Topics that we discuss include a brief introduction to the science of astrobiology, the nature of science and philosophy of science as applied to astrobiology, the religious issues connected to life elsewhere, the history of science and the popular and scientific interest in extraterrestrial life, the definition of life, the recent history of astrobiology (the rise of exobiology, the Viking biology experiments, the ALH84001 controversy, the relationship between astrobiology and solar-system exploration, etc.), the nature of sentience and the potential for extraterrestrial intelligence, the interactions between the sciences and the humanities, the cultural influence of astrobiology (including science fiction, movies and TV, UFOs, and the Face on Mars), and the philosophical significance of finding or not finding life elsewhere.

The approach of the class is to discuss the relationship between science and society, from the perspective of the practicing scientist. Although undergraduate and graduate students usually are not well trained in the philosophical, historical, or societal issues, the students can play an important role in addressing the boundary between the doing of science and the influence that the science has on society. The goal is to eventually foster a true dialog

between scientists and non-scientists, and to encourage scientists to think about the broader implications for non-scientists of astrobiology research.

Readings from the class include original literature in the areas of philosophy of science (Popper, Kuhn, Feyerabend), history of science (Aristotle, Plato, Darwin), religion (Pope John Paul II), history of astrobiology (the scientific literature dealing with Viking, ALH84001), current status of astrobiology (the recent NRC reports on astrobiology), and science and society (C.P. Snow), as well as synthesis and integration of the issues by modern scholars.

An outline of the course and a complete listing of readings is available from the authors.

# Abstract # 12722 - **Origin and Evolution of the UCLA Astrobiology Society**

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Co-sponsored by the NASA Astrobiology Institute (NAI) at UCLA and the Center for the Study of Evolution and the Origin of Life (CSEOL), the UCLA Astrobiology Society (ABS) was founded in 1999 to become the first student-run organization devoted to astrobiology. An interdisciplinary group, ABS unifies undergraduates, graduate students, and faculty of all fields through events and discussions centered on the diversity of themes that compose astrobiology science.

ABS provides particular benefit to NAI's Education and Public Outreach efforts as a means of increasing awareness of and appreciation for astrobiology, particularly in the college community. The society's outreach activities include a monthly newsletter, future research opportunities for undergraduates, an upcoming astrobiology-themed symposium open to the public, and a joint project with the Space Frontier Foundation aimed at high school students. Additionally, ABS is doing research for NAI's Astrobiology Pathfinder program, which will help students at all stages to become astrobiologists. A greater goal of the organization involves networking to seed astrobiology societies on other college campuses nation-wide.

# Abstract # 12725 - **Astrobiology in High School Classrooms**

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The REVEL Project, an education and outreach program in Oceanography at the University of Washington, integrates middle to high school science teachers into deep-sea research cruises that study the spectrum of processes associated with submarine volcanism. The scope of this cutting-edge research encompasses a wide variety of scientific problems that range from the origin of life to new aspects of biotechnology. For example, recent research indicates that in the presence of liquid water, volcanoes on the seafloor can sustain life-forms without sunlight. By inference, volcanoes on other planets may sustain similar life-forms. REVEL explores the relationship between different types of volcanoes and life on Earth, one aspect of the new exciting field of astrobiology, the study of life in the Universe. Using the central concept of volcanism and life, the program trains teachers and their classes in today's scientific quest.
http://www.ocean.washington.edu/outreach/revel

Since 1996, the project has provided science teachers opportunities to explore the nature of mid-ocean ridge volcanism and the life it supports along the Juan de Fuca spreading center in the Pacific Ocean. Through the program, science educators practice the scientific process through direct interaction and collaboration with scientists on board research cruises. As a result of their combined, sea-going and research experiences, educators inject into the classroom issues and ideas associated with this rapidly growing research effort. They develop new ways to bring the study of earth, ocean, planetary, and life processes in the solar system into the classroom through their first-hand exposure to research into the unknown.

Students at Sunnyside High School in Sunnyside, Washington designed and implemented astrobiology research activities under the guidance of their science teacher, a REVEL 1999 participant. The science educator initiated preliminary research questions for a research project she worked on during a REVEL cruise. Upon return to the classroom, she not only shared science content on extreme environments with students, but also the steps researchers take during the research process fostering the creation of students' scientific investigations for the school year. The three astrobiology problems addressed by the students will be presented with detailed descriptions of the experimental procedures selected to collect data and the results obtained by students.

• *How does a simulated Martian atmosphere affect stomatal density and growth of astroplants (Brassica rapa)?*

This experiment was designed to demonstrate how an enriched atmosphere of carbon dioxide would affect leaf stomatal density, leaf surface area, root length, plant height and biomass.

• *Can yeast survive in extreme environments on Earth, Mars, and Europa?*

To simulate extreme environments such as deep-sea, hydrothermal systems on Earth or conditions that might be found on Mars and Europa, yeast cells were exposed to varying levels of pressure, hydrogen sulfide, and low temperatures.

• *What are the effects of extreme environments on cellular physiology?*

The objective of this experiment was to determine the effects of extreme environments (including pressure, vacuum, low temperatures, ultraviolet light, and hydrogen sulfide) on enzyme kinetics, membrane permeability, and photosynthetic activity.

# Abstract # 12731 - **UCLA Astrobiology Society Pathfinder Group**

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The NASA Astrobiology Institute (NAI) has received many letters and emails requesting advice on how to become an astrobiologist. In order to provide useful and personally relevant responses to these questions, the NAI Education and Public Outreach (E/PO) program designed the Astrobiology Pathfinder feature. The Astrobiology Pathfinder is an online, searchable database that provides information on astrobiology-related courses and programs available in each state and profiles people working in the field of astrobiology. UCLA's Astrobiology Society Pathfinder group (UCLA ABS) contributes college course and program information to the content of the Astrobiology Pathfinder feature. The society is comprised of a group of student researchers from the University of California at Los Angeles (UCLA) and is supported by the NASA Astrobiology Institute (NAI).

# Abstract # 12746 - **Laboratory Training Courses Related to Astrobiology at the Marine Biological Laboratory, Woods Hole, MA**

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The Marine Biological Laboratory, Woods Hole, MA provides training opportunities for teachers as well as advanced graduate students, postdoctoral scientists, and researchers in areas related to astrobiology. Our teacher enhancement workshops allow middle and high school teachers first-hand exposure to current astrobiology topics presented by active research scientists. Teachers also spend significant time in the laboratory and gain hands-on experience with essential lab and teaching techniques, plus available classroom activities. At present, we are able to offer workshop opportunities three times a year. These include: Living in the Microbial World, a one week intensive workshop focusing on microbial diversity and evolution; Life and Living in Space, a 3.5 day workshop which features content and activities in planetary protection issues and general astrobiology concepts; and a one day workshop focusing on a single aspect of astrobiology research. This year's Astrobiology Workshop focused on extremophiles. Using an inquiry format, teachers had the opportunity to directly view results from experiments on thermophiles and hyperthermophiles, halophiles, acidophilic eukaryotes, and UV exposure experiments. From these, participants designed and carried out further experiments based on their own questions formulated as a result of their laboratory observations.

Two advanced training opportunities are available to researchers who want to take advantage of comparative molecular and genomic approaches to address questions of phylogeny, early evolution, or ecology. The Workshop on Molecular Evolution brings together a world-renowned faculty to present lectures and lead laboratory sessions on the most current methods of molecular phylogenetic analyses. The workshop features a well-equipped laboratory with Linux and Unix workstations and servers while authors and experts in the use of computer programs such as Clustal W and Clustal X, FASTA, GCG, LAMARC, MrBayes, PAML, PAUP*, and PHYLIP provide demonstration and consultation. Lecture topics include databases and database searching; theoretical, mathematical, and statistical bases of phylogenetic analysis; microbial evolution, estimating divergence times, and population biology; biogeography; ecology; systematics and comparative genomics, including genome content, structure, and evolution.

Advances in Genome Technology and Bioinformatics is a comprehensive, four-week course in genome science that integrates bioinformatics with the latest laboratory techniques for genome sequencing, genome analysis, and high throughput gene expression (DNA microarrays). A distinguished faculty from major universities, bioinformatic centers, The Institute for Genomic Research (TIGR) and the Marine

Biological Laboratory trains students in the latest laboratory and computer techniques. The major instructional modules include: 1) Genome Sequencing (vector development, library construction, high throughput sequencing technologies, principles of automation using advanced robotic liquid handlers, genome assembly algorithms and closure strategies); 2) Bioinformatics (gene prediction algorithms, annotation, database construction and searching, phylogenetics, and molecular evolution); and 3) Functional Genomics (DNA microarrays, data analysis). Symposia focusing on Environmental and Evolutionary Genomics , Eukaryotic Microbial Genome Projects, Organelle Evolution and other topics are also featured.

Further information about each of these courses can be found at http://courses.mbl.edu

# Abstract # 12797 - **Cosmic Origins: A Traveling Science Exhibit and Education Program**

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The Space Science Institute of Boulder, Colorado, is developing a 3,000 square-foot traveling exhibition, called Cosmic Origins, which will bring origins-related research and discoveries to students and the American public. Cosmic Origins will have three interrelated exhibit areas: Star Birth, PlanetQuest, and Search for Life: Are We Alone? Exhibit visitors will explore the awesome events surrounding the birth of stars and planets; they will join scientists in the hunt for planets outside our solar system, including those that may be in "habitable zones" around other stars; and finally they will be able to learn about the wide range of conditions for life on Earth and how scientists are looking for signs of life beyond Earth. Visitors will also learn about the tools scientists use, such as space-based and ground-based telescopes, to improve our understanding of the cosmos.

Exhibit content will address age-old questions that form the basis of NASA's Origins and Astrobiology programs: Where did we come from? Are we alone? In addition to the exhibit, our project will include workshops for educators and docents at host sites, as well as a public web site that will use a virtual rendering of exhibit content. The exhibit's size will permit it to visit medium-sized museums in underserved regions of the country. It will begin its 3-year tour to 9 host museums and science centers in early 2005. A second 3-year tour is also planned for 2008. The Association of Science-Technology Centers (ASTC) will manage the exhibit's national tour. Current partners in the Cosmic Origins project include ASTC, the Denver Museum of Nature and Science, Lawrence Hall of Science, NASA Astrobiology Institute, NASA missions (e.g. PlanetQuest, SIRTF, and Kepler), New York Hall of Science, the SETI Institute, the Space Telescope Science Institute, and TERC. The exhibition is supported by grants from NSF and NASA.

# Abstract # 12834 - **Increasing Minority Involvement in Astrobiology Research, Education and Outreach**

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During the Astrobiology Conference held at NASA Ames in April 2002, less than 1% of the 800 attendees were African-American. To increase the visibility and participation of under-represented scientists, The Minority Institution Astrobiology Collaboratory (MIAC) was formed. This organization is a "virtual collaboration" of faculty and students from 10 minority institutions focused on achieving common educational and research goals in astrobiology. These goals include: (1) developing astrobiology course work and educational outreach that will attract significant numbers of minority students into the field of astrobiology; (2) creating and enhancing research opportunities in astrobiology for minority students; (3) providing a forum for student presentations and publications in astrobiology; (4) nurturing a collaborative research environment in minority institutions to make them competitive enough to become a NASA Astrobiology Institute (NAI) Lead Team by 2007; and (5) building a successful model for collaborations among scientists and educators at minority institutions (MIs) that results in funding peer-reviewed publications and shared resources which benefit minority students.

In addition to describing MIAC, Dr. Gary will describe his role as one of the first participants in the NAI-sponsored minority faculty sabbatical in astrobiology. His sabbatical focused on genomic evolution and was spent at UCLA in the laboratory of Dr. James Lake, a pioneer in our understanding of the ribosome structure and molecular evolution. Specifically, Dr. Gary learned and applied computational methods to determine the evolutionary relationships between cryptochromes in plants, animals, and bacteria. Cryptochromes are photosensory receptors that mediate various light responses in plants and animals, such as those regulating the flowering time in plants and regulating the circadian clock in animals.

# Abstract # 12836 - **Education and Public Outreach at the Penn State Astrobiology Research Center**

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The major goal of the research being conducted at the Penn State Astrobiology Research Center (PSARC) is to increase our understanding of the connection between the changes in the environment of the early Earth and the changes in the biota on Earth, especially during the period between 4.5 billion to 500 million years ago.

This presentation will outline several of the education and outreach activities being carried out by the Penn State Astrobiology Research Center (PSARC). Program activities target undergraduate students, K-12 educators and students, and the general public.

**Higher Education**
Astrobiology Minor: Undergraduate students at Penn State can earn a Minor in Astrobiology. The program requires 18 credit hours of courses from the Departments of Geosciences, Astronomy & Astrophysics, Biology, Microbiology, and Biochemistry & Molecular Biology with at least 6 credits at the 400-level.

WISER (Women In Science & Engineering Research): First-year undergraduate students gain invaluable experience and mentoring from PSARC scientists in this research internship program, which is designed to retain women students in the science and engineering fields.

**K-12 Education**
Teacher Workshop: An annual five-day residential workshop for 6-12 grade teachers in life science, chemistry, earth science, and space science. The workshop is designed to provide teachers with astrobiology content knowledge as well as inquiry-based activities for use in the classroom. The teachers interact directly with several of the PSARC co-investigators through research presentations, laboratory tours, and field trips.

WISE Camp: An annual two-week residential program for young women in the 11$^{th}$-12$^{th}$ grade. PSARC investigators participate by involving the students in hands-on workshops during the first week and week-long projects during the second week.

"What's In The News?": PSARC scientists work with Penn State Public Broadcasting to introduce the exciting field of astrobiology through this multimedia children's current events program. Aimed primarily at grades 4-7, the weekly programs reach more than five million children in thirty two states across the country. Along with the broadcasts, the program provides printed support materials, a newspaper column, instructional kits, and web-based information and activities that offer a range of resources for both teachers and students. The online component of the program is archived online at this website: http://witn.psu.edu/2223/ Two astrobiology segments have been produced:

- "Alien Hunting," aired on March 3, 2000
- "The Stories Rock Tell: Learning about Early Earth," aired Sept. 21, 2001

**General Public**

Astrobiology Supplement: Penn State hosted a series of Saturday public lectures on Astrobiology. The standing-room-only series featured NAI scientists from Penn State, Harvard, and the University of Colorado, as well as scientists from the SETI Institute and Rice University. The lecture series was captured in an outstanding article by Research Penn State magazine entitled "Astrobiology: The Search for Life in the Universe." The publication is available as a separate magazine supplement and is appropriate for educators, students, researchers, and the community at large.
Website: http://www.research.psu.edu/rps/0101/Astrobiology.pdf

Space Day at Penn State: PSARC participates in this annual one-day event designed to showcase the exciting space-related research being carried out at Penn State. PSARC members help introduce the field of astrobiology to students of all ages by engaging them in hands-on activities and exhibiting technical posters. During the 2002 celebration, students in the Penn State Science Education Program collaborated with PSARC researchers to develop activities.

# Abstract # 12878 - **Astrobiology Research, Education and Outreach at Tennessee State University, a Historically-Black University**

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Tennessee State University (TSU) is one of the few minority institutes with a significant publication record in astrobiology. This involves searching for extrasolar planets. In late 1999, Greg Henry, an astronomer at TSU, was the first to detect a transit of an extrasolar planet (Henry, G. W., et.al. "A Transiting 51 Peg-like Planet," *Astrophysical Journal* **529**, L41, 2000.) and more recently directly detect another extrasolar planet around 55Cancri. In addition to the involvement of TSU astronomers, TSU biologists have begun research in Astrobiology. One TSU biologist has just completed a NAI sponsored faculty fellowship program in Astrobiology at UCLA.

Tennessee State University has built a reputation for offering outstanding programs in space science education for teachers and students, including teacher workshops in astrobiology. Astrobiology is a relatively new and exciting area of scientific discovery and has captured the attention of our community. Because of Tennessee State University's unique role as a historically-black university, we have been able to have the spotlight on astrobiology in our education and outreach activities. Two of the factors that have made the education component so successful are: (1) the partnerships and relationships with schools, universities, organizations, and the media; and (2) the connection of astrobiology content with the Tennessee Framework for Science Standards for elementary, middle, and high school (a critical factor). We have worked diligently to show teachers how teaching information from astrobiology will not only make their classroom an exciting place but also be helpful in building their skills for the Tennessee State achievement test and the Gateway graduation exams.

We have built partnerships and relationships with groups in five important areas:

- Universities (both locally and in other states)
- Local School Systems
- Informal Education Intuitions
- Professional Organizations in Education and Science
- Professionals in Print Media

# Abstract # 12913 - **Funding and Outreach: Astrobiology Society's Budget**

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Founded in 1999, the UCLA Astrobiology Society (ABS) is a student run organization focused exclusively on Astrobiology and its related fields. Co-sponsored by the NASA Astrobiology Institute (NAI) at UCLA and the Center for the Study of Evolution and the Origin of Life (CSEOL), the interdisciplinary society brings together a vast array of students, faculty and interested community members, all in turn from various backgrounds. Our current outreach projects include a monthly newsletter, future research opportunities for undergraduates, an upcoming astrobiology-themed symposium open to the public, and a joint project with the Space Frontier Foundation directed towards high school students. ABS further conducts research for NAI's Astrobiology Pathfinder program, a program designed to facilitate students along their way to becoming astrobiologists.

As the first student organization of its kind, we have definitely encountered problems, funding being one of them. We wanted to do more than the regular bake sale most student groups conduct, and we have therefore constantly been looking for new innovative methods of fundraising. The Pathfinder program, for example, allowed us to obtain 5000 dollars from NAI in return for our research. We have been able to send some of our members to conferences as far as Austria. We are currently in the process of becoming a nonprofit organization and want to share our budget information in order to help those who are interested in starting similar societies, as well as obtaining grants and other sources of income for their organization. Since one of our major goals is to provide outreach to different communities, funding has come to play a key role in our objectives. Funding allows us to continue with our outreach objectives, and it enables the society to undertake new projects and further build a support network.

# Abstract # 12943 - **Project AstroBio: Scientist-Teacher Partnerships in the Greater Seattle Area**

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The Center for Astrobiology and Early Evolution of the University of Washington sponsors Project AstroBio, a program that matches scientists and grades 3-12 teachers for year-long partnerships in the classroom. Each spring we solicit applications from both teachers and scientists who would like to volunteer their time. We then make matches for new partnerships (typically 20-25 each year) based on geographic locations and preferences for grade-level, type of scientist, available times, etc. Each of these partnerships is then required to attend our two-day summer workshop, wherein we explain our philosophy, model many possible classroom activities, introduce resources of many kinds, and strive to start partners off on the right foot for the coming academic year. (A main point: as in any relationship, frequent and frank communication is essential for the partnership to work.) During the school year each scientist agrees to visit his/her classroom for at least five visits (most do more), the first of which is primarily for observation and introduction to the students. We do not impose any specific curriculum, except that it should broadly bear on some aspect of astrobiology – thus each teacher/scientist pair chooses their topics and what they want to do and when and how. During the school year, we provide further support through activities such as stargazing parties, planetarium shows, half-day workshops, and visits to the Pacific Science Center (a key member of our Consortium, a board that advises and supports us).

The project began in 1997 as Project ASTRO/Seattle, based on the successful model invented by the Astronomical Society of the Pacific, and now found in ten regions around the nation: see http://www.astrosociety.org/education/astro/project_astro.html. Now in our sixth year, we have trained 140 partnerships within a 50-mile radius of Seattle, of which 65 are known to be presently active. Last year we began morphing Project ASTRO/Seattle into the present Project AstroBio by explicitly introducing more content in the biological sciences, especially as they bear on life in the universe. This has meant firstly that our scientist partners are no longer confined to astronomers and other physical scientists, but now include biologists of all types. Secondly, we are beginning to collect and create a stable of suitable classroom activities that include a biological component.

We don't yet have anything as comprehensive as *The Universe at your Fingertips*, a compilation of over one hundred activities for K-12 astronomy (and related areas such as space sciences, geology, chemistry, physics, and math), but this is the ultimate goal.

Funding was initially 1.5 years from NSF, and then until 2001 from private sources such as individual philanthropists and the Boeing Company. The Washington State Space Grant program has also been a steady supporter. With the UW's membership in NAI beginning in 2001, about 70% of our funding is currently from NASA via NAI and the remainder from a single, loyal benefactor.

More information: http://www.astro.washington.edu/projAstroBio

# Abstract # 12945 - **Maximizing Astrobiology Education and Public Outreach at Johnson Space Center**

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The Center for the Study of Biomarkers at Johnson Space Center maximizes astrobiology education and public outreach opportunities by leveraging our money and time with a variety of programs and funding sources. The JSC Astromaterials Research and Exploration Science (ARES) education and public outreach (E/PO) team receives funding from six NASA programs with the NASA Astrobiology Institute as one. Yet, almost every aspect of ARES E/PO has an astrobiology component that helps to share the search for signatures of life in early Earth rocks and in meteorite samples from Mars.

Our special E/PO multiplier effect is possible due to the overlapping content areas of our major funding sources. The expertise we have accumulated while developing curriculum and sharing the science of meteorites and Moon rocks with educators and the public is the foundation of our outreach. We also develop and present materials that reflect the Mars exploration and sample science research expertise of Johnson Space Center ARES. Thus, working to share astrobiology and the search for biomarkers in Earth and Mars samples extends and overlaps the other areas of our outreach efforts.

The other aspects of our funding focus directly on engaging the public, delivering science activities and curriculum support materials to educators, and inspiring future scientists. Through the NASA Minority Outreach Program, we train high school and college undergraduate students from minority serving institutions to share astrobiology and Mars activities with young students and the general public at schools and public venues. Through this program we also bring students into the laboratories to conduct research with our science team as mentors. Another outreach to those underrepresented in science research involves sharing the excitement and the can do science attitude with young girls and women. By training adult volunteers and girl program aides to share the excitement

of exploring the solar system,we reach thousands of Girl Scouts in troop meetings, camps and council events. The search for life beyond our world is an exciting hook to capture the interest of young potential scientists. The Expanding Your Horizons program and Science Itís a Girl Thing are other programs where we engage young women directly in astrobiology activities and the excitement of the exploration of the solar system.

The ARES E/PO team is very active in sharing astrobiology, rocks from space, and Mars with K-14 educators. Through workshops and short courses at national, regional, and local science education events, we share aspects of research on extraterrestrial rocks blended with the search for early life documented in ancient Earth rocks. We work to make the research information and activities appropriate for the curricula and standards set by the educators. Museums and science centers are also a perfect setting to share the combined message of space rocks and exploration thus we leverage our time and money by sharing aspects of astrobiology with displays focused on Mars. Public science venues want to intrigue their visitors with a mystery or tell a good story and astrobiology has that story.

Our teamís blend of multiple science outreach topics and funding support puts us in a position to extend astrobiology outreach to areas far beyond the scope of a singly funded program. The synergism of our programs enables us to reach far more interested students, teachers and members of the general public.

# Abstract # 12954 - **JSC's NAI Scientists and Educators — Partners in Success**

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The Johnson Space Center Astromaterials Research and Exploration Science(ARES) education team is a continuing relationship between scientists and educators. In the early 90's Marilyn Lindstrom, a cosmochemist and curator of the JSC Antarctic Meteorite Lab, and Jaclyn Allen, scientist and experienced education trainer, were looking for a better way to develop curriculum and activities. They wanted the science of the team accurately represented in a format that classroom teachers would use. They also wanted scientists accurately represented in how and why they pursue their work. Their idea that scientists and classroom educators should work together has resulted in an ongoing, working partnership. Together the team has produced materials that are used in classrooms across the nation. The most recent publication *Fingerprints of Life?* reflects the JSC NAI team's work searching for bio-signatures in ancient Earth rocks and Martian meteorites. Teachers and scientists continue the teamwork in NSTA workshop presentations, local in-services, and participation at science meetings. This partnership is offered as model for others in developing partnerships with educators.

The goal of the team is to translate the science of the JSC ARES group. In order to be successful, the scientists are willing to share their time, research skills and data with educators. The educators bring the education expertise to develop engaging activities for the classroom. The original team of teachers and scientists established the initial goals and expectations. Over time other points have emerged. For example, keeping the scientists involved in the development of the materials is essential to success. The scientists share the results of their research in the early development stages of the

education projects and then tutor the teachers throughout writing process. While we do not offer a formula for developing a partnership, experience has provided us with insights to be shared.

This summer, two of the teachers from the JSC ARES team were invited to attend the IAU Symposium 213 "Bioastronomy 2002: Life Among the Stars" and Australian American Fulbright Symposium 2002 "Science Education in Partnership" that were held concurrently on Hamilton Island, Australia. Classroom educators who had participated in education partnerships with scientists were invited to share their experiences. The classroom teachers represented a diverse range of the science within the astrobiology community. However, beyond our content we found that we shared common experiences in our partnerships with the science community. Most programs were long-term relationships. The educators were experienced classroom teachers; the scientists were eager to have their science shared in the classroom. The partners worked comfortably together, sometimes developing programs beyond the original goals. These similarities reinforce the experiences of the JSC ARES team and suggest that this type of partnership can be replicated.

Education partnerships are important to science and education. Good science can be delivered to and used in the classroom. The on-going relationships are economical for the teachers and the scientists. The teachers are an eager and enthusiastic audience that looks at the research with fresh eyes. The scientists give the educators opportunities to be the learner while also using their expertise in classroom instruction to develop useful and usable materials.

# Abstract # 12960 - **Voyages Through Time: An Integrated Science Curriculum**

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*Voyages Through Time* is a new and unique one-year integrated curriculum for high school science delivered on CD-ROM. Built around the theme of evolution, *Voyages Through Time* (VTT) provides inquiry approaches to the study of astronomy, earth sciences, biology, anthropology, and technology in a cross-disciplinary framework that is the essence of astrobiology. The six five-week modules, Cosmic Evolution, Planetary Evolution, The Origin of Life, Evolution of Life, Hominid Evolution, and The Evolution of Technology, use the constructivist approach (BSCS, 1996) as an instructional framework. The content and instructional approach of the material addresses national standards and recommendations. Each module is published on CD-ROM with hardcopy student readers, and is available as a complete set for use in a yearlong integrated science course, or individually for discipline-based courses. The curriculum was developed by the SETI Institute, NASA Ames Research Center, California Academy of Sciences, and San Francisco State University, and funded by the NSF (IMD #9730693), with support from Combined Federated Charities, the Foundation for Microbiology, Hewlett-Packard Company, the NASA Astrobiology Institute, and the NASA Fundamental Biology Program.

The overarching goals for *Voyages Through Time* are for students to understand:

- evolution as cumulative changes over time;
- the various processes underlying these changes;
- the differing time scales and rates of change;
- the connections and relationships across these realms of change; and
- science as a process for advancing our understanding of the natural world.

The VTT curriculum was tested nationally during the 2001-2002 school year by over eighty teachers in twenty-eight states, with support for the field test provided by the NASA Astrobiology Institute and the NASA Fundamental Biology Program. Evidence from student and teacher evaluations and focus groups indicate that the material and the CD-ROM approach are very successful in the classroom.

Teachers appreciated using technology to supplement traditional teaching, and found that VTT provided powerful images, database activities, and other media that enhanced student learning in both classroom-based group and individual activities. Scientists became welcome experts in the classroom via video segments on the CD-ROMs. It is clear that the productive collaboration between scientists, teachers, curriculum writers, and media specialists has been the key to making VTT a successful, scientifically accurate, and involving curriculum.

# Abstract # 12967 - **Astrobiology at Arizona State University: Research and Outreach Highlights**

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The ASU Astrobiology Program is an interdisciplinary program that includes faculty researchers and students from the Departments of Geological Sciences, Chemistry and Biochemistry, Biology, Plant Biology, and Microbiology. The program is also supported by affiliated research in Astronomy, Aerospace Engineering and Biotechnology. These research opportunities are available to both undergraduate and graduate students at ASU. Additionally, the current program has collaborative ties with the University of Alaska, University of Arizona, University of Connecticut, University of Puget Sound, University of Tennessee, Indiana University, the College of William & Mary, and the National University of Mexico (UNAM), Mexico City.

Active research areas include: (1) cosmochemistry of carbonaceous meteorites; (2) organosynthesis in seafloor hydrothermal systems; (3) the origins and evolution of photosynthesis; (4) studies of the microbial fossil record; (5) environmental conditions on Archean Earth; (6) the structure, function and persistence of complex ecosystems in extreme environments; (7) the effects of impact processes on planetary habitability and evolution; and (8) the exploration for habitable environments and life on Mars and Europa.

Education and public outreach activities have included participation in ASU's Earth Science Day and SEE ASU, a two-day K-12 outreach program that provides students from Arizona schools with the opportunity to investigate the research activities at the university. The ASU Astrobiology Program also has a highly developed web site that keeps students and the general public updated on Astrobiology Program activities at ASU. These include the latest research publications, ASU astrobiologists in the news, public outreach activities, upcoming events, focus group activities, plus links to the NASA Astrobiology Institute and other institute members. Our presentation will review current research highlights and review Education and Public Outreach activities from the past year.

# Abstract # 12969 - **Contents of Astrobio 101**

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Introductory college-level courses in astrobiology are becoming popular in American universities. For the most part, these are being offered by astronomy departments, often as one of several options to meet general-education requirements for non-science students, but sometimes also as upper-level undergraduate courses. The introduction of such courses has so far outpaced the availability of textbooks, and many instructors have found themselves inventing astrobiology (in courses often called "the search for life in the universe") with relatively little direct input from NAI or other researchers. This paper outlines several possible "Astrobio 101" courses, based in part on available textbooks. Anecdotal evidence suggests that the three most popular texts are *Life in the Universe* by Bennet, Shostak and Jakosky (Addison Wesley, 2003)*, The Search for Life in the Universe (3rd ed)* by Goldsmith and Owen (University Science Books, 2002), and *The Search for Life on Other Planets* by Jakosky (Cambridge U., 1998).

The purpose of this paper is to suggest possible contents for one-semester and one-quarter Astrobio 101 courses, using the organization of these three textbooks convolved with the contents of the astrobiology discipline adopted by the research community (*e.g.,* in the *NASA Astrobiology Roadmap* and the research projects described in the *NAI Annual Report*s). The most striking differences between the texts and the research agenda are as follows: (1) A major part of current astrobiology research deals with the origin and evolution of terrestrial microbial life, including genomic analysis, with special emphasis on life in extreme environments. In contrast, these topics typically occupy only about 15% of the three texts examined. (2) The discussion of possible biomarkers, especially detectible evidence of life on distant planets, is more prominent as a research topic than in the texts, perhaps because it is a relatively new area of emphasis. (3) The study of the future of life, including the responses and possible adaptation of terrestrial life to conditions in space or on other planets, is given a prominent place in the *NASA Astrobiology Roadmap* but is hardly discussed in the texts. (4) SETI, which represents a small (but enthusiastic) research area, is treated extensively in the texts, which devote 10% or more to this subject. (5) The texts also discuss interstellar travel, UFOs, and possible contact with intelligent aliens, areas of wide public interest that do not appear in the astrobiology research agendas.

The remainder of this abstract presents a possible organization of a one-semester Astrobio 101 course, where is it assumed that there are 14 weeks available for actual instruction. The Bennett *et al*. text itself has 14 chapters and is organized for the same kind of course, but the following syllabus does not exactly follow the Bennett *et al*. sequence. The topics for each week are keyed in the table to chapter numbers in the three texts: (1) Bennett *et al.;* (2) Goldsmith & Owen; and (3) Jakosky.

| Week | Topics | Text 1 | Text 2 | Text 3 |
|---|---|---|---|---|
| 1 | Introduction; nature of science; overview of Earth's place in the universe | 1, 2 | 1, 2, 3 | 1 |
| 2 | Origins; formation of biogenic materials; formation of solar system & Earth | 3 | 3, 11 | 1, 3 |
| 3 | Definitions of life; metabolism & energy sources; genetics & tree of life | 3 | 7 | 5 |
| 4 | Origin of life; prebiotic environment; Miller-Urey synthesis; impact frustration | 4, 5 | 8 | 4, 6 |
| 5 | Co-evolution of life and environment; evolutionary process; changing atmosphere | 4, 5 | 9 | 2, 3 |
| 6 | Life in extreme environments; limits of life; impacts & mass extinctions | 5 | 10 | 2, 5 |
| 7 | Planetary habitability; role of liquid water; luminosity of the Sun; greenhouse effect | 6 | 10, 16 | 7, 16 |
| 8 | Mars as a planet; search for life on Mars; Viking; ALH84001; future Mars missions | 7 | 13, 14 | 8, 9 |
| 9 | Life in the solar system beyond Earth & Mars, especially on Europa & Titan | 8 | 12, 15 | 12, 13 |
| 10 | Other planetary systems; planet detection; comparison of other systems to ours | 10 | 17 | 14, 15 |
| 11 | Searching for life in other planetary systems; habitable zone; biomarkers | 9, 10 | ? | 16 |
| 12 | Evolution of intelligence; SETI; consequences of contact | 11 | 18, 20 | 17 |
| 13 | Future of life; response to conditions in space and on other planets; terraforming | 9, 12 | ? | 10, ? |
| 14 | Other topics; aliens and UFOs; societal implications of finding extraterrestrial life | 13, 14 | 19, 21, 22 | 1, 16 |

# Abstract # 12983 - **The Australian-American Fulbright Sympsoium 2002: Science Education in Partnership**

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The Australian American Fulbright 2002 Symposium: Science Education in Partnership was held in parallel --in partnership-- with the scientific meeting of the IAU 213 Bioastronomy 2002 Symposium: Life Among the Stars. In practice, the two meetings modeled partnership between educators and scientists, both professional events interacting while maintaining individual goals. Leading scientists attending the IAU meeting participated in the Fulbright with presentations based upon their work and their experiences. Educators and scientists interacted on how their work impacts science education and strategies for building direct connections between scientists and classrooms. Educators attending the Fulbright Symposium attended a number of scientific presentations in IAU meeting as well.

A major issue in science education is teaching science in a way that is relevant to the student. Partnerships between scientists and teachers can provide real-life scientific research experience in the laboratory and the field for teachers and students. These partnerships enhance the quality of both teaching and learning, and they engage students directly in projects and curricula that lead to a better understanding of the nature and practice of science. Scientists are often engaged in the development of new curricula as a part of the education and public outreach programs affiliated with research programs. Participants explored the similarities and differences between the approach to this endeavor in Australia and the US. Partnerships between all the professionals involved -- scientists, teachers, and writers-- create an opportunity for innovative, cutting-edge research to reach the classroom. The excitement of seeking new knowledge and exploring the unknown can motivate students to pursue science studies in high school and beyond at the university. Oral papers, posters and workshops presented the results of partnerships between scientists and educators in Australian and the US, as well as opportunities for future partnerships. The proceedings of the Fulbright Symposium will be published in mid-2003. Please contact the authors for further information on this publication.

# Abstract # 12984 - **Collaborating With Minority Institutions: NAI Minority Institution Faculty Sabbatical**

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"Training the next generation of astrobiology researchers" is one of the 5 pillar mission statements of the NASA Astrobiology Institute (NAI). In March of 2002, the NAI developed the Minority Institution Involvement Program (MIIP) in an effort to ensure that the next generation of astrobiologists also reflects the ethnic diversity of the United States.

The MIIP launched with the introduction of a Minority Institution faculty sabbatical that provides opportunities for Minority Institution faculty researchers to collaborate with NAI Lead Team researchers. The Minority Institution faculty researcher travels to the NAI Lead Team research site, supporting another pillar statement in the NAI mission to "carry out, support and catalyze collaborative interdisciplinary research." The MIIP addresses both mission goals and opens a conduit for scientific collaboration between the participants. The sabbatical is for a period of 8 weeks, and it includes the following:

- A stipend of $1K per week sent directly to the selected applicant
- Travel reimbursement for one round trip travel fare to the host site
- Paid registration and travel reimbursement (within 1 year of the sabbatical completion) for the faculty member and up to 2 of the faculty member's students to attend the NAI General Meeting or the NASA Astrobiology Science Conference
- Up to $3K for institutional fees, lab and office set-up for the faculty participant

<u>What is a Minority Institution?</u> The definition of a minority institution by Federal mandate includes four types of colleges and universities:

• Historically Black Colleges and Universities (HBCUs): defined under Title III of the Higher Education Act of 1965, HBCUs are accredited institutions of higher learning established prior to 1964 whose educational mission is to provide education to Black Americans.

• Hispanic-Serving Institutions (HSIs): defined under Title III of the Higher Education Act of 1965. HSIs are institutions of higher education that are determined to be eligible; have undergraduate enrollment that is composed of at least 25 percent Hispanic students; and with no less than 50 percent low-income individuals

• Tribal Colleges and Universities (TCUs): TCUs are defined as those colleges and universities cited in Section 532 of the Equity in Educational Land Grant Status October of 1994; Tribally Controlled Community College Assistance Act of 1978; or the Navajo Community College Assistance Act of 1978. A "tribally controlled college or university" is an institution of higher education, which is formally controlled, or has been sanctioned, or chartered, by the governing body of an Indian tribe or tribes. No more than one such institution shall be recognized with respect to any such tribe.

• Other Minority Universities (OMUs): OMUs are defined as colleges or universities with enrollment of a single underrepresented minority group or a combination of underrepresented minority groups that exceeds 50 percent of the total student enrollment as defined in the Higher Education Act.

Further information and a current list of accredited minority institutions can be found at: http://www.ed.gov/offices/OCR/minorityinst.html

The first NAI Minority Institution faculty sabbatical participants were selected and have completed their 8-week collaboration with NAI Lead Teams during the summer of 2002. The participants were:

Dr. Todd Gary
Tennessee State University
Host: University of California, Los Angeles
PI: Jim Lake

Dr. M. F. Mahmood
Howard University
Host: Carnegie Institution of Washington
PI: Andrew Steele

In October of 2002, a third sabbatical participant was selected:

Dr. Lekan Latinwo
Florida A&M University
Host: Michigan State University
PI: Michael Thomashow

All NAI Investigators are highly encouraged to participate in the program by serving as a host for a Minority Institution faculty researcher. To serve as a host or provide information on any current research collaborations with accredited Minority Institutions, please contact the NAI MIIP Program Lead, Karen C. Bradford, by email (kbradford@arc.nasa.gov) or phone (650 604 0809).

# Abstract # 12986 - **Living with Little Green Men: NAI's Education and Public Outreach**

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Public involvement with astrobiology is often centered around science fiction. In our role of communicators with the public, students and teachers, we are confronted with the historical context for astrobiology: little green men. One major focus of our Education and Public Outreach efforts is to bring astrobiology beyond the realm of science fiction, into public awareness, focused on current and accurate science and presented in multiple venues for the maximum possible impact. The goal is to achieve a cultural shift, an advance in the education of at least those individuals who are interested in science and ideally in the minds of students and their teachers as well.

Where do we find science-interested audiences, and how do we communicate with them? One answer is that we find them in museums, science centers, planetaria, and IMAX theaters. The attendees at these venues are self-selected for their interests in science, and the core questions of astrobiology continue to garner tremendous public interest. Two major museum exhibits on astrobiology are underway: the New York Hall of Science is planning "Extra-terrestrial Life", a 5000 square foot permanent exhibit, and the Space Science Institute is developing "Cosmic Origins", a 3000 square foot exhibit which will travel to medium sized museums and science centers around the country. In addition to these, MacGillivray and Freeman Films Distribution Company is in the early stages of a new IMAX film, "Space Journey", and KTCS Public Television in Seattle is doing a remake of a Japanese program entitled, "Space Millennium" for PBS. You probably know of others.

These programs are all focused on astrobiology and will each reach many thousands of visitors and/or viewers. NAI has the opportunity to utilize these mechanisms to communicate with our audiences and to assure that the content moves beyond science fiction and into science reality. This is where little green men turn into tiny crystals of questionable origin, and warp drives become six-month journeys to Mars. It is also where family time spent together in an IMAX theater or a museum on a Sunday afternoon might be connected and thus enhanced with classroom time on Monday where students discuss what it means to be alive and the search for life beyond Earth.

NAI accomplishes these goals in two ways. First, NAI researchers play significant roles as advisors and content editors. These contributions are incredibly important in maintaining scientific accuracy and keeping the developers of these programs abreast of current findings. Second, NAI's E/PO program, through both the Central office and the

efforts of the individual Lead Teams, builds partnerships with the developers of these programs. This helps to secure the resources necessary for the productions and supplements the content with educational materials for use by students and teachers, extending the learning opportunities provided by the exhibits and films. In this way, it is possible to capitalize on the expertise of the developers in capturing public interest and the expertise of the NAI, both in science and in E/PO, in the real science of astrobiology. The original intent to provide a community with information on astrobiology is, in essence, amplified and extended; the programs reach broad audiences and offer opportunities for deeper understanding.

Like the science of astrobiology, accomplishing these objectives requires collaboration and communication. Sharing information about activities and opportunities as they develop, and working together as scientists, educators, exhibit developers, and film producers, in order to present the full and complete story of astrobiology to the full and complete range of audiences is the most effective way to have the biggest impact. This is not science fiction; it is NAI's education and public outreach program.

There are many activities going on in NAI's Education and Public Outreach program. Information regarding them can be found on the NAI website and in the Annual Reports. Please get involved.

# Abstract # 12995 - **The NAI Website Video Archive**

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Over the past two years, the NAI Education and Public Outreach team has been video taping interviews with NAI scientists and other members of the Astrobiology community in order to document their ground-breaking work and ultimately interpret it for public and educational audiences. In all, over 70 interviews have been conducted at various meetings and conferences, and several types of video-based pieces have been produced to serve different purposes. Now collected into an archive on our website, these pieces fall into three broad categories: (1) Astrobiology Features, showcasing the work of NAI scientists; (2) Ask an Astrobiologist Featured Questions, providing in depth responses to frequently asked questions; and (3) Astrobiology Profiles, serving as a role modeling tool for young aspiring astrobiologists. Additionally, we have packaged the video pieces with some of our other electronic products on CD-ROM, which have been distributed at educational conferences.

The video medium, especially a video interview, carries with it the unique capability to convey information as close to first hand as possible. For example, when Astrobiology Profile videos are played for a classroom, the students can be inspired by a variety of scientists sharing their 'Paths to Astrobiology' without the scientists having to physically be there. Another benefit is to scientists, who can spend relatively little time with the interviewer, but can reach a large community through an electronic distribution network. And finally, having a centralized video archive can serve the NAI's virtual community by providing a place for everyone to stay in touch with the work of our often very distant colleagues.

Contributing in this way, scientists can make a difference in the lives of students, foster collaboration, as well as help bring astrobiology into public consciousness.

# Abstract # 13028 - **The Search for Extraterrestrial Life: An Education and Exhibition Program for Science Centers**

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*For more than 3 billion years, life has evolved to fill nearly every niche on Earth where energy is available; sites once labeled uninhabitable or dead are now known to be teeming with microbial life. These insights, along with new information about potentially "habitable" extraterrestrial sites (Europa and other planets), allow us to be more optimistic about the possibility of finding life elsewhere. Dr. Kenneth H. Nealson, JPL/NASA, Pasadena California*

Extraterrestrial Life will be a science center exhibition that will engage visitors in applying the fundamental biology of life on Earth to understanding the search for extraterrestrial life. The 3,500 square foot exhibition and accompanying programs will engage visitors in investigating three interrelated themes:

1. The basic requirements of life and the environments in which life can prosper on Earth;
2. Extraterrestrial conditions that might support life currently or in the past and how organisms might survive in these conditions;
3. Contemporary and future strategies and technology for discovering life in other parts of the universe.

We anticipate that 500,000 visitors would participate in the exhibition and associated programs each year at the New York Hall of Science. There are over 300 science-technology centers in the US and researchers suggest that they have about120 million visitors a year so there is a significant audience for a traveling version of this exhibition. Science-technology centers are good venues for informal learning as they are respected by the public and offer a neutral, non-pressured environment for learning a wide range of our population.

**LEARNING OBJECTIVES**

Visitors will:

1) Investigate the breadth of conditions that support life on earth to understand the definition of life and its requirements;
2) Compare the environments of Mars and Earth, and investigate how these might affect the search for extraterrestrial life;
3) Learn about scientific models guiding which extraterrestrial environments to explore for life, and the strategies and technologies scientists are developing to detect life.

***National Significance.*** During the 1960's manned space travel and the "race to the moon" ignited the imagination of millions of Americans, encouraging a surge of participation in the sciences. No aspect of the space program has yet generated the sustained excitement of that period. The search for life in the solar system and beyond has the potential to be similarly compelling (quotation about public interest), and we are proposing to capitalize on that interest to engage a diverse visitor-ship in inquiry-based science learning.

Public perception of the search for extraterrestrial life has been dominated by science fiction and by the Search for Extraterrestrial Intelligence (SETI). Only recently has a research agenda combining fundamental terrestrial biology, the understanding of planetary history, and space exploration technology been defined. This agenda is the basis of a revised scientific inquiry into the search for extraterrestrial life in which models and hypotheses have evolved that are susceptible to systematic testing and the technologies for that testing are challenging but well understood.

*Extraterrestrial Life* will be the first major exhibition to introduce the public to this approach to the search for extraterrestrial life. Though the timetable for some of the space agencies responsible for this search has been changing recently, it is clear that the next several years will yield valuable data. Some of the missions in progress or planned for the next several years include: orbital missions to Mars (2001); Europa orbiter (2003); the first interferometry-based space telescope (2004); Cassini atmospheric probe of Titan (in progress – flyby in 2004); Kepler mission to detect earth size planets (proposed for 2003). All of these missions will yield key pieces in the scientific puzzle of the search for extraterrestrial life, and the proposed exhibition will offer the public a window into that process. In addition, there are literally hundreds of ongoing research projects that are testing the environmental boundaries of terrestrial life. The search for the boundaries of life on earth, in the solar system, and beyond is one of the critical inquiries of our generation.

***Summary***. *Extraterrestrial Life* will build upon the public fascination with the possibility of extraterrestrial life and planetary exploration to engage them in understanding the actual science behind the contemporary search for extraterrestrial life.
The contemporary science of the search for life has produced several important, timely, and ongoing scientific advances. Moving from the most local to the most far-flung, these include:

1) We have discovered that life on earth can exist under a much broader range of environmental conditions than we had previously suspected. Organisms that live at the extremes of these conditions we are calling "extremophiles."
2) In our own solar system, we have discovered significant evidence that Mars and Europa (a moon of Jupiter) may have sustained habitable environmental conditions in the past, and we are actively seeking evidence about these conditions in the present.
3) We have discovered planetary systems beyond our solar system, and are actively developing theoretical and experimental strategies for exploring the possibilities of life on these other systems.

# Abstract # 13036 - **Partners in Science Education: SOFIA EPO Program**

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NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA) represents a unique opportunity for education and public outreach (EPO). SOFIA is the first research observatory--airborne or ground-based--in which close participation by educators and journalists is being designed into both the physical facility and the administrative structure of the observatory. With the overall goal of contributing to the public's awareness and understanding of science in general and astronomy in particular, the SOFIA EPO program will include formal K-12 and undergraduate educational activities, informal education, public outreach, and media relations.

One of the most exciting and unique aspects of the SOFIA EPO program is the observatory's ability to carry up to 10 educators on science flights, enabling these educators to partner with scientists and see science in action. Some 200 formal and informal educators per year are expected to participate in the SOFIA Airborne Astronomy Ambassadors program. Educators who have participated in Airborne Astronomy Ambassadors program will be encouraged to continue their scientist partnerships and will be supported in their efforts to carry their new-found knowledge and enthusiasm to their students, other educators in their communities, and the general public. The Airborne Astronomy Ambassadors will be supported as a national network via continued communications and material support from the observatory's EPO program office, and will constitute a wide-spread outreach cadre for NASA in general, and space sciences in particular based upon their affiliation with airborne astronomy.

Scientists, engineers, and other members of the SOFIA team will be encouraged to partner with local teachers and visit their classrooms as a part of the SOFIA Education Partners Program. Training for scientist-educators will be offered via the Project ASTRO network of astronomy education sites around the USA. This program will enable students to interact with scientists and other professionals on a one-on-one basis. Participating

educators may fly onboard SOFIA with their scientist partners. Scientists who participate in this program will be able to work with educators and students in their local communities to forge long-lasting science education partnerships.

The professors and instructors at community colleges, small colleges, and minority serving institutions teach astronomy in general education courses; they teach astronomy and space sciences to the majority of future K-12 teachers. SOFIA EPO will provide an opportunity for this important segment of the college/university faculty to learn about research astronomy first hand. Each summer, educators and faculty involved in undergraduate instruction, science and technology centers, and planetariums will have the opportunity to participate in special workshops at the SOFIA Science and Mission Operations Center at NASA's Ames Research Center in Northern California. Participants will be encouraged to develop partnerships with SOFIA-affiliated scientists and participate in research flights.

The SOFIA EPO staff is interested in forming collaborations with interested organizations, other NASA missions, and individual astronomers. SOFIA is being developed and will be operated for NASA by USRA. The EPO program is being developed and will be operated jointly by the Astronomical Society of the Pacific and SETI Institute. . For more information please contact the authors: Edna DeVore, edevore@seti.org and Michael Bennett, mbennett@astrosociety.org.

# Evolution of Life Abstracts

# Abstract # 12540 - **Pattern of Early Triassic Recovery from the End-Permian Extinction on the Great Bank of Guizhou, Guizhou Province, China**

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The Great Bank of Guizhou, an isolated Late Permian to Late Triassic carbonate platform in the Nanpanjiang Basin, southern China, contains an essentially complete stratigraphic record of the Permo-Triassic boundary, end-Permian extinction and the recovery interval of the Early and Middle Triassic. The pattern of biotic recovery was examined in biostratigraphically and geochronologically controlled sections in the platform interior and the basin margin. Diversity was measured at the class level in standard thin sections, and abundance of biotic groups was determined by point counting. The basin margin and in the platform interior exhibit distinct abundance and diversity patterns. Diversity on the basin margin increased through the Early Triassic, with recovery accelerating in the Spathian and into the Anisian. The abundance of skeletal debris closely parallels diversity. The skeletal component of the rock is dominated by crinoids in the Spathian and by *Tubiphytes* in the Anisian, with minor contributions from foraminifera, cephalopods, echinoids, brachiopods, bivalves, and gastropods. In the platform interior, the greatest diversity and abundance of biotic debris occurs within the basal fifteen meters of the Triassic, associated with a calcimicrobial horizon. After this interval, skeletal debris consists entirely of bivalves, gastropods, brachiopods, and annelid tubes. Abundance and diversity of biotic debris were correlated throughout the Early Triassic of the platform interior. The skeletal component rarely exceeded 5% by volume.

Recovery from the mass extinction proceeded slowly in the Early Triassic. While an apparent diversity increase occurred on the basin margin, the skeletal grains are nearly all derived from the platform margin. Combining the diversity data from the platform interior and the basin margin sections suggests that total diversity on the platform remained nearly unchanged during the Early Triassic. Only with accelerated Middle Triassic evolution did recovery approach completion.

# Abstract # 12547 - **Detecting Ancient Duplications using Whole Genome Data**

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One way to root the universal tree of life is to use anciently duplicated paralogous genes that are present in all three domains of life (Schwartz and Dayhoff, 1978; Gogarten et al., 1989; Iwabe et al., 1989; Brown and Doolittle, 1995; Gribaldo and Cammarano, 1998). Only few pairs of anciently duplicated genes have been identified so far. With the availability of several completely sequenced bacterial and archaeal genomes, it is now possible to search for the pairs of ancient paralogs systematically.

We chose 12 representative genomes (6 archaeal and 6 bacterial) and constructed the 36 Archaeal-Bacterial (A-B) genome pairs possible with these genomes. For each A-B genome pair, we built a list of putative ancient paralogs with this method: For all genome pairs, we performed BLAST searches of proteins encoded in genome A against genome B, plus all proteins from genome B against genome A, saving all hits with E-values below $10^{-8}$. Two A-B gene pairs of reciprocal top-scoring BLAST hits were classified as putatively paralogous if the A gene from the first pair picked up the B gene from the second pair among the significant hits in the BLAST search. This selection of paralogous gene pairs does not guarantee that they are ancient duplications. Therefore, we ranked the putative paralogous gene pairs according to their presence in other A-B genome pairs. This ranking also disfavors horizontally transferred genes, because these usually have a disjunct distribution. Next for all of the top-ranked pairs, we constructed extended datasets of the homologs from 50 representative Bacterial and Archaeal genomes and performed phylogenetic analyses to ensure that the putative paralogous pairs are indeed instances of the ancient duplications. Datasets that survived this scrutiny were classified with respect to mono-, poly-, or paraphyly of the Archaeal and Bacterial homologs and the placement of the root (i.e., the ancient gene duplication event) relative to the two prokaryotic domains. Eukaryotic homologs were added from the SWISS-PROT database, and their placement in relation to the prokaryotic domains was determined.

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# Abstract # 12587 - **Production and Consumption of Reduced $C_1$-Gases in Microbial Mats**

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Methane, low-molecular weight halocarbons, and methylated sulfur compounds are among the small carbon ($C_1$-) compounds that have substantial potential for impacting atmospheric chemistry and ultimately its composition. Microbial mats (which include cyanobacteria, methanogens, methylotrophs, sulfate reducers, and sulfate oxidizers) present the modern analogue of the oldest ecosystems known on Earth. Moreover, these mats are the ideal ecosystem to study production of the aforementioned $C_1$-gases, because of the high metabolic rates that characterize these mats. The small spatial scales over which a variety of metabolic reactions are found create the ideal environment for combined biological-chemical reactions. The community structure and functioning of the mat ultimately dictate the net flux rates of the gases. The production and consumption of methane, methyl sulfides and halomethanes (including methyl bromide and methyl chloride) have been studied using microbial mats from a variety of marine ecosystems, including hypersaline ponds, temperate intertidal zones and salt marshes, and subtropical lagoons.

Here we present an overview of potential mechanisms and rates of volatile $C_1$ production in different microbial mats. Microbial transformations, often coupled to chemical reactions, served as sources or sinks for a variety of gases. Processes traditionally believed to be restricted to anoxic sediments (e.g., methane production and methylation of sulfide) were in fact often associated with the oxic part of the mats. Our findings may facilitate a better understanding of the evolution of the atmosphere during the Earth's history.

# Abstract # 12601 - **Genomic Clocks and the Accuracy of Divergence Time Estimates: A Comparison of Methods**

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Molecular clock studies have allowed biologists to estimate divergence times for many groups of organisms that lack a fossil record. These include microscopic (single-celled or multicellular) organisms and those with soft bodies not prone to fossilization. However, the lack of abundant and reliable fossil calibrations and uncertainty of evolutionary rate differences have led many to criticize the use of molecular clocks to date divergences. Genomic clocks use many nuclear genes to increase the precision of time estimates, but it is unknown how differences in available methodology affect those time estimates.

Here, we will present two examples from multicellular eukaryotes (vertebrates and arthropods; plants, animals, and fungi) illustrating different methods of divergence time estimation. We compare the results of global clock methods, where a constant rate model of change is used, with local clock methods, where rates may vary among branches and nodes according to different models and prior information such as fossil constraints. Ultimately, the estimation of accurate divergence times among organisms will facilitate the comparison of biological events with geological and environmental events throughout Earth's history.

# Abstract # 12634 - **The Fate of Oxygen During the Early Paleoproterozoic Carbon Isotope Excursion**

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Karhu and Holland (1996) compiled geochronologic and geochemical evidence for the existence of a worldwide carbon isotope excursion in marine carbonates during the early Paleoproterozoic between ca. 2.22 and 2.06 Ga. The evidence for this major perturbation in the carbon cycle has now been corroborated by data for carbonates on every continent except Antarctica. The shape and the duration of the carbon isotope excursion are still somewhat uncertain due to poor age constraints. However, the available data indicate that the d13C value of seawater was above +6‰ during most of the excursion; in the middle of the excursion d13C values were generally above +10‰ and in some areas as high as +28‰ (Bekker et al., in press). The carbon isotope excursion approximately coincides in age with the change in the oxidation state of the atmosphere that was named the Great Oxidation Event (GOE; Holland, 2002) and confined between the late stages of the glacial epoch at ca. 2.3 Ga and the end of the carbon isotope excursion at ca. 2.06 Ga. Karhu (1993) estimated that the amount of excess oxygen released during this event was between 12 and 22 times the oxygen content of the modern atmosphere. We seek to determine what happened to this excess oxygen. S and Fe are the only sufficiently abundant elements in the Earthís crust to consume such a large amount of atmospheric oxygen during weathering and sedimentation. The oxidation of sulfides on continents, a subsequent increase in the concentration of sulfate in the oceans, and the deposition of bedded sulfate evaporites represent a possible sink. However, bedded sulfate evaporites are rare in Paleoproterozoic successions, and the restrained isotopic fractionation of

marine S suggests that the sulfate concentration in seawater remained quite low until near the end of the Proterozoic. We have therefore investigated how the oxidation state of iron in sediments changed between 2.3 and 2.0 Ga and whether a change in the geochemistry of Fe could have absorbed the excess O2 generated during the carbon isotope excursion.

Shales have a higher Fe content than most other sedimentary rocks and are abundant in the sedimentary rock record. They are therefore an important component of the redox budget of Fe. We have compiled a database of major element analyses in shales, selecting analyses of shales that were not altered by metamorphism or by recent weathering. The database was then subdivided into four time slices: pre-GOE, GOE, Precambrian post-GOE, and Phanerozoic. On a plot of the Fe2O3 vs. the FeO content the analyses of pre-GOE shales have a large scatter but in all of the analyses Fe2O3/FeO < 1, with the exception of a few analyses of shales deposited during the Paleoproterozoic glacial events. The average value of the Fe2O3/FeO ratio of pre-GOE shales plots somewhat below that of the average crust, suggesting that Fe-containing minerals in pre-GOE shales experienced no oxidation during weathering, transport and deposition. The analyses of GOE and post-GOE shales can be divided into two groups. One group consists of shales with an Fe2O3/FeO ratio that is similar to those of pre-GOE shales. The second group has Fe2O3/FeO ratios > 1. Shales from the latter group were clearly affected by oxidation. The averages of the Fe2O3/FeO ratio of the two groups plot along a line for which the sum of Fe2O3 and FeO is between 6 and 7 weight %. The average values of the Fe2O3/FeO ratio of both the Phanerozoic and the GOE reduced shales plot close to the average for pre-GOE shales. Independent evidence that the surface environment responded to the rise of atmospheric oxygen by oxidizing FeO to Fe2O3 is provided by the extensive and thick red beds and hematitic ironstones associated with shallow-water sandstones during and after the glacial epoch (e.g., Timeball Hill Formation, South Africa; the upper part of the Huronian Supergroup, Canada; Cercodinho Formation of the Minas Supergroup, Brazil; and Mapedi Shale, South Africa among many others). In addition, very large volume of iron ore formed in Australia and South Africa during this time by the circulation of oxidized meteoric waters through (2.45 Ga old BIFs.

The available data can be used to estimate the increase in the Fe2O3/FeO ratio of shales during the GOE. This increase can be translated into an approximate figure for the quantity of O2 required to convert pre-GOE into GOE shales between ca. 2.3 and 2.06 Ga. The quantity is roughly equivalent to the quantity of excess O2 generated during the d13C excursion, indicating that the conversion of FeO to Fe2O3 during weathering and sedimentation may have been the major sink of the oxygen produced during the Paleoproterozoic d13C excursion. The uninterrupted length of the carbon isotope excursion for more than 120 Ma is unique in Earth history. Its length, as yet rather poorly constrained, is close to the probable half-life of sedimentary rocks at 2.0 Ga, suggesting that the recycling of sedimentary rocks might have had a significant influence on the duration and magnitude of the early Paleoproterozoic carbon isotope excursion.

# Abstract # 12646 - **Evidence of an A/V type ATPase in *Thermus scotoductus* and Other Closely Related Species**

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ATP synthases, also known as proton-pumping ATPases, function either as ATP driven cation pumps or they can synthesize ATP, utilizing transmembrane ion gradients. The ATP synthase family can be divided into three types: the A-ATPases found mainly in Archaea; the F-ATPases in mitochondria, plastids, and Bacteria; and the V-ATPases in Eukaryotes, predominantly on vacuoles and other vesicles of the endo- and exocytotic pathway.

Based on ribosomal RNA sequence, cell wall, and lipid composition, the Deinococci are classified as Bacteria (Woese 1987, Hensel *et al*. 1986). In 16S rRNA phylogenies, the Deinococci form a lineage that branches off before the radiation of most other bacterial lineages. At present the class Deincocci is divided into three genera, the radiation resistant *Deinococcus*, thermophilic *Thermus,* and mesophilic *Meiothermus* species. Until recently, all members of the Deinococcci were known to contain an A/V- type ATPase. The presence of an A/V-ATPase in different *Thermus* species, as well as in the deeper branching *M. ruber* and *D. radiodurans* suggests that the presence of this type of ATPase is a primitive character of the Deinococci that was acquired by an ancestor of the Deinococci through horizontal gene transfer (Olendzenski *et al*. 2000).

However, based on immunological cross reactivity, inhibitor sensitivity, and amino terminal protein sequences, two *Thermus* species (*T. scotoductus* DSM 8553 and *T. filiformis* DSM 4687) were reported to contain bacterial type F-ATPases (Radax *et al*. 1998). This surprising finding suggested either a recent replacement of the ancestral V-type ATPase in *T. scotoductus* and *T. filiformis* with a newly acquired F- type ATPase (most likely from a member of the *Geobacillus* group), or a long term persistence of both

F and A type ATPase in the Deinococci, implying a recent loss of the typical Bacterial F-ATPase in those Deinococci that only possess the A-ATPase.

Using PCR with redundant primers, sequencing, and Southern blot, we investigated for the presence or absence of an F-ATPase in the genomes of *T. scotoductus* and *T. filiformis,* plus further study the distribution of ATPase type among members of the Deinococci. We conclude that no F-type ATPases are present in any of the Deinococci species used in this study. The previously described F-ATPase in *T. scotoductus* and *T. filiformis* (Radax *et al.* 1998) were probably due to a contamination with a thermophilic *Bacillus* species.

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# Abstract # 12667 - **Distribution of Photosynthesis in the Alpha Proteobacteria**

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Photosynthesis is polyphyletic among the alpha Proteobacteria. There is currently a debate over whether this polyphyly represents an early photosynthetic ancestor and rampant loss of function or a series of horizontal transfer events. Using Bayesian analysis, a maximum likelihood tree was constructed for 435 members of the alpha Proteobacteria using 16S rRNA sequences. Metabolism was mapped onto the tree to determine the relative merit of the two hypotheses. An additional phylogeny was constructed with known photosynthetic reaction center genes from the alpha Proteobacteria. Comparison of the two phylogenies suggests that horizontal transfer is the better explanation.

# Abstract # 12684 *(Oral Presentation)* - **The Role of Chlorophyll *d* in *Acaryochloris marina***

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(Chls) play a key role in photosynthesis. Their role depends on the characteristics of the electronic spectra of chlorophylls to absorb light from near UV to near-IR and to convert it into photochemical energy [1]. Chl *d* was often considered to be a by-product of the pigment extraction process until the discovery of the prokaryotic oxygenic photosynthetic organism *Acaryochloris marina* (*A. marina*) in 1996 [2], which revealed the *in vivo* existence of Chl *d* as a major photosynthetic pigment (over 95%) in nature. Chl *d* in *A. marina* acts not only as major light-harvesting pigment [3,4], but also as special pair (P740) in photosystem (PS) I reaction centers [5,6], where it performs a function similarly to that of P700 in that well-known Chl *a*-containing analogues [7]. However, it is uncertain which chlorophyll acts as the primary donor in PS II of *A. marina*, with the possibilities being either Chl *a* or Chl *d* dimer. If indeed it is Chl *a* dimer, then uphill energy transfer is required in order to purvey excitation from the antenna system to the special pair.

In order to understand the role of the Chl *d* in *A. marina* and how photosynthetic reactions proceed in the system containing Chl *d* and Chl *a* mixtures rather than Chl-*b*/Chl-*a*, the study of the structure and spectroscopic properties of Chl *d* becomes very important. It is well known that Raman shifts of photosynthetic pigments can provide important details of the structural organization of the underlying environment and that electronic absorption. The Raman spectrum of Chl *d* isolated from *A. marina* has been

measured at 77 K for the first time and analyzed by aid of hybrid density-functional vibrational analyses. A Raman peak specific to Chl *d*, which arises from the formyl group $3^1$ C=O stretching, was clearly observed at 1659 $cm^{-1}$ with medium intensity. Peaks due to other C=O stretching vibrations of the $13^1$ keto-, $13^3$ ester- and $17^3$ groups were also observed. Four very strong peaks were observed in the range of 1000 - 1600 $cm^{-1}$, assigned to the CC stretching and mixtures of the $CH_3$ bend and CN stretching. CCC and NCC bending contribute to medium intensity peaks at 986 and 915 $cm^{-1}$. Out-of-plane CH bending at Chl *d* sites 10, 5 and 20 contribute to observed peaks at 885, 864 and 853 $cm^{-1}$, respectively. A few modes involving the MgN stretching and MgNC bending motions were observed in the very low frequency range.

We have also isolated Chl *d* in pure form in methanol and carried out detailed spectral analyses. We have modelled the energy distribution of the excited states and have shown how energy transfer may occur *in vivo* between Chl *d* molecules. "Uphill" energy transfer of energy could be accommodated by this model.

The overall results show how a small change from a vinyl group to a formyl group at the C3 position in Ring I can modify the spectral and chemical properties of this chlorophyll to allow it to play such a large role in the photochemical reactions of *Acaryochloris marina* and to extend its spectral absorption in the near far-red region of the spectrum.

In *Acaryochoris* the Chl *d* is bound to special proteins in the reactions centres of Photosystem I and Photosystem II and the light harvesting chlorophyll protein which is in the pcb (prochlorophyte chlorophyll protein) class. Two linked genes have been probed and sequenced and the putative amino acid sequences compared by phylogenetic tree analysis to pcb and isiA (iron stress-induced protein A) proteins in other Cyanobacteria, showing that there is a close relationship of **Sequence 2** to CP43/isiA-like protein. In Cyanobacteria CP43 and the isiA protein are similar. **Sequence 1** is similar to the pcb group. The predicted tertiary protein structure for **Sequence 1**, deduced from the primary sequence (hydrophobicity and α-helices), is consistent with this conclusion; however, the identity of **Sequence 2** analysis needs to be confirmed. The role of these light harvesting proteins and their position in relation to Photosystem I and Photosystem II will be discussed.

# Abstract # 12690 - **Cell Wall Biochemistry and the Proliferation of Vascular Cell Types During the Evolution of Complex Land Plants**

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The evolution of vascular tissue was essential for the evolution of large, structurally complex land plants and the number of functions these tissues were required to fulfill continued to rise as size and complexity increased. For example, the tracheid cell type was involved only in water conduction in the earliest vascular plants, but tracheids soon became the primary source of structural support for the plant. Over subsequent evolution these vascular cells have also played roles in wounding responses, nutrient storage, and the reversible regulation of water and nutrient supply. Even the original function of water conduction has involved the evolution of divergent specializations, such as for efficient long distance transport versus equitable short distance distribution of water and for conduction in mature tissues versus young, actively expanding tissues.

Tracheid function is entirely dependent upon wall structure since the cells are dead at maturity. Because of this, tracheid functional characteristics have typically been evaluated in terms of cell dimensions, wall thickness and morphological details. However, cell wall chemistry may also be extremely important: tracheid walls are composed of both lignin and polysaccharides and the distribution of these hydrophobic and hydrophilic compounds within different wall layers could greatly influence all aspects of tracheid function. In the past, longstanding technical limitations have impeded the precise evaluation of the spatial distribution of cell wall constituents. We have now overcome these complications with X-ray spectromicroscopy, which allows determination of lignin distribution within wall layers with submicron resolution. We have found that the diversification of vascular cell types and functions has not required any large changes in overall cell wall chemical composition or plant biosynthetic capabilities, but has instead been accommodated by several revolutions in the fine scale distribution of chemical constituents in different wall layers. By these means, a large increase in the number of cell types and in the morphological and functional complexity of land plants could evolve by relatively small modifications of developmental and biochemical pathways already in place in the simplest early vascular plants.

# Abstract # 12691 - **A Genomic Perspective on the Evolution of Magnetite Biomineralization in Magnetotactic α-Proteobacteria**

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Recently a number of genes encoding magnetosome-specific proteins were found to be clustered in three different magnetotactic bacteria of the α-proteobacterial class. This suggests that the biologically controlled mineralization of magnetite (BCMM) has been inherited either vertically or horizontally and that it was not invented multiple times within the α-proteobacteria.

In an effort to understand the evolution of BCMM and to identify genes involved in this process, we compared the genomes of the two sequenced magnetotactic bacteria, *Magnetospirillum magnetotacticum* (MS-1) and *Magnetococcus* sp. MC-1. We focused on finding genes conserved only between the two sequenced magnetotactic bacteria, which in our study means that the genes have a higher BLAST score to each other than to any non-magnetotactic organism. In MS-1 we found 217 conserved genes, all but 19 of which were in clusters in either MS-1 or MC-1. The conserved genes include some of the genes thought to be required for magnetite formation, most notably the *mam* cluster and the *nap* cluster. The signature of transposon and/or phage activity in 14 of the 30 clusters in MS-1 indicate that both vertical inheritance and lateral gene transfer have played a role in BCMM evolution in MS-1 and that BCMM is ancestral to the α-proteobacteria.

# Abstract # 12697 - **Genomic Evidence Bearing on the Number of Symbiotic Events in the Origin of Eukaryotes**

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The origin of eukaryotes remains an important biological question. It is generally, although not universally, agreed that eukaryotes evolved from prokaryotes through endosymbiosis, and that the mitochondrion arose from an alpha-proteobacterium and the plastid from a cyanobacterium. Beyond this, there is considerable debate as to the number of additional symbiotic events, the characteristics of the first eukaryotic cell, the nature of the original host and symbiont, and the timing of events. Genomic data are ideal for testing these theories because it is now known that genes were transferred from the symbiont genome to the host genome (nucleus) during or after a symbiotic event. Clear evidence for the symbiotic origin of the mitochondria and plastids can be seen by many eukaryotic nuclear gene sequences clustering in phylogenies with sequences of their respective prokaryote progenitors. Some additional phylogenetic groupings have been found, suggesting the possibility of premitochondrial symbiotic events, but the small number of available genomic sequences has limited efforts to resolve these patterns and identify the number of symbiotic events.

In this study, we have analyzed genomic data for 73 prokaryote and four eukaryote genomes with a variety of bioinformatic and phylogenetic methods to identify the number of symbiotic events. Because of lineage-specific rate differences, phylogenies must be carefully scrutinized. As in previous studies, eukaryotes cluster quite strongly with alpha-proteobacteria in many genes, reflecting the origin of mitochondria. However, we also find that eukaryotes sometimes form a robust and ancient grouping with other eubacteria (e.g., spirochetes) and will discuss the significance of this finding for the origin of eukaryotes.

# Abstract # 12712 - **Adaptive Variation and Horizontal Gene Transfer: Implications for Understanding Evolution of Life on Early Earth**

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The Cuatro Ciénegas basin, Mexico, represents one of the finest surrogates for early Earth ecosystems, making it a prime location for investigations pertaining to the emergence and persistence of life on Earth. The basin contains a remarkable diversity of aquatic environments, including physicochemically constant thermal springs, environmentally harsh evaporative sinks, and connecting regions of intermediate severity.

We are studying hybridization between two pupfish species, *Cyprinodon bifasciatus* and *C. atrorus* (endemic to Cuatro Ciénegas) to assess the impact of horizontal gene transfer between forms occupying extreme environmental gradients. These species inhabit opposite extremes of a severe environmental gradient, but they hybridize extensively in the physicochemically intermediate mid-reaches. Previous research on the relationship between environmental and genetic variation in this system suggests these species and their hybrids exhibit vast differences in their physiological tolerances. Such differences, when recombined in introgressed populations, could fuel local adaptation across the physicochemical gradient that separates these species. Reciprocal transplant experiments were performed to test whether there are significant physiological tolerance differences between *C. bifasciatus* and *C. atrorus*. Both species experienced very low mortality in the physicochemically stable environments that typify *C. bifasciatus* habitats. In contrast, *C. bifasciatus* suffered significantly higher ($p < 0.001$) mortality than *C. atrorus* in the severe and fluctuating environments representative of *C. atrorus* habitats. These results provide the first empirical evidence that *C. bifasciatus* and *C. atrorus* exhibit profound physiological tolerance differences. Ongoing research is focusing on the potential role of such physiological differences to influence local adaptation in this system, which ultimately can provide important insights for understanding the significance of horizontal gene transfer in the evolution of life on early Earth.

# Abstract # 12714 - **A Stable Isotope Test for Anaerobic Methane Oxidation in Pure Archaeal Cultures**

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Understanding the major sources and sinks controlling atmospheric methane levels is important for estimating past and future concentrations of this potent greenhouse gas. Stable isotope and lipid-based studies propose an anaerobic oxidation of methane (AOM) pathway intertwined with sulfate-reduction present in some marine systems. Stable isotope and molecular evidence suggest an Archaean with close phylogenetic relationship to modern methanogens composes a crucial segment of this pathway with a second, sulfate-reducing metabolism also required.

While there is significant evidence of its existence, the Archaean catalyzing anaerobic methane oxidation has not been isolated in pure culture. We are examining cultured Archaeal species related to the proposed anaerobic methane oxidizer. We seek to determine whether any of these organisms can, to even a small extent, reverse their biochemical machinery to anaerobically consume methane like their closely related, but thus far not isolated, counterpart. Until this organism is isolated, analyzing Archaean species capable of even trace amounts of methane oxidation may aid in understanding the chemical reactions and enzymology used for the anaerobic oxidation pathway.

Cultures used in this study cluster into two distinct groups selected for their metabolic and phylogenetic similarities to anaerobic methane oxidizers observed in natural systems. The first group consists of three species from the Archaeal genius *Archaeoglobus*. The ability of *Archaeoglobus* spp. to perform both sulfate-reduction and trace levels of methanogenesis suggests they may contain the enzymatic prerequisites to anaerobically

oxidize methane. The second microbial group contains three methanogen species. The first species, *Methanosarcina acetivorans*, is closely related phylogenetically to the Archaeal AOM components. The other two methanogen species tested were selected for containing the carbon dioxide reduction pathway for methanogenesis, a pathway not found in *M. acetivorans*.

We are using $^{13}C$ labeled methane to test for methane oxidation in anaerobic, pure Archaeal cultures. Analysis of the $\delta^{13}C$ of $CO_2$ in the bottles before and after incubation with the labeled methane indicates the extent of methane to carbon dioxide conversion, and thus methane oxidation, in each culture. Initial results show trace levels of methane oxidation in the methanogen, but not *Archaeaoglobus* spp. cultures. Under a variety of different conditions, the *M. acetivorans* cultures oxidize approximately 0.1% of available methane while the two other methanogen species oxidize approximately 0.01% of available methane. Through chemical alterations of the culturing media we hope to optimize the oxidation signal.

# Abstract # 12719 *(Oral Presentation)* - Evolution of Replicator Populations under High Mutational Pressure: Stationary States and Muller's Ratchet in RNA Virus

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Viral populations are excellent test beds for the study of evolution in the laboratory. Their complexity lies halfway between DNA-based organisms and simple replicators: they are able to change fast and adapt to varying environments in a time scale ameanable to human study while preserving enough genetic information to behave as a (quasi)species. The analysis of their evolution and adaptation through carefully designed laboratory experiments can be complemented through simple models of replicating agents subject to high mutation rates. These high mutation rates are the reason for large populations of viral sequences to form highly variable, complex swarms which undergo collective evolution.

Currently, a number of experiments have tried to shed light on the structure of in vitro quasi-species through analysis at the phenotypic level. In this contribution, we will review some recent experiments which have studied the diversity of viral populations by measuring the fitness of their components, that is, their ability to replicate and produce viable "offspring". Duarte and co-workers (1994) have studied the subclonal components of consensus fitness in an optimized RNA virus clone. They have obtained a broad distribution of fitness and observed that the typical sequence is not the variant with highest fitness. Starting with individual clones of very different fitness from one single population, Burch and Chao (2000) have recovered broad fitness distributions in the resulting quasi-species after many replication cycles. These two experiments analyse highly adapted populations where competition among variants has permitted Darwinian selection to act. Other experiments analyse the response of viral populations to frequent perturbations in the form of genetic bottlenecks (Escarmís et al., 2002; Lázaro et al., 2002). Due to the action of Muller's ratchet (and in the absence of compensatory mutations), deleterious mutations should accumulate and the population would eventually cross the error catastrophe and get extinct. However, these experiments have identified the presence of stationary states of low fitness decorated with large fluctuations. Apparently, the quasi-species evolves at a rate fast enough as to avoid extinction upon successive passages.

In this contribution, we study by means of numerical and analytical techniques a simple model of evolution of replicators -- which could represent viral sequences or any other self-replicating agent. Each element is characterized by a fitness f and is able to produce a number of daughter copies proportional to its fitness. With probability q (p) the new sequence is fitter (less fit) than the mother sequence in one unit. Starting with a single sequence which seeds the system, we study the evolution of the exponentially growing population with the constraints that (i) there is a maximum fitness F that can be attained and (ii) sequences with f<1 are no longer viable and disappear from the system. Depending on the dynamical protocol used, the system evolves in three different regimes:

I. Growth in population numbers proportional to the fitness of the seed. This corresponds to low values of the mutation parameters and few replication cycles. If one or few of the produced sequences are used to found a new population, the model mimics the behavior of slowly mutating replicators subjected to genetic bottlenecks. Bacterial populations adapting to a medium are an example to which our model could apply.

II. Growth in population numbers proportional to the highest fitness F. This corresponds to a system after many replication cycles have elapsed. Competition among variants can take place and darwinian selection acts. The relative number of sequences in each fitness class attains a constant value. Our results are in agreement with the observations in the experiments of Duarte et al. (1994) and Burch and Chao (2000).

III. Intermediate regime with mutation parameters of order 10-3 or larger and small number of replication cycles (say up to 20). This situation corresponds to plaque-to-plaque transfers of few randomly selected sequences. The results produced by our model closely reproduce the large fluctuations observed in in vitro experiments (Lázaro et al., 2002; Manrubia et al., 2002).

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# Abstract # 12735 *(Oral Presentation)* - Evolution and Diversity of Dissimilatory Sulfite Reductase (*dsr*) in the Guaymas Basin

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Sulfate and/or sulfite respiration was a possible source of energy for early prokaryotes. Sulfates of magmatic origin were common in the Archaean, and sulfur isotopic records suggest that dissimilatory sulfate reducing bacteria existed 2700 million years ago, well before the advent of a significant oxidizing environment . Shen and associates, based on stable isotope analysis of the early rock record, provide support for an origin of sulfate respiration as early as 3.47 GYA. Sulfite could also be derived from the hydration of out-gassed $SO_2$. Sulfate and sulfite reduction based on the key gene dissimilatory sulfite reductase might predate cytochrome-based aerobic respiration. Siroheme found in the dissimilatory sulfite reductase (*dsr*) active site may be the ancestor of cytochrome cofactor as it can be derived from early intermediates in the heme synthesis pathway. Siroheme-like porphyrins would have been more stable than unsaturated porphyrins to the photoreducing environment of the Archaean.

The utilization of sulfur compounds for energy yielding processes seems to have developed very early during prokaryotic evolution. Prokaryotes still play a dominant role in the oxidative and reductive phases of the natural sulfur cycle. Chemotrophic and

phototrophic sulfur- and sulfide-oxidizing prokaryotes produce sulfate, which is the electron acceptor in dissimilatory sulfate reduction, an anaerobic respiratory process that regenerates sulfide. Three enzymes appear to be involved in dissimilatory sulfur metabolism: ATP sulfurylase; the iron-sulfur flavoprotein adenosine-5'-phosphosulfate (APS) reductase (EC 1.8.99.2); and siroheme sulfite reductase (EC 1.8.99.1). Since APS and sulfite reductases are highly conserved, they appear to be ideal candidates for phylogenetic analysis.

To search for deeply branching and (possibly) ancestral representatives of sulfate reducing microorganisms and *dsr* genes, we focused on hydrothermally active sediments of the Guaymas Basin (Gulf of California, Mexico). Hydrothermal vents possibly represent habitats that were relatively protected from the repeated impacts of early Earth; they can in principle occur on every planet with active plate tectonics and volcanism. We analyzed the *dsr* diversity in Guaymas Basin sediments in parallel with 16S rRNA phylogeny studies. The *dsr* survey was based on a 1.9 kb *dsr* gene fragment, and it revealed a novel clade of deeply branching *dsr* sequences in the Guaymas samples, with no cultured representatives.

The amino acid sequence alignment of some of the cultured sulfate reducers and the Guaymas sequences from the novel clade showed conservation in the protein, especially in the siroheme- and ferredoxin- (containing the $Fe_4S_4$) binding site responsible for electron transport. Sequence and structure comparisons of these enzyme systems will be studied to understand their evolutionary history, which could lead to new insights into the evolution of the microbial sulfur cycle.

# Abstract # 12745 *(Oral Presentation)* - Stable Isotope Results from the Permian/Triassic Boundary, South Africa, and Triassic/Jurassic Boundary, Western Canada: Evidence Against Single Strike Impact as Causes for These Two Mass Extinctions

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There is now little doubt that the largest single cause of the Cretaceous /Tertiary (K/T) mass extinction was the impact of a large comet or asteroid in the Caribbean region, leaving the Chicxulub impact structure. With this mass extinction thus accounted for, increasing attention has been paid to the end-Permian and end-Triassic mass extinctions.

In the last two years, separate groups of investigators have reported the presence of impact ejecta or geochemical anomalies at P/T and T/J boundary sections, indicating that both of these mass extinctions were likewise the result of large body impacts with the Earth. In this talk, we present new evidence arguing against these conclusions. We suggest that neither the P/T nor T/J mass extinctions was either completely, or even largely the result of environmental effects of large body impact. New evidence from the Karoo of South Africa also indicates that the terrestrial portions of the P/T event may have predated the marine extinctions (thus refuting hypotheses of a single contemporaneous cause, such as large body impact). New data from T/J sections in Western Canada indicate two pulses of extinction (one at the end Norian and one at the end Rhaetian Stages) and also argue against a single cause.

# Abstract # 12750 *(Oral Presentation)* - **The Large Scale Topology of the Tree of Life**

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Phylogenetic trees, based on gene sequences of ribosomal RNAs and other elements of the nucleic acid-based information-processing system of cells, outline the evolutionary course of the genetic machinery (below). As deeply divergent lineages have been discovered and added to the known collection, the resolution of branching orders in the tree of life has improved. The three domains (Bacteria, Archaea and, Eucarya) are well established by many phylogenetic and biochemical criteria. The structure of the bacterial tree is seen as a "polytomy," an unresolved radiation of about forty relatedness groups currently known. Archaea split early into two kingdoms, which in turn radiated. The detail of this topology is limited severely by sequence representation. Sequences that represent the diversity of microbial eucaryotes also are limited, but the emerging picture is of about 25-30 "kingdom-level" relatedness groups. The eucaryotic nuclear line of descent clearly is as old as the archaeal line, and it evolved in a more complex way. One of the early radiating lines of descent incorporated a cyanobacterium that became the chloroplast, and an $\alpha$-proteobacterium that became the mitochondrion. Possibly this event sparked a subsequent radiation, one line of which again diversified, into the "crown" radiation of plants, animals, stramenopiles, etc.

Sequence-based phylogenetic trees cannot be used to date branch points because different lines of descent have evolved at different rates, and the course of sequence change is non-linear. There is no "molecular clock." On the other hand, correlation of dated geological features with biological invention seen in the phylogenetic tree can place constraints on the timing of branch-points. The most conspicuous of early such correlations is the occurrence of banded $Fe_2O_3$ in 3.8 billion-year-old rocks. Oxygen is produced biologically only by cyanobacteria. That trait must have been invented in the cyanobacterial line of descent, and possibly sparked the cyanobacterial radiation. The chloroplast lineage diverges from the base of the cyanobacterial radiation, so the chloroplast must have been incorporated into a eucaryote as soon as cyanobacteria came to be. Mitochondria probably originated about the same time; mitochondrial and chloroplast nodes are at about the same depth in their respective lines in phylogenetic trees. Consequently, if the oxygen in the oldest banded iron is of biological origin, then the modern kind of eucaryotic cell, complete with mitochondria and chloroplasts, must have been in place before 3.8 billion years ago.

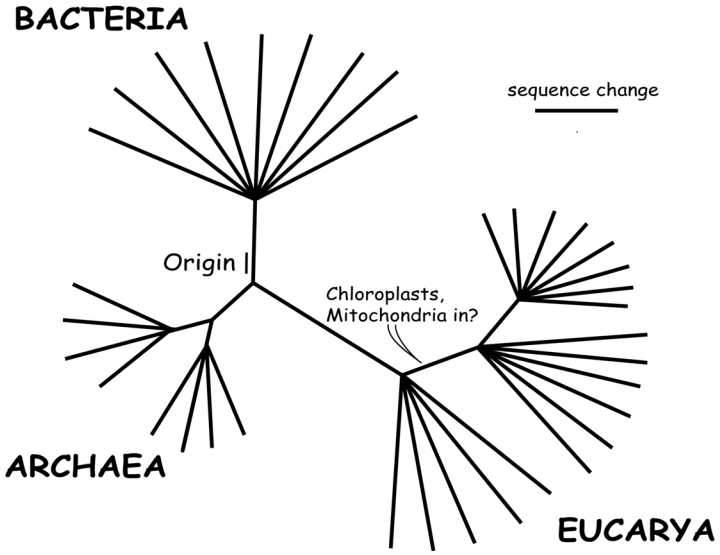


Figure. Diagram of universal phylogenetic tree based on rRNA sequences. (For further information, see Pace, N.R., A molecular view of microbial diversity and the biosphere, *Science* 276:734-740, 1997.)

# Abstract # 12752 *(Oral Presentation)* - micro*scope: A Web-based Tool for Research and Education in Microbial Diversity and Astrobiology

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The micro*scope web site (http://www.mbl.edu/microscope), developed in collaboration with the NASA Astrobiology Institute at the Marine Biological Laboratory, Woods Hole, is an innovative biodiversity bioinformatics web site which greatly improves access to information about microbes. Increasingly, information about the microbial world is necessary as we try to understand current research in molecular biology, ecosystem science, paleogeology, biogeochemistry, or astrobiology. Microbial communities dominated most of the history of Earth and provide us with the biosphere on which we now rely. They are ubiquitous and include the most significant parasites and pathogens. They are key members of most ecological communities, and are especially prominent in the extreme environments that help shape our strategies for the exploration of life beyond Earth. Tools for gathering information about microbes are few in comparison to those available for larger organisms, yet there are many instances in which this information is crucial for advancing research and improving material presented in the classroom.

The micro*scope website fills the gap in available resources and provides students, teachers, and researchers with easy access to high quality digital micrographs and information about diverse microbes, both prokaryotic and eukaryotic. Presently micro*scope has a number of major components. It is an image rich resource providing descriptions and pictures of all categories of microorganisms. It currently contains 4500 freely downloadable high-resolution images. Images and accompanying information can be accessed by a number of methods, including by habitat, cell shape, and alphabetically by genus name. Habitats that have been surveyed include marine, saltwater marshes, fresh water ponds, and other environments including Yellowstone National Park, Rio Tinto, and Lake Toolik in Arctic Alaska. Laboratory culture collections (e.g., American Type Culture Collection) are also included. A unique feature of micro*scope is that it contains the first complete list of all bacteria and protists organized into a hierarchical

classification. This list can be also be used as a method to find images and those of closely related organisms.

The underlying organizational structure of micro*scope is flexible and can be adapted to the needs of both researchers and educators. One of the most innovative aspects of the site is the use of uBio software, developed in conjunction with the MBL-WHOI Library, which uses a registry of names as part of the navigational structure and as a filing system upon which to attach information about organisms. Micro*scope is not designed to be self-contained, but rather it brings together information distributed at other authoritative sites. Micro*scope uses software to track the taxonomic location of the user and to initiate searches into remotely located databases or other sites generally available on the web and based on the genus being examined. Searches can be customized to search only certain selected databases. Since micro*scope can collect all types of information from local or remote locations around the name of an organism, it has the capacity to organize and interpret information in an expert fashion. With the increased dominance of molecular techniques being used to map out the distribution, abundance, and activities of microbial communities, micro*scope can play a critical role for researchers in organizing molecular information by linking general biological information to names arising from queries of molecular databases.

Micro*scope is a flexible, continuously expanding resource. Currently, we are developing micro*scope to be a central educational repository for students and teachers interested in astrobiology and microbial diversity. Educational resources being developed for the site include an Astrobiology Gallery (a page that highlights organisms of interest to astrobiology researchers), plus a collection of hands-on activities related to microbes, which will be sortable in a variety of ways (e.g., by grade level or content area). Information on how each activity ties into the National Science Content Standards, links to other useful educational sites in microbiology and astrobiology, glossary elements, and instructions on using Lucid guides are also being added. A comment function will available to teachers that will allow them to add input and feedback to the educational resources pages containing activities.

Development of micro*scope is on going. Our goal is to maintain micro*scope as a resource to assist those interested in gathering information about microbial taxa and in understanding better the diversity, complexity, and evolution of the microbial world.

# Abstract # 12764 - **Development of DNA Microarray Technology for the Study of Population Dynamics and Evolution of RNA Virus Quasi-Species**

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One type of virus (with RNA as genetic material) and another virus type (with DNA genome and using RNA as a molecular intermediate during its infective cycle) both replicate as complex distributions of related, but non-identical, genomes and are called viral quasi-species. The quasi-species theory was purposed as a model for explaining the auto-organization and adaptability of primitive replicons during the early evolution of life. It also provides a suitable framework for studying the population dynamics and evolution of present-day RNA virus. It has been recently described (using foot-and-mouth disease virus (FMDV) as a model system) that viral quasi-species possess a molecular memory in the form of minority components of their mutant spectra, which reflects the previous evolutionary history of the virus (Ruiz-Jarabo et al. 2000, J. Virol. 74: 3543; Domingo et al. 2000, Virology 270: 251; Ruiz-Jarabo et al. 2002, J. Mol. Biol. 315: 285). The existence of this "historical record" of the genomes that were selected in the past may allow viral quasi-species to module the nature and intensity of the response to new selective pressures. Minority memory genomes (constituting from 0.1 to 20% of the total quasi-species) may be selected and become dominant in the viral quasi-species if they show any replicative advantage. Therefore, it is important to detect and quantify majority and minority genomes in the mutant spectra of viral population.

During the last two years, DNA microarray technology has been developed at the Centro de Astrobiología for detecting mutations and single nucleotide polymorphisms (SNPs) in majority and minority genomes of viral quasispecies. DNA microarrays provide a number

of advantages with respect to the genetic techniques based on sequencing or hybridisation to nitrocelulose strips. Such advantages include: i) high sensitivity; ii) high specificity; iii) high speed of sample processing; iv) the possibility of simultaneous analysis of thousands of mutations in viral genomes, and quantification of levels of salient mutations. A progress report on detection of mutations present at memory levels and its use for studying population dynamics of RNA virus will be presented.

# Abstract # 12772 *(Oral Presentation)* - **Identification of Symbiotic Partners in Hypersaline Microbial Mats**

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Symbiosis, the synergistic partnership between two or more organisms, is an evolutionary force that has shaped present-day life on Earth. The most conspicuous example of symbiosis-shaped evolution is that of multicellular eukaryotes, from the definitive incorporation of bacterial symbionts that became organelles. Less conspicuous, and far less understood, are symbioses between microbial organisms. Associations that enhance the survival of microbial partners, such as the coupling of metabolisms that are thermodynamically more favorable in combination than individually, are thought to be very common in microbial communities. Yet, for most microbial communities we know neither the symbiotic partners nor the biogeochemical prossesses that they impact. In this study, we are investigating the symbiotic partners of the cyanobacterium *Microcoleus*, a conspicuous member of hypersaline microbial mats.

As part of the NAI Ecogenomics study of hypersaline microbial mats at Guerrero Negro, Baja California Sur, Mexico, we have conducted a general survey of the microbial community that comprises the photic zone of the mats by cloning and sequencing ribosomal RNA (16S rRNA) genes. We have found at most 12% of the bacterial community to be members of the Cyanobacteria. This was surprising, because microscopy-based studies have suggested that the filamentous cynaobacterium *Microcoleus* constitutes a major fraction of the biomass and therefore is the principal primary producer. Microscopy studies have also, however, noted the presence of unidentified filamentous bacteria tightly bundled with *Microcoleus* cells inside polysaccharide sheaths. In these studies, the unidentified symbionts were found to be more numerous than the *Microcoleus* filaments. We therefore hypothesized that the microbes abundant in our gene survey were likely to be the unidentified symbionts within the *Microcoleus* sheaths. Specifically, we expected to find bacteria belonging to the bacterial groups Green Non Sulfur and Proteobacteria (Alpha subgroup), both of which constitute >25% of our 16S rRNA gene survey.

We are testing this hypothesis by: 1) extracting genes from isolated *Microcoleus* sheaths, and 2) using autofluorescence as a means to visualize particular bacteria or bacterial

groups. In the first approach, *Microcoleus* sheaths are isolated by micromanipulation, lysed, and the 16S rRNA genes are amplified by PCR, cloned, and sequenced. In the second approach, differential autofluorescence is being investigated as a possible identifier of specific kinds of microbes. We have noted differential autofluorescence of the unidentified filaments and the *Microcoleus* cells within the sheaths. We will confirm the identity of the unidentified filaments by fluorescent *in situ* hybridization. If autofluorescence is species- or group-specific, it will be a useful tool for the rapid detection, localization, and quantification of the *Microcoleus* symbionts.

The identification of the symbionts within the *Microcoleus* sheaths will provide clues as to the nature of the symbiosis. Microbial mats dominated the Archean world and hugely impacted the Earth's atmosphere and biogeochemical cycles. Characterization of the symbiotic interactions that comprise microbial mats is necessary to understand how community structure and biogeochemical cycles are linked, plus how genomes interact to form microbial communities.

# Abstract # 12793 - **A Patchwork Approach to Evolution of a New Metabolic Pathway**

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Living organisms have an intricate network of metabolic pathways for biosynthesis of the building blocks of proteins, nucleic acids, lipids and carbohydrates, and the catabolism of diverse compounds to drive cellular processes. How these pathways have evolved has been discussed for decades. In 1945, Horowitz postulated that the earliest biosynthetic pathways evolved in a backwards direction. This proposition was based upon the assumption that life evolved in a rich soup of organic molecules that provided the basic needs of the primordial life form. As certain organic molecules were depleted, a selective advantage could be gained by organisms that found a way to synthesize those molecules from precursors in the environment. This reasoning also applies to catabolic pathways. If an organism can convert a compound present in the environment into a metabolite in an existing catabolic pathway, it will gain a selective advantage by being able to exploit that compound as a source of carbon, energy, or both.

Since the early days of evolution, Nature has surely employed other strategies to evolve metabolic pathways. Evolution of metabolic pathways in a backwards direction requires special environmental conditions in which useful organic compounds and potential precursors have accumulated. Although these conditions may have existed at the dawn of life, they must have become less common as life forms became more complex and depleted the environment of useful compounds. Furthermore, many metabolic pathways have intermediates that are unstable and could not have persisted in the environment to provide selective pressure for the recruitment of an enzyme to catalyze a new reaction. Finally, pathways for the biosynthesis of elaborate secondary metabolites seem most likely to have evolved by gradual addition of steps to decorate simpler precursor compounds.

An alternative paradigm for pathway evolution is the assembly of new pathways by a novel association of pre-existing enzymes, a strategy that became more likely as life became more complex and the number of enzymes for organisms to draw upon increased. The repertoire of available catalytic activities is expanded further by the ability of many enzymes to catalyze secondary reactions at a low but potentially useful level. These "catalytically promiscuous" enzymes can be recruited to provide new functions when catalysis of these secondary reactions provides a selective advantage to the organism.

Although the major metabolic pathways evolved millions of years ago, molecular evolution has not ceased. Human perturbations of the environment, particularly the introduction of anthropogenic chemicals, have created new opportunities for microorganisms to evolve metabolic pathways in order to either exploit a new carbon source or to detoxify a toxic compound. These metabolic pathways provide a window on

the process of evolution at a very early stage in the process. The evolution of the pathway for degradation of penta-chlorophenol (PCP) in *Sphingobium chlorophenolicum* (Figure 1) is a particularly striking example of a "patchwork" combination of enzymes. Our work has suggested that this pathway has resulted from the recruitment of enzymes from two or possibly three different pre-existing pathways. Notably, two enzymes have been recruited from sources that we would not have predicted based upon the overall chemical transformations they catalyze. Tetrachlorobenzoquin-one reductase is most closely related to reductases that transfer electrons from NADPH to the active site iron of Class Ia dioxygenases, but is not related to the many enzymes that reduce naturally occurring quinones that might have been expected to provide the precursor of this enzyme. An even more dramatic example of recruitment is suggested by our finding that tetrachlorohydroquinone (TCHQ) dehalogenase appears to have originated from an enzyme that catalyzes the isomerization of double bonds from the cis to the trans configuration (see Figure 2). In both cases, we expect that the active site of the progenitor enzyme was suitable for recruitment because of underlying mechanistic similarities between the normal reaction and a secondary activity that are not obvious from a consideration of the overall chemical transformations. These results provide important new insights into Nature's ability to generate metabolic complexity by recruiting enzymes to serve new functions and thereby increase the fitness of organisms under novel and/or stressful conditions.

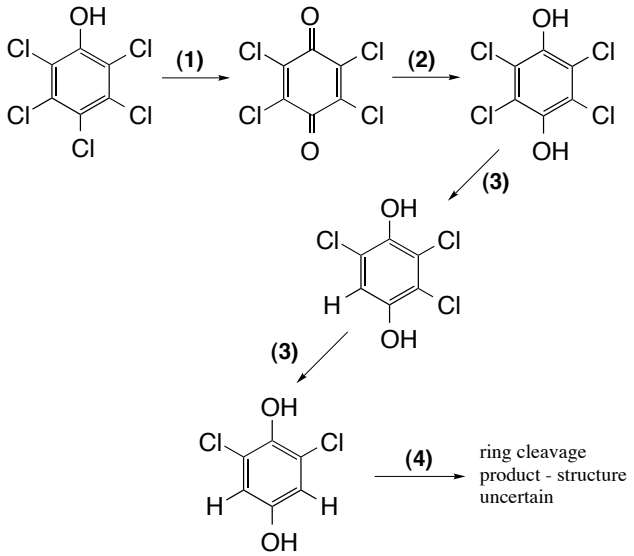


Figure 1. Pathway for degradation of PCP in *S. chlorophenolicum*. (**1**), PCP hydroxylase, $O_2$, NADPH; (**2**), tetrachlorobenzoquinone reductase, NADPH; (**3**), tetrachlorohydroquinone dehalogenase, 2 glutathione; (**4**), 2,6-dichlorohydroquinone dioxygenase, $O_2$.

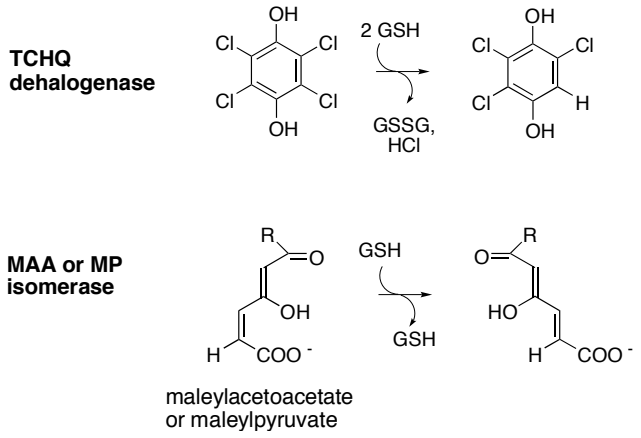


Figure 2. Strikingly different reactions catalyzed by TCHQ dehalogenase and its apparent progenitor, a glutathione (GSH)-dependent double bond isomerase that utilizes either maleylacetoacetate ($R = CH_2COO^-$) or maleylpyruvate ($R = COO^-$).

# Abstract # 12794 - **An Ancient Microbial Ecosystem: Understanding Life and Death in the Bambuí**

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The study presented here focuses on the recently discovered, but as yet almost entirely undescribed ~850-Ma-old (Neoproterozoic) microbial community petrified in carbon-rich cherts of the Bambuí Group of south-central Brazil, "the best preserved and most diverse Precambrian microbiota known from South America…" This fossil biocoenose contains a wide variety of cyanobacterial and noncyanobacterial prokaryotes, the investigation of which will lead to increased understanding of the fields of Precambrian paleontology and microbial evolution.

Following the completion of traditional morphology-based study, this study will center on use of two new techniques for chemical analysis of individual microscopic fossils--laser-Raman spectroscopy of their molecular makeup and ion microprobe mass spectrometry of their elemental and isotopic compositions. Attention will be focused on whatever vestiges of original biochemistry are preserved in these microfossils. Attempting to correlate cellular morphology with chemical composition, the ultimate goal is to elucidate the physiological characteristics of the major biotic components and the carbon and energy flow of this ancient ecosystem. Understanding the metabolic characteristics of these fossil microbes will help to reconstruct the ecology and evolution of early life on Earth and may eventually lead to an understanding of such systems on other worlds.

Precambrian rock units occupy more than half of the total terrain of the nation of Brazil. Although this presents tremendous opportunities for paleobiological research, little has been reported to date. This study focuses on samples from the Proterozoic Bambuí chert of the Paranoá Group of south-central Brazil. The microfossils within these samples have and will continue to be investigated -- categorized by morphological comparison with modern analogs and by biochemical means using ion microprobe and Raman spectroscopy. The goals are to define the living physiological capabilities of these fossil organisms and elucidate the flow of carbon and energy in this fossil ecosystem.

The first step in the study of this diverse, well-preserved assemblage has been to define the range of morphologies present and to place them in taxonomic context based on modern morphological analogs. This portion of the study is currently underway and has already reinforced our confidence in the diversity and importance of this formation. This morphological analysis is performed with optical microscopy of petrographic thin-sections and is documented using optical photomicrography.

Thus far, this study has focused on the spheroidal, likely cyanobacterial cells, within the thin-sections. These cells range in size from 8 to 48 $\mu$m in diameter (a measure only of cell size -- not including sheaths). They are sorted into taxonomic categories by morphologic features such as cell size, sheath lamellation, sheath thickness, etc.
Work has just recently begun on the filamentous fossil forms found within this formation. In the preliminary grouping, many subdivisions are already becoming evident -- categorization based upon filament diameter, sheath presence or absence and inferred *in vivo* "flexibility." The bacterial filament *Archeotrichion* sp. is especially abundant throughout this formation. *Archeotrichion* sp. has been described in other Precambrian units such as central Australia's Bitter Springs formation. Later in this paper, a few of the preliminary photos of these filamentous fossils may be found.

The next step in this study will be to begin searching for whatever vestiges of biochemistry may remain within these fossils. Using two techniques new to paleobiology-ion microprobe mass spectrometry (to detail the elemental and isotopic makeup of these samples) and laser-Raman spectroscopy (to determine molecular composition), we hope to begin to understand the function of this ancient microbiota.

With the isotopic measurements, we may be able to determine how these organisms were making their living. Were they iron-reducers, sulfur-reducers, autotrophs, heterotrophs, chemolithotrophs? Isotopic fractionation measurements may provide information making the aforementioned questions answerable.

Laser-Raman spectroscopy offers a chance to gain understanding of a fossil's molecular makeup. Since this formation has endured moderate metamorphism, we do not expect to gain functional group information from these samples. However, we do anticipate basic information regarding the carbonaceous and kerogenous nature of the specimen, the native polycyclic aromatic hydrocarbon (PAH) compounds, and carbon/carbon double and triple bond characters. The pilot work for paleobiological applications of these two new techniques has already been completed. This rich and diverse assemblage provides an opportunity to further define the abilities and limitations of these techniques in the field of paleobiology.

Completion of this study will add measurably to knowledge of the paleobiology of the Brazilian Precambrian, in particular, and to understanding of Neoproterozoic ecosystems in general. Use of these two new techniques to correlate chemical composition and morphology may for the first time provide a sound basis for inferring the physiology of diverse fossil bacteria -- an insight of obvious relevance to a field rife with controversy.

# Abstract # 12798 - **Life Beyond the Planet of Origin: Microbes in Space**

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The novelty of astrobiology stems in part from its goal to understand the future, including the transport of life beyond the planet of origin. Moving beyond the planet of origin requires a vehicle for transport, a mechanism to leave the parent body, the ability to withstand transport, and the ability to colonize, thrive and ultimately evolve in the new environment. We focus on the ability of organisms to withstand transport, and to that end, microbes have been flown and exposed to the space environment since the 1960's. All have died except *Bacillus subtilis* spores in multi-layers, or overlain with a variety of substances which had a ~80% survival rate after 6 years. The focus of the current study is on natural transport, such as on a meteorite, where radiation, the ability to withstand the vacuum of space, desiccation, and time in transit are the primary factors determining survival. The core of this study is to identify organisms and ecosystems that are likely to withstand the rigors of space using as a guiding principle the hypothesis that desiccation resistance is a good predictor of radiation resistance. We hypothesized that organisms living in high salt environments could withstand osmotic stress and would be desiccation resistant. Organisms have been, and are being, collected from salt brines, evaporitic minerals, and the Pacific intertidal area. These organisms are tested for desiccation and UV radiation resistance in the laboratory. In addition organisms are subjected to UV radiation and desiccation resistance simultaneously using the space simulation facilities at the DLR in Cologne, Germany. We have tested *Synechococcus* (Nägeli), a cyanobacterium isolated from the evaporitic gypsum-halite crusts that form along the marine intertidal, a species of the extremely halophilic genus *Haloarcula* (designated G), a member of the Archaea isolated from an evaporitic NaCl crystal, *Lyngbya aestuarii* obtained from the Pacific intertidal, and as controls we have tested *Halobacterium salinarium* NRC-1, and *Deinococcus radiodurans*. So far, *Synechococcus* (Nägeli), and *Haloarcula* – G have been exposed to the space environment using ESA's Biopan facility. They survived the entire two week exposure time to the space environment and can probably survive longer. These halophiles are the first demonstration of a vegetative cell surviving exposure to the space environment. We are currently examining potential mechanisms for survival of these microbes. Our proposal to ESA to expose a variety of organisms to the space environment for one to two years aboard the International Space Station using an external platform has been accepted and will fly in October 2004. We are currently testing the candidate organisms for flight and have begun performing experiment verification tests at the DLR space simulation facilities.

# Abstract # 12801 - **Stromatolite Grazers in Thermal Spring Systems: Effects of $PO_4$ Enrichment Experiment on Oncoids of Cuatro Cienegas, Mexico**

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Thermal spring systems of Cuatro Ciengas (Coahuila, Mexico) host an uncommon, anachronous association of microbial mats and stromatolites with metazoan grazers and other consumers. Thus, these Cuatro Cienegas thermal springs provide a modern laboratory in which to examine the development of and controls on stromatolite-based food chains important during early Earth ecosystems. This ecosystem is also an ideal place in which to examine the role nutrients and nutrient limitation may have on the development of stromatolite-consumer community structure.

The theory of ecological stoichiometry suggests that nutrient limitation of primary production imposes stoichiometric constraints on herbivorous animals because nutrient-limited autotrophs develop biomass with high C:nutrient ratios that are unsuitable for the consumer. Microbial biomass of the Cuatro Cienegas oncoid stromatolites has extremely high C:P and N:P ratios relative to previously documented autotroph communities, suggesting a strong potential for stoichiometric constraints on herbivores in these food webs. In three experiments during 2001 and 2002, we examined the effects of increased phosphorus content of stromatolite biomass on the grazing snail *Mexithauma quadripaludium*. We incubated oncoids with added $PO_4$ in the presence of *M. quadripaludium* and compared the P content, RNA:DNA ratio, and growth of the snails

grazing on P-enriched stromatolites relative to unenriched controls. In a 2- week experiment in 2001, snails feeding on P-enriched stromatolite biomass had higher P-content and RNA:DNA ratio than the control individuals, consistent with the existence of a stoichiometric constraint on their growth. However, during longer-term experiments (summer 2002), results indicated more complex relationships between phosphorus enrichment and snail population dynamics. There was a statistically significant difference in mortality associated with the phosphorus-enriched samples as compared to the control oncoids. While the average mortality rate was 16.2%, mortality ranged from 13.3% to 60% on enriched samples and only 0% to 16.7% on controls. Another observation is that the number of unmarked individual snails -- perhaps representing new colonizers -- accounted for 20-32.3% of the control populations, but only 0-17.6% in the enriched experiments. Reconciling the results from these enrichment experiments may require a better understanding of the effect of enrichment on the oncoid microbial communities, the entire metazoan stromatolite food web, and genetic constraints on gastropod growth.

# Abstract # 12808 - **The Verification and Insertion Sequences in the Saccharomyces Genome through PCR and Sanger Sequencing in Preparation for Functional Analysis of the Yeast Genome**

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The yeast genome of *Saccharomyes cerevisiae,* yeast, has been completely sequenced revealing over 6,000 open reading frames (ORFs). Approximately one third of these ORFs currently have no known function. A whole genome approach is being used systematically to determine the function of these ORFs. This approach, the *Saccharomyces* Genome Deletion Project, involves disrupting and creating thousands of yeast strains. Each strain has a disruption in a unique ORF and is labeled with a unique 20-base tag sequence "DNA bar code" that can be detected by hybridization to a high-density oligonucleotide array.

To verify the correct insertion of a deletion cassette with a selectable gene marker into each gene in the yeast genome, we performed the following: Yeast strains from the *Saccharomyces* Genome Deletion Project were grown up in rich medium and Polymerase Chain Reaction (PCR) was performed on these stocks to amplify the insert sequence in over 6000 distinct strains. Each sequence was checked, and statistical data were generated on the rate of mutation of each bar code. This involved the culturing of each set of cells and qualitatively testing the expected tag DNA sequence to differentiate between strains along with a statistical analysis of mutation rates. Since each strain has a unique DNA sequence in it, the identity of any one strain compared to the others could be determined through sequencing.

This functional analysis of the yeast genome represents the most complete understanding of a eukaryotic organism. Understanding the function of all the genes in yeast will be important to astrobiologist interested in understanding the evolutionary relationships between organisms and in assigning functions to related DNA sequences in other organisms that share DNA sequence similarity with yeast.

# Abstract # 12823 *(Oral Presentation)* - Chert Dikes: Perhaps the Best Sites for the Preservation and Discovery of Archean Microfossils and Biological Remains

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Problems in interpreting the origin and significance of putative Archean microfossils have arisen in part because of inferences that the rocks containing the questionable materials were collected from chert dikes or veins (e.g., Brazier et al., 2001). Some chert dikes may have formed much later than the enclosing rocks and therefore any biological materials they contain may represent much younger organisms. It has also been suggested that some Archean chert dikes and the carbonaceous materials and microforms within them formed by hydrothermal processes. C-isotope compositions consistent with fractionation via biological Fischer-Tropsch reactions have even been interpreted to have originated through similar hydrothermally-driven abiotic processes (Brazier et al., 2001).

Rocks 3,470 to 3,225 myr old in the Barberton Greenstone Belt, South Africa, include a diverse, multi-generational assemblage of silica-rich dikes and veins from centimeters to over 200 m long and up to 20 m wide. At many localities, the oldest dikes are composed of chert with lithologies dominated by black carbonaceous chert and greenish non-carbonaceous chert, but including a wide variety of accessory sedimentary materials. In virtually all cases, these dikes occur within or below in-section sedimentary units that include lithologic equivalents of the rock types in the dikes, and most dikes can be traced laterally or upward into their source horizons. Some dikes consist of thoroughly mixed sedimentary materials, such as carbonaceous chert containing isolated sand-sized impact-produced spherules (Lowe et al., 1990) injected downward from in-section sedimentary layers composed of black chert containing one or more intact spherule beds. Other dikes are zoned, formed through multiple soft-sediment injections. In one area, individual dikes include zones of black chert and pale greenish chert. The source horizon consists of bedded black chert and pale greenish chert, the latter representing silicified fine, soft, volcaniclastic and chemical sediments. A distinctive layer of impact-produced spherules is interbedded with these cherty units in the source horizon and several of the chert dikes contain either loose spherules mixed with the injected cherty sediments or masses of spherules representing soft chunks ripped from the source layer during downward injection. Where beds containing coarse detrital quartz sand or barite are interbedded with cherts in source horizons the dikes also commonly contain isolated floating quartz sand grains or barite chunks. Other chert dikes are breccias composed largely of clasts of the source beds, including spherule, jasper, white chert, and sandstone beds, that have not been fully disaggregated during injection. Collectively, the composition, structuring, and distribution of these dikes indicates that they formed through downward injection of soft,

unlithified or semi-lithified sediments penecontemporaneous with accumulation of the source horizons.

Whether these same dikes provided conduits for the upward movement of cold or even hot fluids remains speculative, and may have varied from site to site. No vent build-ups have been observed above the dikes, although it is likely that the injections were localized along fractures or even faults and that subsurface fluids, hot or cold, would have found these features easy routes for egress to the surface. All of these rocks have experienced complex post-depositional diagenetic, metasomatic, and low-grade metamorphic histories and the present mineral compositions and textures commonly reflect mainly the latest, often hydrothermal or metamorphic events in this long history.

Rapid burial enhances the preservation of Phanerozoic fossils by removing fragile biological remains from surface chemical, physical, and biological processes of degradation. Although the Archean surface milieu may have contrasted substantially with that of the modern world, there is little reason to suspect that preservation of Archean microbial fossils would not also have been enhanced by rapid removal from the surface system. The chert dikes studied contain abundant carbonaceous matter. Petrographic examination indicates that these materials have commonly suffered little or no compaction and may display less disruption at a fine scale than comparable carbonaceous materials remaining in the source beds. It seems likely that the early, rapid removal of large masses of soft, ooze-like carbonaceous sediments from the ravages of the surface environment and rapid lithification through silicification of the injected sediments may have enhanced the preservation of microbial remains. Clearly, subsequent diagenetic processes of silica recrystallization and upgrading have damaged all carbonaceous materials and affected their integrity at a fine scale. Nonetheless, these and similar carbonaceous chert dikes should be carefully examined, not studiously avoided, in the search for Archean microfossils and biological remains.

While it is clear that many crosscutting silica-rich bodies in Archean greenstone belts are hydrothermal veins, others clearly represent early dikes formed by the downward injection of soft surficial sediments. Inferences that putative microfossils in Archean cherts dikes may be artifacts or later-introduced biological remains or that the chert dikes themselves may be hydrothermal features need rigorous testing at the level of individual dikes or dike sets. Putative Archean microfossils cannot be discredited because they occur in chert dikes nor can chert dikes be routinely interpreted as hydrothermal features. In fact, early-formed chert dikes may offer the best opportunities for future Archean microfossil discoveries.

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# Abstract # 12835 - **A Living Laboratory for Astrobiology: The Desert Springs at Cuatro Cienegas, Mexico.**

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Astrobiologists seeking to understand general properties of life and its interactions with diverse environments are constantly searching for appropriate localities on Earth for such studies. In this talk we describe the environments and biota at Cuatro Cienegas, Mexico, that make them ideal for many such studies and describe some of our ongoing astrobiology work in these unique ecosystems. The basin is dominated by an amazing number (>300) and diversity of springs, and spring-fed aquatic habitats exist within this small (~500 $km^2$) intermontane basin at the eastern edge of the Chihuahuan Desert. The area is hot and arid, with most of its <15.0 cm of annual precipitation falling in summer. Fossil pollens document relative stability over the past 40,000 years. Geologic inference, coupled with concentration of endemics and their levels of differentiation, support a far longer existence, perhaps since Miocene or before. Geothermal waters are associated with a major N-S fault bisecting the basin. Cooler springs likely come from karstic carbonates of surrounding mountains. Springheads are small to large (<1.0 $m^2$ surface area to >1.0 ha), with surface outflows varying from seepage to ~1.0 $m^3 \cdot sec^{-1}$, temperatures from 24-~40º C, total dissolved solids (TDS) from 0.3-2.0 $mg \cdot l^{-1}$ and chemistry from $MgSO_4$- to $Ca(HCO_3)_2$-dominated. In addition to streams, outflow

habitats include lagoons and marshes leading to desiccating playa lakes ~2.0 $km^2$ in surface area, where water temperatures vary seasonally from 0.0-~50° C, major chemical constituents change toward NaCl and TDS may exceed 300 $g \cdot l^{-1}$. Thermal springs (>30°C) lie in an arc around the tip of a southern mountain, flowing to the basin floor through natural and man-made channels onto the basin floor. They have $MgS0_4$-dominated chemistry and TDS higher than 1.2 $g \cdot l^{-1}$. Gradation, with water shifting from warm to cool, high TDS to lower [~0.3 $g \cdot l^{-1}$] and high $MgS0_4$ to $Ca[HCO_3]_2$), occurs S-SE. Springs thus differ dramatically from system to system (but also within systems), so a given taxon often inhabits both similar and quite different springs. Further, within-system conditions change predictably as water flows away from headsprings under increased influences of evapotranspiration, temperature, etc., and biota changes accordingly.

These environmental differences present an unusual opportunity to evaluate how ecosystem conditions influence and constrain characteristics and diversity of the biota that comes to inhabit them. Our astrobiology studies have focused on: 1) primary producers as represented by stromatogenic microalgae); 2) associated heterotrophic microbes; and 3) their metazoan primary consumers (hydrobdiid snails, crustacea, various pupfish). We have gathered data related to calcification by stromatogenic microbes, cyanobacteria community structure, nutrient availability and effects of nutrients on stromatolites and their snail grazers, morphological diversity of hydrobdiid snails, environmental adaptation of pupfish across salinity and temperature gradients, and genetic diversity of Eubacteria and Archaea in diverse habitats. Our data to date indicate an active role of biological metabolism in calcification, an extreme sensitivity of the communities to nutrient addition, and a high level of micro-adaptation and hyperdiversity in fish, snail, and microbial assemblages.

# Abstract # 12841 *(Oral Presentation)* - Carbon and Oxygen Budgets of Hypersaline Cyanobacterial Mats: Effects of Tidal Cycle and Temperature

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The hierarchical organization of microbial ecosystems determines the rates of processes that shape Earth's environment, define the stage upon which major evolutionary events occurred, and create biosignatures in sediments and atmospheres. In cyanobacterial mats, oxygenic photosynthesis provides energy, organic substrates and oxygen to the ecosystem. Incident light changes with depth in the mat, both in intensity and spectral composition, and counteracting gradients of oxygen and sulfide shape the chemical microenvironment. A combination of benefits and hazards of light, oxygen and sulfide promotes the allocation of the various essential mat processes between light and dark periods and to various depths in the mat. Microbiota produce hydrogen, small organic acids, and nitrogen and sulfur species. Such compounds fuel a flow of energy and electrons in these ecosystems and thus shape interactions between groups of microorganisms. Coordinated observations of population distribution, abundance, and activity for an entire community are making fundamental questions in ecology accessible. These questions address those factors that sustain the remarkable diversity of microorganisms that are now being revealed by molecular techniques. These questions also target the processes that shape the various kinds of biosignatures that we will seek, both in ancient rocks from Earth and Mars, and in atmospheres of distant planets beyond our Solar System.

At Guerrero Negro, BCS, Mexico, we examined mats that are dominated by *Microcoleus* (subtidal) and *Lyngbya* (intertidal to supratidal) cyanobacteria. We observed the

exchange of $O_2$ and dissolved inorganic C (DIC) between mats and the overlying water, during diel (24 hr.) cycles. *Microcoleus* mats assimilated near-equal amounts of DIC during the day as they released at night, but *Lyngbya* mats typically showed net uptake of DIC over the diel cycle. Patterns of $O_2$ daytime release and nighttime uptake mirrored these DIC trends in both mat types. Nighttime DIC effluxes from *Microcoleus* mats were equivalent in the presence versus absence of $O_2$, whereas nighttime DIC effluxes from *Lyngbya* mats dropped markedly in the absence of $O_2$. Thus, aerobic diagenesis was more important in *Lyngbya* mats than in *Microcoleus* mats, perhaps because trapped $O_2$ bubbles persist only in *Lyngbya* mats at night and thus sustain populations of aerobes. In both mat types, effluxes of $H_2$, $CH_4$ (Hoehler et al., 2001) and short-chain fatty acids were much greater at night in the absence of $O_2$ (Albert et al., 2000), emphasizing the importance of fermentation. Differences observed between *Microcoleus* versus *Lyngbya* mats forecast differences in their microbiota and in their patterns of gene expression.

Subtidal *Microcoleus*-dominated mats were examined in seawater concentrating ponds (S ~70 to 90 permil) at Exportadora de Sal, S.A., Guerrero Negro, BCS, Mexico. Between May and October (diel temperatures ranged between 15 and 27ºC), mats exhibited high gross rates of production and consumption of oxygen ($O_2$) and dissolved inorganic carbon (DIC), but only a slight net $O_2$ release and DIC uptake over a full diel cycle. Fermentation became relatively more important at night and maintained fluxes of reduced products into the water column at low $O_2$ levels. At higher temperatures, higher irradiance levels were required to initiate detectable $O_2$ production. Net/gross $O_2$ production was always <0.7 and decreased at higher temperatures. As temperature increased by 10ºC, rates increased approximately as follows: gross $O_2$ production: 1.5X; net daytime $O_2$ flux to water column: 1X; net nighttime $O_2$ uptake from water column: 2X; net nighttime DIC flux to water column: 2X; net daytime DIC uptake from water column: 1.1X. At higher temperatures, the downward $O_2$ flux below the photic zone increased and $O_2$ penetration shallowed. Temperature markedly affects gross versus net gas fluxes.

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# Abstract # 12851 - **Photosynthesis and Iron in Hot Spring Microbial Mats**

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Chocolate Pots Hot Springs in Yellowstone National Park have emerging anoxic source waters high in dissolved Fe(II) (ranging from 45 to 200 μM) at temperatures from 52 to 54°C. The vent waters flow over phototrophic mats composed primarily of the cyanobacteria *Synechococcus* sp. and *Cyanothece minnervae* along with the anoxygenic photosynthetic bacterium, *Chloroflexus* sp. An iron deposit of ferrihydrite and siliceous and carbonaceous minerals is accumulating at these springs. We are studying the interactions of the phototrophic bacteria with iron in the mats as a possible model for the role of phototrophs in the oxidation and mineralization of iron in the Precambrian contributing to the deposition of banded iron formations.

Species composition of the mats was assessed with fluorescence microscopy and absorption spectra of suspensions of mat microorganisms. Spectra had peaks typical of chlorophyll *a* in cyanobacteria (679 nm), bacteriochlorophyll *a* in *Chloroflexus* (875 and 802 nm) and bacteriochlorophyll *c* in *Chloroflexus* (737 nm).

Micro-electrodes were used to determine levels of oxygen, $H_2O_2$, Fe(II), and Mn(II) with changes in depth in the mat. In the light $O_2$ had a sharp increase in the top mm that was accompanied by an increase in $H_2O_2$. The oxygen maximum occurred at a depth 0.4 mm. The oxygen was very low in the water above the mat and fell to zero at a depth of 1.8 mm. The peroxide maximum was also in the top mm. Fe(II) concentration was highest in the

water above the mat surface and fell to zero in the top mm of the mat where $O_2$ and peroxide were high. The Fe(II) increased deeper in the mat when oxygen levels fell. Mn(II) concentrations were constant in the water above the mat and within the zone of high oxygen levels. Mn(II) increased in the anoxic zone beneath the top mm. In the dark both $O_2$ and $H_2O_2$ were zero throughout the mat. Fe(II) levels remained high in the top mm of the mat in the absence of oxygen and decreased with depth. The pH values within the mat were similar in light and dark and ranged from 5.4 to 6.2**.**

Cells from the mat were suspended in spring water containing $^{14}C$-bicarbonate and incubated in light and dark to test for stimulation or inhibition of photosynthetic activity with added Fe(II). Photosynthetic $CO_2$ fixation was stimulated in the presence of added iron. The response increased with increasing concentrations of iron up to 200 μM or 500 μM in some suspensions. The light-dependent stimulation with added iron ranged from 150 to 200% of the controls with no added iron.

Light-dependent oxygen production occurs in these mats as in other cyanobacterial mats. The levels of oxygen produced in these particular mats, however, are lower than in other mats we have studied. The pH values are also lower than in similar mats found in low iron environments. We have shown that photosynthesis is responsible for the iron oxidation occurring in the top mm of this mat and that the presence of Fe(II) stimulates $CO_2$ fixation in the organisms present.

# Abstract # 12854 *(Oral Presentation)* - **Sulfur Isotopic Constraints on the Archean Atmosphere and Oceans**

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The seminal discovery of mass-independent sulfur isotope fractionations in Archean sulfide and sulfate minerals raised hopes that a quantitative, time-resolved history of the oxygenation of Earth's atmosphere during the critical era of 2.3 to 2.1 Ga was at last in hand[i]. According to the original hypothesis, the measured mass-independent fractionation of sulfur isotopes was caused by photochemical reactions of atmospheric sulfur species induced by ultraviolet radiation in an atmosphere devoid of an ozone shield[i,ii]. The absence of mass-independent fractionation in rocks younger than 2.0 Ga was attributed to an increase in atmospheric oxygen levels and the establishment of an ozone shield blocking ultraviolet radiation[i,ii]. We will present time-resolved analyses of multiple sulfur isotope ratios ($^{34}S/^{33}S/^{32}S$) for pyrite sulfur in shale and carbonate lithofacies. Samples were collected from three drill cores collared in the Hamersley Basin, Western Australia. Detailed measurements allow us to model the isotopic compositions of Archean sulfur reservoirs, the exchange between reservoirs, and preservation of the atmospheric signature in the rock record. Our model proposes constraints on the composition of the atmosphere and oceans, and distribution of sulfur metabolizing microbes on the early Earth.

We have measured the largest mass-independent $^{33}S$ anomaly ever reported in pyrite sulfur in pelagic organic rich shales of ~2.5 Ga and ~2.7 Ga age. The range of this anomaly is larger than previously reported by a factor of three. The value of $\Delta^{33}S$ varies dramatically within each core ($\Delta^{33}S$ is a measure of mass-independent anomaly, defined as: $\sim \delta^{33}S - 0.515 \times \delta^{34}S$). Although three cores are separated in time (by ~200 million years) and space (two ~2.7 Ga shale units were collared more than 300 km apart), they yield similar positive correlation between $\delta^{34}S$ and $\Delta^{33}S$. In contrast, pyrite in ~ 2.6 Ga

shallow water carbonates yield a wide range of variation in $\delta^{34}S$ but a relatively small variation and negative values in $\Delta^{33}S$.

Our data are consistent with the presence of two sulfur reservoirs in Archean ocean; one is seawater sulfate (with $\Delta^{33}S < 0$), and the other is elemental sulfur (with large positive $\Delta^{33}S$)[i,ii]. The positive correlation between $\Delta^{33}S$ and $\delta^{34}S$ as well as the time shift in $\Delta^{33}S$ of shales can be explained by mixing of sulfur from both reservoirs. Based on the experimental data of $SO_2$ photolysis at 193nm and the photochemical model of the Archean atmosphere, atmospheric deposition of $S_8$ and $H_2SO_4$ are likely sources of oceanic elemental sulfur and sulfate, respectively[ii,iii]. Atmospheric oxygen level of less than $10^{-5}$ of present atmospheric level is required for the depositions of such multiple sulfur atmospheric species.

The lithology-dependent pattern of sulfur isotope compositions may be related to the biological processes in the ocean. The large mass-dependent fractionation found in shallow water carbonates suggests relatively rapid microbial recycling of sulfur. These processes would: 1) minimize atmospheric signature by mixing two oceanic sulfur reservoirs; and 2) fractionate sulfur isotopes mass-dependently[iv]. In contrast, the large mass-independent signature in pelagic sediments suggests the microbial sulfur cycle was not as important in deep water environments, thus allowing for preservation of atmospheric signature.

In order to test our hypothesis, additional experiments are required to closely investigate photochemically induced fractionation mechanisms. The systematics of multiple sulfur isotope compositions for rocks representing different depositional environments should provide additional insight into biogeochemical cycling of sulfur and its geographic variations during the Archean. Thus, multiple sulfur isotope systems in early sedimentary rocks hold great potential to trace evolution of the early Earth's Atmosphere, oceans and biosphere.

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# Abstract # 12862 - **Endosymbiotic Bacteria and the Evolution of Bacteriophage**

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The earliest planetary fossils indicate that bacteria have existed and therefore dominated life on Earth for more than 3 billion years. Their success is evident by numerous factors, including the colossal number of species currently living, their diversity in metabolic capacities, life styles, and ecological niches, and their ability to interact with other bacteria as well as other kingdoms to fashion more complex life. Without symbiosis and the capacity for organisms and their genomes to interact, life as we know it would be unrecognizable. The origin of the eukaryotic cell and organelles, the colonization of plants in terrestrial habitats, and the evolution of mammalian and insect herbivores that digest cellulose are just a few of the many key events that depended critically on symbiotic interactions.

Endosymbiotic bacteria represent perhaps the most intimate form of contact between two organisms. These bacteria make their living inside the cells of other organisms and have been shown to be the evolutionary precursors to mitochondria and chloroplasts. They can be widespread in certain animal groups and be a source of evolutionary innovation, for example, imparting novel biochemical abilities that allow insect hosts to diversify and exploit novel ecological niches. However, endosymbiotic bacteria are not always beneficial passengers that serve to increase the fitness of their host. Some take quite the opposite evolutionary path and parasitize on their hosts in rather intricate ways. Indeed, many severe human disease agents are bacteria that live and infect our own cells. Given these drastic differences in how bacteria interact with their hosts, we are left with an essential question: What determines whether some endosymbiotic bacteria are harmful and others are beneficial? More simply, what makes a pathogen a pathogen and a mutualist a mutualist? By answering this question, specifically for endosymbiotic bacteria, we may gain key insights into the evolutionary genomic factors and processes that have led some bacteria to become organelles and others to remain parasites.

To address this question, we are engaged in characterizing the effects of gene acquisition, gene loss, gene expression, and genomic rearrangements that have led to the diversification of *Wolbachia* – likely the most abundant group of endosymbionts on the

planet. They have an unparalleled host range, occurring in up to 75% of all insect species, several other arthropod taxa, and nearly all filarial nematodes. The limits of their distribution are not currently well resolved. *Wolbachia* primarily infect the reproductive tissues of all their hosts, yet in arthropods, *Wolbachia* are typically parasitic and modify host reproduction to enhance their spread, while in nematodes *Wolbachia* are required for oogenesis and larval moulting.

Recent advances in understanding the biology of bacterial-host interactions highlight the importance of mobile genetic elements such as transposons, plasmids, and bacteriophages in the emergence of virulence and pathogenecity. These elements are especially of interest since they can potentially 'jump' out of their resident genome and copy themselves into a naive genome, bringing along large blocks of DNA and surviving harsh environmental conditions.

Here we describe results related to the distribution and transmission of a bacteriophage element of *Wolbachia*. We show that this element is extremely abundant in the parasitic *Wolbachia*, infecting nearly 100% of the lineages sampled. We also show that a single arthropod host can carry multiple lineages of this element and that this bacteriophage can be transmitted horizontally between parasitic *Wolbachia* lineages that are relatively distantly related (estimated divergence times of ~60 million years). This endosymbiont bacteriophage is therefore abundant, widespread, moves laterally between genomes, and sees little to no 'genetic boundaries' in moving into another lineage. The genome sequences of distantly related mutualistic endosymbionts show no such pattern and are often devoid of such mobile genetic elements. Bacteriophage may be a significant source of evolutionary potential for the *Wolbachia* parasites.

# Abstract # 12864 - **Effects of Grazers and $PO_4$ Enrichment on Biomass, C:N:P Stoichiometry, and Microbial Community Structure of Oncoid Stromatolites at Cuatro Cienegas, Coahuila, Mexico**

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Many hypotheses have been formed about the environmental and ecological factors affecting the growth, metabolism, morphometry, and community composition of the microbial mats that generated laminated structures in the fossil record ("stromatolites"). Here we take advantage of a spring-fed hardwater stream at Cuatro Cienegas (Mexico) that supports living stromatolites along with a community of grazers that includes hydrobiid snails (in this case, the genus *Mexithauma*). During the summer of 2002, we manipulated the presence or absence of *Mexithauma* in concert with addition of potentially limiting $PO_4$-P in a factorial design (2 x 2 x 6) in a field experiment that lasted 8 weeks. A large suite of response variables were recorded, including surficial biomass and C:N:P stoichiometry along with community structure of cyanobacteria (using DGGE) and bacteria (using TRFLP). $PO_4$ enrichment had major effects on various aspects of the mats but effects of grazers were subtler. These data suggest that P-limitation has important effects on the structure and dynamics of laminating microbial mats such as these. Interactions between P availability and interactions with the Ca – $CO_3$ chemical system may be involved in mediating such effects.

# Abstract # 12869 - **Molecular Insights into the Colonization of Land by Animals: A Multigene Analysis of Arthropod Evolution**

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A better understanding of how organisms colonized land in Earth history will provide insights into the evolution of terrestrial life in general. The geologic record provides evidence of terrestrial prokaryotes in sedimentary rocks as old as the Archean. However, fossil evidence for terrestriality among complex multicellular organisms is not seen until much later, in the Paleozoic. Molecular clocks have suggested that plants and fungi colonized land in the Precambrian, but they have not yet addressed the question of terrestriality in animals. In this study, we have attempted to better define the relationships and times of origin of arthropods to better understand of the colonization of land by animals.

Several research groups have studied arthropod phylogeny with DNA sequence data during the last few years. These studies have found that insects are most closely related to crustaceans, forming a single large group called "Pancrustacea." This is in contrast to the classical relationship, based on morphology, of the two large terrestrial groups: myriapods (centipedes and millipedes) and hexapods (insects). However, the details of this insect-crustacean relationship remain unclear, and there has been no consensus as to the relationship of Pancrustacea to the myriapods and chelicerates (spiders, mites, horseshoe crabs, etc.).

We have sequenced two nuclear genes, G3PDH and enolase, in several representative arthropods and combined these new data with all available sequence data from the public databases bearing on higher-level arthropod evolution. Our phylogenetic analyses of nuclear gene data support Pancrustacea and a chelicerate-myriapod group, in agreement with some previous analyses of mitochondrial sequence data. Our molecular clock analyses indicate that the initial radiation of arthropods occurred in the Precambrian.

# Abstract # 12872 *(Oral Presentation)* - **The Evolutionary Relationship Between Nitrogen Fixation and Bacteriochlorophyll Synthesis**

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Photosynthesis arguably developed relatively soon after the origin of life on Earth. Some reports of stromatolites suggest this development occurred as early as 3.5 Ga, just after the late-heavy meteoric bombardment period ended at 3.9 Ga. However, due to the complexity of photosynthesis, it is highly likely that the earliest life forms were not photosynthetic. It is thus proposed that photosynthesis developed as a favorable branch of a pre-existing, more fundamental pathway. From phylogenetic analyses and emerging biochemical data, it is possible that this pre-existing pathway was that currently utilized for nitrogen fixation (the Nif proteins). However, it is currently unclear if the Nif proteins were originally utilized in nitrogen fixation (in the case of a neutral atmosphere), or hydrocyanic acid detoxyase (in the case of a reducing atmosphere). If the atmosphere was indeed reducing, an enzyme like a hydrocyanic acid detoxyase might have independently been the precursor of both Nif and Bch proteins. In this study, work towards the study of the genetic, structural, functional, and mechanistic relationships between selected proteins in the anaerobic bacteriochlorophyll synthesis (bch) pathway and the nitrogen fixation (nif) pathway of Rhodobacter capsulatus are presented (BchNB [protochlorophyllide reductase, PR], BchYZ [chlorophyllide reductase, CR] with NifDK [dinitrogenase] and NifNE [FeMo-co synthesis protein]; BchL [PR reductase] and BchX [CR reductase] with NifH [dinitrogenase reductase]).

As shown in the presentation ìHorizontal Gene Transfer in the Evolution of Nitrogen Fixationî by Jason Raymond, analysis of the whole genomes of several organisms for the presence of NifH or NifD/K homologs revealed the presence of several atypical sequences. A radial plot of the phylogenetic analyses shows that these sequences lie in between the Nif and Bch clades. One of the organisms containing these atypical

sequences has not been shown to perform either photosynthesis or nitrogen fixation. This organism is Methanococcus jannaschii, a thermophilic methanogenic member of the euryarcheota.

We are currently studying the functional relationships of the proteins encoded by these ìatypical Nif-likeî genes to their Nif and Bch homlogs. We are also looking into the physiological roles of these proteins in M. jannaschii. This includes testing under which conditions these proteins are expressed (e.g. growth in the presence of cyanide). It is possible that these ìatypical Nif-likeî sequences represent a relic precursor protein to both the Nif and Bch lines, or another branch off a more ancient, possibly extinct, precursor.

# Abstract # 12876 - **Characterization of a Cytochrome *c*-Containing Complex of *Chloroflexus aurantiacus* and Its Interaction with Auracyanin A**

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All photosynthetic organisms contain a photoreaction center in which light energy is transduced into chemical redox energy and an electron transport chain in which the primary photoproducts are stabilized and coupled to either cyclic electron or noncyclic transport processes leading to generation of stable photoproducts. In all known cases, a protonmotive force is generated across the photosynthetic membrane and the energy used to make ATP. A cytochrome $bc_1$ or $b_6f$ complex is involved in this process. A reduced quinone serves as electron donor and either a small *c*-type cytochrome or a copper protein serves as an electron acceptor. However, recent biochemical and genomic information indicates that the green anoxygenic photosynthetic bacterium *Chloroflexus aurantiacus* does not contain either a cytochrome $bc_1$ or $b_6f$ complex. The absence of a classic cytochrome *bc* or *bf* complex in *C. aurantiacus* presents the question of what proteins are involved in energy conservation in this organism. The cells contain a membrane-bound tetraheme cytochrome *c*-554, the direct electron donor to the photosynthetic reaction center, and auracyanins, small blue copper proteins peripherally associated with the cytoplasmic membrane. The suggested function of auracyanin is similar to that of soluble cytochrome $c_2$ found in purple bacteria and that of the copper protein plastocyanin in oxygen evolving organisms. The gene for auracyanin A has now been cloned and the protein successfully expressed in *Escherichia coli*.

Recently, two similar novel multisubunit complexes with two heme *c*-bearing subunits were purified from *C. aurantiacus* (1). One of them was predominantly expressed in the anaerobic phototrophic culture of the bacterium while the other was isolated from aerobically grown cells. The anaerobic complex, designated as Cz, is proposed to play the functional role of a cytochrome *bc* complex in light-dependent cyclic electron transport. Liposomes containing succinate: quinone oxidoreductase, the cytochrome Cz-complex, and menaquinone-4 were capable of

transferring electrons from succinate to auracyanin, while the same liposomes without Cz-complex were not.

Characterization of the subunits of the cytochrome Cz-complex was done by tryptic digestion and mass spectrometry. Prediction of digests were done on open reading frames containing heme-binding motif(s) CXXCH from the *C. aurantiacus* genome. Four of the predicted digests matched those of the fragments from mass spectrometry of four subunits. Three of these subunits belonged to one contig of the genome and may represent part of an operon encoding subunits of the Cz-complex. The alpha subunit contains four FeS clusters, the beta subunit is a hydrophobic polypeptide with ten transmembrane alpha-helixes; these two subunits have numerous and strong homologs among Bacteria and Archaea. The epsilon subunit is a mono-heme cytochrome *c*, and the zeta subunit is an unknown polypeptide. The last two subunits have few counterparts among bacteria.

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# Abstract # 12883 - **Carbon-Cycle Modeling of the Permian-Triassic Mass Extinction**

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The cause of the worst disaster ever to befall multicellular life on Earth remains unknown, but the possibilities are significantly constrained by recent geological data obtained from a non-marine Permian-Triassic boundary in the Blue Mountains of Australia (Buick et. al., manuscript in preparation). Seven rapid negative excursions in $\delta^{13}C_{org}$ of up to 7 per mil followed by a 3 per mil positive spike directly at the palynological P-Tr boundary are observed, separating two distinct mass extinction events in the terrestrial and marine communities. Various causes proposed in the literature for the P-Tr mass extinction include Siberian Traps flood basalt volcanism, methane hydrate releases, massive bolide impact, oxidation of peat-bog kerogen, and widespread ocean stagnation and/or anoxia. These hypotheses are tested by numerical modeling using the new isotopic and geologic constraints of the Blue Mountains data.

The numerical model developed to test the various hypotheses consists of eleven coupled non-linear differential equations. Carbon and $\delta^{13}C$ are followed through 4 reservoirs - biomass, atmosphere, (warm) surface ocean, and deep ocean. The model incorporates a number of feedback process including a global rock cycle, $CO_2$ dependent temperature/isotope fractionations, and surface water carbonate equilibrium chemistry, along with parameterizations of biological productivity, ocean mixing, carbon burial fractions, weathering rates, forest area, and $CO_2$ injections (volcanism, kerogen oxidation, methane hydrate releases.)

The hypotheses are investigated with a $CO_2$ dependent photosynthetic isotope fractionation parameterization appropriate for the woody gymnosperms that covered Australia during the latest Permian. Kerogen oxidation and flood basalt volcanism are shown to be inadequate to produce the observed shifts in $\delta^{13}C_{org}$. While methane hydrate releases and bolide impacts can produce 7 per mil shifts in biomass $\delta^{13}C_{org}$, it is difficult to imagine scenarios in which 7 isotopic shifts of this magnitude are generated in a short time period. The data appear most consistent with the repeated overturning of a stratified anoxic ocean.

# Abstract # 12884 - **Cyanobacterial Signature Genes**

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The complete genomic sequences from *Synechocystis* PCC 6803 (3.6 Mb), *Anabaena* PCC 7120 (7.2 Mb), *Thermosynechococcus elongates* BP-1 (2.6MB), *Synechococcus* WH8102 (2.72 Mb), *Prochlorococcus marinus* MED4 (1.6 Mb), *Prochlorococcus marinus* MIT9313 (2.4 Mb), *Nostoc punctiforme* (9.2 Mb), and *Trichodesmium erythraeum* IMS101 (6.5MB) were intercompared. These eight cyanobacteria, span much of the known cyanobacterial genetic diversity and are therefore reasonably representative of the group as a whole. Together, they share a common set of approximately 180 genes that do not have obvious equivalents in known non-cyanobacterial genomes. Although these signature genes are highly characteristic of the cyanobacterial genotype, in most cases they have not yet been assigned a function. The nucleotide sequences of these genes were extracted from the various genomes and multiple protein sequence alignments were constructed for each gene. This allowed the construction of 180 individual gene trees. Although minor variation exists, in toto these trees exhibit considerable concordance as regards the major branching among these eight organisms. One can infer that there have not been large numbers of lateral gene transfer events involving the signature genes subsequent to the origin of the cyanobacterial phenotype over 2 billion years ago. This result supports the notion that, despite the rapid flux of genes in and out of genomes, there may be a core of genes that can be reliably used to define the phylogenetic history of at least some major bacterial groupings.

# Abstract # 12890 - **Horizontal Gene Transfer in the Evolution of Nitrogen Fixation**

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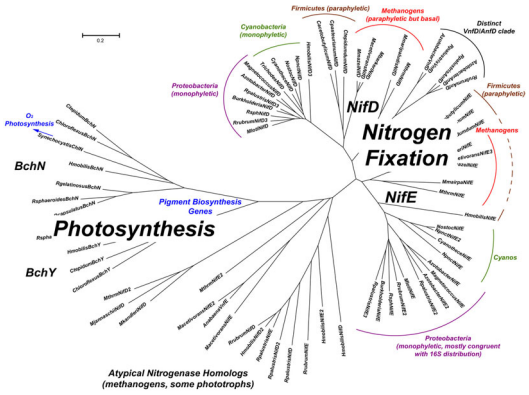
Whole genome sequences for nearly twenty nitrogen-fixing prokaryotes are now available, and we have analyzed each of these organisms for presence of one or more nif (nitrogenase-gene encoding) operons and conserved synteny. Additionally, we have used standard tools of sequence analysis to evaluate the evolutionary history of every characterized gene found in these nif operons and observe that the core genes segregate phylogenetically into the known metal-binding classes (iron-, vanadium-, or molybdenum-containing) of nitrogenase. We have also used molecular phylogenetic techniques to analyze a fourth group of yet-uncharacterized nitrogenase homologs, found in archaea and in a limited number of phototrophic bacteria, that appear to be ancestral to nitrogenase genes and to essential genetic components of chlorophyll and bacteriochlorophyll biosynthesis found in all known phototrophs. This fourth group of nitrogenase homologs may function as an electron sink or possibly as a non-specific detoxyase or reductase, and is likely a relic of some ancient metabolic trait. Here we trace the early origins of nitrogenase genes and the subsequent horizontal gene transfer events that have resulted in the current distribution of prokaryotic nitrogen fixation.



# Abstract # 12896 *(Oral Presentation)* - **Plankton and Isotope Changes at the Late Neoproterozoic Acraman Impact Ejecta Layer**

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The c.580 Ma Acraman structure is one of the ten largest and best-documented impact structures in the geological record and meets all recognition criteria for large bolide impacts. The impact site (Lake Acraman, Gawler Craton, South Australia), displays typical cratering morphology, geophysical characteristics, shock metamorphic features (devitrified melt particles, shatter cones, and shocked quartz), and is associated with microspherules, an iridium anomaly, evidence of a tsunami, and a debris layer. A collapse crater ~90 km in diameter indicates impact by a 4.8 km-diameter bolide. The associated ejecta layer is known from 12 outcrops >200 km E of the impact site, in drillhole WWD 1 near Lake Torrens, and from drillholes >500 km W of the impact structure (Lake Maurice West 1, Observatory Hill 1, as redeposited ejecta in Munta 1, and recently discovered in two additional drillholes, Murnaroo 1 and Giles 1). The ejecta blanket is consistent in extent with patterns for 80-90 km diameter lunar craters, such as Tycho and Copernicus.

The ejecta horizon is a significant synchronous marker layer providing an appropriate datum for plotting relative distributions of planktonic acritarch species observed during biostratigraphic studies of the terminal Proterozoic of Australia. As data compilation progressed, a remarkable coincidence between the first appearance of the acanthomorphs (spiny acritarchs) after the Marinoan glaciation, a negative $\delta^{13}C_{org}$ excursion, and the Acraman impact ejecta layer became apparent. The observed biotic changes are radical. An older leiosphere-dominated palynoflora is abruptly succeeded by a complex acanthomorph-dominated palynoflora. There is a rapid increase in abundance, size, morphological complexity, and taxonomic diversity. These changes indicate a major evolutionary radiation in the green algae. The actual or presumed position of the transition matches a negative $\delta^{13}C_{org}$ excursion that coincides with the Acraman impact layer, and indicates a rapid fall in organic productivity. Preliminary results suggest the Ediacarian acritarch diversification may be a recovery event following a bolide impact, which may also have triggered other significant biotic changes. The recovery event coincides with a rapid positive $\delta^{13}C_{org}$ excursion.

Whether the events are related or fortuitous is currently under further investigation. The original sampling interval for $\delta^{13}C_{org}$ was large (10-40 m) but recent, intensive sampling of seven drillholes has improved this interval to 1-5 m. Evidence for a relationship between the impact event, the observed changes in acritarch assemblages and the $\delta^{13}C_{org}$ excursions is still circumstantial, but the demonstrated large bolide impact supplies a plausible explanation for dramatic biotic changes that are otherwise difficult to explain.

# Abstract # 12901 - **Primary Mineral Phases and Biosignatures Associated with the Phototrophic Mats of Chocolate Pots Hot Springs, Yellowstone National Park, USA**

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The occurrence of an active iron-depositing thermal spring ecosystem dominated by phototrophs provides an opportunity to further our understanding of the biogeochemistry of iron in terrestrial thermal spring systems. Though most studies to date have focused on chemotrophic iron-oxidizing communities, recent research has demonstrated that phototrophs have a significant physiological impact on iron hot springs systems. Work by Pierson and colleagues (Pierson et al., 1999; Pierson and Parenteau, 2000) has shown that as oxygen becomes supersaturated in the photic zone of the phototrophic microbial mats, the pH increases by 1-2 units and the filamentous organisms play an active role in the trapping and binding of sediments.

Our efforts to understand this ecosystem focus on the influence of the phototrophic mats on the structure and mineralogy of the stromatolitic iron deposits. Specifically, we are documenting the changes that occur in iron mineralogy and fabric development from the time the primary precipitates form through the earliest stages of diagenesis to elucidate how microbes contribute to biosignature formation in such deposits. By characterizing across a range of spatial scales the mineralogical, sedimentological, and paleobiological attributes of the iron deposits, a robust suite of biosignatures will be identified that can be used to assess the biological contribution to ancient iron deposits on Earth (e.g., Banded Iron Formations) and, potentially, to those found on Mars. This is a three year project and here we present the results of our field and laboratory efforts for year one: characterization of the primary minerals, microorganisms, microfossils, and biofabrics

associated with the mats using optical and scanning electron microscopy (SEM), energy dispersive spectrometry (EDS), and powder X-ray diffraction (XRD).

Chocolate Pots Hot Springs in Yellowstone National Park is a series of high iron thermal springs that flow into the Gibbon River. The source water that issues from five of the vents studied (temperature 51-54°C and pH 5.8 - 6.0) contains approximately 100 to 1000 times higher Fe(II) concentrations than those documented in any other neutral spring in the Park (Pierson and Parenteau, 2000). Iron oxides and oxyhydroxides form distinct streaks of color down the steep face of the iron deposits and range from 5 - 90 cm in width. A hard, deep burgundy-colored deposit is associated with voluminous rapid flow, while a soft yellow ochre precipitate is associated with sheet flow over the phototrophic mats. Microelectrode profiles of the phototrophic mats yielded a vertical gradient in pH (Pierson et al., 1999), while traverses of two vents yielded a lateral gradient in pH and temperature. XRD of mineral samples associated with the microbial mats and vent source pools indicate that 2-line ferrihydrite is the dominant phase in Chocolate Pots Hot Springs and is the only phase found associated with microbial mats. Other mineral phases (goethite and siderite) were also detected in dry mineral samples on the surface face of the main iron deposit. Though this suite of phases have also been identified by Mössbauer spectroscopy (Agresti et al., 1995, Agresti et al., 1997, Wade et al., 1999), our study demonstrates how mineral phases are associated with mat types and/or biofabrics.

Chocolate Pots is dominated by three major phototrophic communities: a narrow *Oscillatoria* from 36-45°C, *Pseudanabaena* from 50-54°C, and *Synechococcus*/*Chloroflexus* from 50-54°C (Pierson and Parenteau, 2000). Our initial identification of fossil phototrophs in the lower depths of the mats was based on morphotype comparisons with living organisms. Filaments of the narrow *Oscillatoria* and *Chloroflexus* and rods of *Synechococcus* were found to be encrusted with ferrihydrite. In some cases, the entombed filaments were degraded, leaving empty sheaths. Deposition of colloidal silica and iron silicates on the cells was also detected by EDS. Amorphous ferrihydrite was identified as the primary phase associated with the mats and encrusted cells.

Our results provide an initial dataset that illustrates the maximum amount of paleobiological and paleoenvironmental information that can be gleaned from these types of iron deposits. Insights from our research may help elucidate the role of phototrophs in the deposition of BIFs on Earth, and may assist in the search for evidence of fossilized microbial life in iron deposits on Mars.

# Abstract # 12905 - **Experimental Paleogenomics as a Tool to Analyze Protein Function and Predict Environmental Temperature during Early Life**

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From 4.5 billion to 3.8 billion years ago, Earth endured a heavy bombardment from meteors. These impacts often had devastating results. Impacts from such large objects would create a superheated atmosphere of vaporized rock, which would in turn have vaporized the oceans and sterilized the surface of the planet. Since the first signs of life appear not long after the bombardments stopped, researchers have used the information to form two hypotheses. First, the only organisms to survive such conditions must have lived deep in the Earth's crust where temperatures were high. This implies that these very early organisms were thermophiles. Alternatively, life may have repeatedly been invented and extinguished by multiple sterilizing impacts. This implies that these very early organisms need not have been thermophiles, but may in fact have been mesophiles.

Meteorite blasts were just one problem facing early life. If, as proposed by Kasting, energy coming to Earth from the Sun was 30% less during our planet's early years than today, the Earth's surface should have been largely frozen, at least until the Sun brightened about 2 billion years ago. This has led researchers to two more ideas. First, early life may have lived in water just beneath the ice surface. Alternatively, early life may not have survived the freeze, except by retreating to thermal vents deep in the ocean.

Today, many researchers trying to understand the nature of early life turn to geology. They hope that by understanding the origins of the planet and its paleoclimate, the conditions of Earth's surface and atmosphere when it first hosted life, they can understand what life forms generated certain geological structures. The principal focuses are hypothetical organisms, defined as the organisms that gave rise to the three individual domains of life.

Historically, the study of these organisms involves identifying the chemical and physical signatures they may have left in the geological record. Alternatively, the nature of these early organisms can be detailed through analyses of extant genomes. This is possible because an organism's survival depends on its ability to interact with its environment, which is ultimately determined by the organism's genome. Thus, genes behave as dynamic fossils: recording ancient events, while enabling adaptation to the current environment. The last common ancestor of the bacterial lineage, and the environmental conditions with which it lived, is the focus of our research. This work utilizes laboratory and computational techniques to explore the likely chemistry of the ancient organism by inferring its genetic structure from the genes of extant organisms. Such reconstructions of ancestral genes define the field of paleogenomics.

# Abstract # 12925 - **Towards an RNA-Only Peptidyl Transferase**

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Recent X-ray crystal structures of the ribosome have suggested that the chemical step of protein synthesis, peptidyl transfer, is catalysed solely by RNA. Catalysis of this step by RNA is arguably fundamental to the transition from the "RNA world" to the current nucleoprotein world. However, the sheer size of the ribosome (~$2x10^6$ Da) and the fact that it contains a number of proteins require that it has evolved considerably since its origin. At present, no RNA exists that is capable of carrying out peptidyl transferase, the transfer of a peptidyl residue from the 3'-OH end of a tRNA to an amino acceptor. We are using *in vitro* selection techniques in order to find RNAs capable of catalysing peptidyl transferase. A truncated portion of Domain V of the 23S rRNA (the domain responsible for peptidyl transferase) has been mutated and provides the starting pools for selections for both peptidyl transferase activity and the ability to bind to a transition state analog. The progress and results of these selections will be presented here.

# Abstract # 12930 - **Respiration in Deeply Buried Marine Sediments (Early Results from ODP Leg 201)**

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Ocean Drilling Program Leg 201 was the first drilling expedition dedicated to the study of life deep beneath the seafloor. Its seven equatorial Pacific and Peru Margin sites were selected to represent the general range of subsurface environments that exists in marine sediments throughout most of the world's oceans. In water depths as great as 5300 meters and as shallow as 150 meters, we drilled up to 420 meters into oceanic sediments and underlying basalt. Recovered sediments ranged in *in situ* temperature from 0°C to 25°C and in age from 0 to almost 40 million years (Shipboard Scientific Party, 2002).

Active respiration occurs in deeply buried sediments at every site. Several metabolic pathways are used by microbial communities in these sediments. Respiration at all sites is supported by diffusion of sulfate from the overlying ocean and by dissolution of manganese- and iron-bearing minerals. At the open-ocean sites, respiration is also supported by transport of sulfate and nitrate from water circulating through the underlying basaltic crust. At the Peru Shelf sites, it is also supported by diffusion of sulfate from underlying deeply buried brine. Methanogenesis consistently co-occurs with other metabolic pathways (sulfate reduction, manganese reduction, iron reduction) at all sites.

Chemical flux calculations for Leg 201 sites suggest that sulfate is generally the principal terminal electron acceptor in the sediments deeper than 1.5 mbsf. However, at the open-ocean sites, rates of manganese and iron reduction may approach rates of sulfate

reduction. At all sites, sulfate reduction appears to be the principal source of respired $CO_2$.

Rates of subseafloor activity vary predictably from the open-ocean sites to the ocean-margin sites. For example, $CO_2$ production (estimated from the stoichiometries of sulfate, manganese, iron and nitrate reduction) is consistently higher at the ocean-margin sites than at the open-ocean sites. At every site, the rate of subseafloor $CO_2$ production is 3 or 4 orders of magnitude lower than the rate of photosynthetic $CO_2$ reduction in the overlying surface ocean. These comparisons reinforce recent inferences from global sulfate and methane distributions (D'Hondt et al., 2002); subseafloor metabolic activity is widespread, geographically predictable, and very low relative to the metabolic activity of the surface world.

The results of this expedition have several interesting implications for our understanding of life in deeply buried marine sediments. They show that multiple metabolic activities occur in deeply buried marine sediments. They demonstrate that both anaerobic and aerobic communities occur deep beneath the seafloor. The high concentrations of nitrate at the base of the open-ocean sediments suggests that there is very little respiration in the underlying old (11 Ma to 40 Ma) basalts. The co-existence of methanogenesis with other metabolic pathways underscores the likely complexity of these subseafloor ecosystems. Although these different metabolic pathways are generally assumed to compete with each other, they may also cooperate in multiple ways.

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# Abstract # 12993 - **A Molecular Analysis of Calcifying Cyanobacteria That Build Dendroidal Oncolites in the Mezquites River of the Cuatro CiÈnegas Basin**

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As part of a multidisciplinary project seeking to understand the dynamics of early ecosystems by using the present as a key to the past, we molecularly characterized the cyanobacterial community that builds oncolites in the Mezquites River. Situated in the Chihuahuan Desert, this river and its spring-fed tributaries cut through the karstic landscape of the Cuatro CiÈnegas Basin in Coahuila, Mexico. There, cyanobacteria build benthic, unattached, lithic, calcareous concretions (oncolites) along many stretches of the riverbed. These, and other microbialites in the basin, have been studied previously using traditional methods, but no studies exist that use molecular techniques for this purpose. Our intention was to characterize the cyanobacterial community, spanning both kilometer-distances and seasons, along the river and to identify cyanobacteria or groups thereof that are present in the oncolite-building community. To do this, we fingerprinted the cyanobacterial community using denaturing gradient gel electrophoresis (DGGE) separation of PCR-amplified 16S rRNA gene alleles. Our data show that the cyanobacterial populations are homogeneously distributed within a single oncolite, and that different oncolites within a collection site are very similar in composition. However, significant changes do occur among kilometer-distant sites. While the populations vary seasonally from site to site, they remain homogenous within each site. Individual bands were excised from DGGE separations and sequenced to determine general affiliations of the cyanobacteria present in the oncolites. The results of this study provide a foundation upon which further research into oncolite calcification processes and microbial community dynamics will be based.

# Abstract # 13005 - **The Archean Biosphere Drilling Project**

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Biogeochemical investigations (e.g., search for microfossils and molecular fossils) of Archean rocks, especially those older than 2.7 Ga (billion years), have been hindered because most Archean rocks have been subjected to high-grade metamorphism (T > 300 °C; P > 3 kb) that has destroyed or altered the original characteristics of biosignatures. Another serious problem for Archean geochemists has been the alteration of Archean rocks by hydrothermal mineralization and/or by modern weathering. The Archean Biosphere Drilling Project aims to recover samples of specific geologic formations in the Pilbara district of Western Australia that are ~3.6 to ~2.7 Ga in age and have escaped high-grade metamorphism, hydrothermal alteration, and modern weathering. The existence of organic carbon-rich sedimentary rocks that have been heated only up to approximately 200 °C in some areas in the Pilbara district has become known only recently.

The Archean Biosphere Drilling Project was initiated in 2002 by Prof. Munetomo Nedachi of Kagoshima University and several of his colleagues from other Japanese universities with a major research grant from the Japanese Ministry of Education and Science. Subsequently, this drilling project has developed into a formal collaborating project involving four partners, Kagoshima University, the Geological Survey of Western Australia, the University of Western Australia, and the NAI; the project has also become a part of the Astrobiology Drilling Program of the NAI. The most important objective of this drilling project is to increase our understanding of early Earth: (a) the nature of the biosphere, especially the types and distribution of organisms in the oceans, lakes, and on land; (b) the chemistry of the atmosphere and oceans; (c) the geochemical fluxes of O, C, S, Fe, and other elements in the atmosphere–oceans–continents-oceanic crust–mantle

system; and (d) the cosmic fluxes on Earth. These objectives will be approached by detailed and coordinated investigations on various geological, geochemical, and paleontological aspects of the "fresh" core samples.

The Archean Biosphere Drilling Team conducted a field survey during the summer of 2002 and selected the following eight drilling targets: (1) the 3.46 Ga Marble Bar Chert of the Towers Formation; (2) the 3.46 Ga Apex Basalt and the "T cherts"; (3) the 3.52 Ga Coucal Formation, the ~3.5 Ga Coonterunah Unconformity, and the 3.46 Ga Strelley Pool Chert; (4) the 2.7 Ga Mt. Roe "paleosols"; (5) 3.46 Ga black shale of the Towers Formation; (6) 3.2 Ga black shales and massive sulfide ores of the Sulfur Spring Group; (7) 2.9 Ga black shales of the Mosquito Creek Formation; and (8) 2.76 Ga black shales of the Hardy Formation. The depth of a typical drill hole will be around 300m. Special cares will be taken to minimize contaminations of organic compounds during and after drilling. The scientific drilling at the above eight sites will be carried out during the summer of 2003.

The entire drill core sections will be logged, photographed, and described in detail. Polished and thin sections will be made from almost all samples for use in sedimentological, petrological, mineralogical, geochemical, and paleontological investigations. The remaining core samples will be subjected to a variety of geochemical analyses, including: the major, trace, heavy metals, and rare earth elements; stable isotopes (S, C, O, Fe, Mo, etc); radiogenic isotopes (Sr, Nd-Sm, Re-Os); and organic matter (kerogen, biomarkers) and their isotopic signatures. The core samples will be made available to other scientists for further investigations.

# Exploring for Life in the Solar System Abstracts

# Abstract # 12589 - **A Comparison of Mars and Antarctica Remote Sensing Data**

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Determining the composition of Mars Polar caps is essential to understand the planetary evolution of the red planet and possible habitats for life. Recently released Mars and Antarctica images and data address a number of issues relating to the similarities of these two sites in terms of physical properties and raise the question of a possible frozen ice water reservoir beneath the Mars polar cap.

Using Mars Global Surveyor's Orbiter Camera's (MOC) passive and active sensors, Mars Orbiter Camera (MOC) and Mars Orbiter Laser Altimeter (MOLA) data, detailed local remote sensing analysis (e.g., topography, temperature, ice cover, ice density profile) and comparison of these regions should give a better understanding of the properties and history of the Martian polar regions. This better understanding, in turn, will contribute to the determination of possible existing life and future landing sites.

# Abstract # 12653 - **Gullies on Mars and Constraints Imposed by Mars Global Surveyor Data**

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The discovery of geologically recent gully features on Mars (Malin and Edgett 2000) has spawned a wide variety of proposed theories of their origin, including water versus carbon dioxide based erosion and shallow versus deep fluid sources. To test the validity of such gully formation mechanisms, data from the Mars Global Surveyor spacecraft has been analyzed to uncover trends in the dimensional and physical properties of the gullies and their surrounding terrain. Over 100 Mars Orbiter Camera (MOC) images containing clear evidence of gully landforms, distributed in the southern mid and high latitudes, have been analyzed in combination with Mars Orbiter Laser Altimeter (MOLA) and Thermal Emission Spectrometer (TES) data to provide quantitative measurements of numerous gully characteristics. Parameters measured include apparent source depth and distribution, vertical and horizontal dimensions, slopes, compass orientations, and factors controlling present-day climatic conditions.

Numerous models have been proposed which invoke various physical processes as well as various agents of erosion to explain the origin of the martian gullies. Mellon and Phillips (2001) suggest that a shallow aquifer may be the source of liquid water that ultimately carves the gully features, while Gaidos (2001) argues for a deep aquifer model. Costard et al (2002) likewise propose that liquid water is the principal agent of erosion, but they suggest that melting ground ice is the source of the water. Christiensen (2002) proposes that the gullies are formed by liquid water from dissipating snowpacks. Other erosive agents such as wind and liquid $CO_2$ have also been suggested.

Images from the Mars Orbiter Camera (MOC) have been systematically examined in search of gully features. Malin and Edgett (2000) report that the gullies nominally occur poleward of 30°S and extend as far south as the south polar pits. Hence all images from the MOC narrow-angle camera between 30°S to 72°S from mission phases AB1 through M18 (September 1997 through August 2000) were individually examined for the presence of gullies. Quantitative measurements of linear distances were then extracted from the MOC images, elevation data was extracted from the MOLA data, and TES

measurements of thermal inertia were used in conjunction with modeled surface temperatures to derive subsurface temperature profiles.

Based on this data, we present numerous trends with respect to the gully systems which must be explained by any viable model of gully formation. We find that the number of gully systems steadily declines as one moves poleward of 30°S, reaches a minimum value between 60°-63°S, and then again rises poleward of 63°S. All gully alcove heads occur within the upper one-third of the slope encompassing the gully and the alcove bases occur within the upper two-thirds of the slope. Also, the gully alcove heads occur typically within the first 200 meters of the overlying ridge with the exception of gullies equatorward of 40°S where some alcove heads reach a maximum depth of 700 meters. Additionally, gullies are found on all slope orientations at all latitudes. Gullies are preferentially found on poleward facing slopes at the extreme high and low latitudes of the studied range but are preferentially found on equatorward facing slopes in the midrange latitudes. Using thermal conductivities derived from TES measurements as well as modeled surface temperatures, we find that ~80% of the gully alcove bases lie at depths where subsurface temperatures are greater than 0°C and ~20% of the alcove bases lie within the solid water regime. Interestingly, none of the gully alcoves lie within the temperature-pressure space of liquid $CO_2$.

No individual model yet explains all of the observed gully features, but based on this study we can place additional constraints on future models and rule out several proposed hypotheses. Based on a comparison of such measured gully features with predictions of the various models of gully formation, we find that the carbon dioxide, melting ground ice, dry landslide, deep aquifer, and snowmelt models are least likely to survive as viable mechanisms to describe the formation of the martian gullies. Although some discrepancies still exist between prediction and observation, the shallow aquifer model remains as the most viable theory.

# Abstract # 12670 - **Beagle 2: Astrobiology's Next Mission to Mars**

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Beagle 2 is a 60 kg probe (with a 30 kg lander) developed in the U.K. for inclusion on ESA's 2003 Mars Express. Beagle 2 will be launched in May 2003 with Mars Express from Baikonur Cosmodrome in Kazakhstan. Beagle 2 will land on Mars in December 2003 in Isidis Planitia (10ºN, 275ºW), a large sedimentary basin that overlies the boundary between ancient highlands and northern plains. Isidis Planitia, the third largest basin on Mars, which is possibly filled with sediment deposited at the bottom of long-standing lakes or seas, offers an ideal environment for preserving traces of life.

Beagle 2 will search for organic materials and other volatiles on and below the surface in addition to studying the inorganic chemistry and mineralogy. It will use a mechanical mole and grinder to obtain subsurface samples, under rocks and inside rocks. A pair of stereo cameras will image the landing site along with a microscope for rock and surface samples. Analyses will include both rock and soil samples at various wavelengths, X-ray and Mossbauer spectrometers as well as a search for organics and other light element species (e.g., carbonates and water) and measurement of their isotopic compositions. Beagle 2 has as its focus the goal of establishing whether evidence for life existed in the past on Mars or at least establishing if the conditions were ever suitable.

A mechanical arm (PAW) is used for science operations along with sample acquisition. Instruments attached to the PAW include: stereo cameras, Mossbauer and X-ray spectrometers, microscope, environmental sensors, rock corer/grinder, a spoon, mirror, brushes, a mole attachment for acquisition of subsurface samples to depths of 1 to 2 meters, and an illumination device. Each camera has 14 filters, which have been optimized for mineral compositions, dust, and water vapor detection. The camera has 4 color capability (red, green, blue, and UV fluoresence). The microscope has a resolution down to 4 microns.

Beagle 2's heart is the life detection package, which is a gas analysis package (GAP) consisting of a mass spectrometer with collectors at fixed masses for precise isotopic ratio measurements and voltage scanning for spectral analysis. Primary aim of the GAP is to search for the presence of bulk constituents, individual species, and isotopic fractionations for both extinct and extent life along with studying low-temperature geochemistry of the hydrogen, carbon, nitrogen, and oxygen components from both the surface and atmosphere. GAP is a magnetic sector mass spectrometer (mass range of 1 to 140 amu) which can be operated in both the static and dynamic modes. A triple Faraday collector array will be used for C, N, and O ratios along with a double Faraday array for H/D. Pulse counting electron multiplier will be utilized for noble gases and selected organics. Anticipated detection limits are at the picomole level for operation in the static mode of operation and high precision isotopic measurements will be made in the dynamic mode. The sample processing and preparation system consists of reaction vessels along with references. Sample ovens capable of being heated are attached to the manifold for sample combustion. Surface, subsurface materials, and interior rock specimens will be combusted in pure oxygen gas at various temperature intervals to release organic matter and volatiles. The combustion process will permit detection of all forms and all atoms of carbon present. A chemical processing system is capable of a variety of conversion reactions. Gases are manipulated either by cryogenic or chemical reactions and passed through the gas handling portion of the vacuum system. There are two modes of operation: quantitative analysis and precision isotopic measurements.

Three main types of analysis will be carried out by the GAP: (1) search for organic matter, (2) stepped combustion of total light element content and speciation, and (3) atmospheric analysis. Isotopic measurement of H/D, $^{13}C/^{12}C$, $^{15}N/^{14}N$, and $^{18}O/^{16}O$, plus a search for possible biogenic methane within the Martian atmosphere will be made. Present methane concentration in the atmosphere is estimated to be <100 ppb. Lifetime of $CH_4$ in Mars' atmosphere is believed to be <300 years. Therefore, no abiogenic methane is anticipated. GAP is capable of concentrating gases and the search for biogenic atmospheric methane will be made. The mass spectrometer will operate in the static mode for the $CH_4$ measurements after chemical reagents have concentrated the atmospheric gases. Conversion to a measurable component will be made to ensure no false positive results will be obtained along with lowering the detection limits. Should methane be detected within the Martian atmosphere, its putative source would have to be biogenic (i.e., methanogenic bacteria).

An environmental sensor system for surface temperature, atmospheric pressures, wind speed and direction accompanies atmospheric sampling. Radiation environment's dose and rates will be characterized. UV flux at the lander will be measured in a variety of wave-lengths longer than 200nm, information relevant to understanding the survival of organics. High sensitivity isotopic analysis of the carbon species present within the samples makes no assumptions about the biochemistry of Mars, but provides clues to past life as inferred from the isotopic fractionations measured directly on Mars.

# Abstract # 12747 *(Oral Presentation)* - **Microbial Adaptation Strategies for Life in the Venusian Atmosphere**

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Several observations from Venus indicate that the lower cloud layer of the Venusian atmosphere is a plausible habitat for microbial life: (1) compared to clouds on Earth, the clouds of Venus are much larger, more continuous and stable environments, with models indicating that cloud particles last for several months in the atmosphere (Grinspoon, 1997); (2) the atmosphere is in disequilibrium, with chemical species such as $H_2$ and $O_2$, and $H_2S$ and $SO_2$ coexisting; (3) the lower cloud layer contains non-spherical particles comparable in size to Earth microbes; (4) conditions at the cloud level at 50 km in altitude are relatively benign at temperatures of 300-350 K, 1 bar pressure and a pH of 0; (5) the super-rotation of the atmosphere enhances the potential for photosynthetic reactions; (6) a UV absorber has been detected in the atmosphere, which may be related to the larger cloud particles; and (7) while water is scarce on Venus, water vapor concentrations in the lower cloud layer reach several hundred ppm. Our assertion that microbial life may exist in the Venusian atmosphere is based on the assumption that microbial life originated in an early Venusian ocean or was brought in by meteorites from Earth or Mars, and that life then adapted to the atmospheric niche when Venus lost its oceans (Schulze-Makuch and Irwin, 2002).

However, there remain problems for putative microbial life in the Venusian atmosphere. They are: (1) the overall viability of an atmosphere as a habitat, (2) the need for enough time for microbial life to adapt to the atmospheric niche from an oceanic-type of habitat, (3) today's scarcity of water, and (4) the high amount of UV radiation in the atmosphere.

Evidence is accumulating that Earth's atmosphere is a habitat for microbial life. For example, Sattler et al. (2001) showed that bacteria in cloud droplets at high altitudes on Earth are actively growing and reproducing, and concluded that the limiting step for microbial processes in cloud droplets is residence time in the atmosphere. Thus, based on a much longer residence time for particles in the Venusian atmosphere with its warmer, more benign atmospheric temperatures, microbial life on Venus should be favored compared to Earth.

It is difficult to establish whether enough time was available for microbes to adapt quickly to changing environmental conditions on Venus. A catastrophic event may have wiped out all life that existed on early Venus. However, given the fast reproduction rates and adaptation capabilities of microbial life, the usually large time scales for atmospheric and geological processes to occur, and the denser atmosphere which would make microbial transport to the atmosphere easier, enough time was likely present.

The probably most challenging adaptation for microbial life would be the adaptation to the scarcity of water and high doses of UV radiation. However, examples of microbial life on Earth show that this type of adaptation is possible. One strategy is used by *Deinococcus radiodurans*, which is extremely resistant to radiation and desiccation. It has multiple copies of DNA, a large nucleus and organelles, and a thick membrane. Other strategies used are shielding by liquids (e.g., water), a geological medium, or organic pigments. Microbes in the Venusian atmosphere, if they exist, would likely adopt one or more of these survival strategies. Given the scarcity of water in the atmosphere, Venusian microbes may be able to assimilate water vapor from the atmosphere, similar to microbes on Earth that can assimilate $CO_2$ from Earth's atmosphere. Since water is not a good UV absorber in minute concentrations, some other compound would be more suitable as a shielding compound. Most desirable would be a compound that not only protects from UV radiation, but absorbs in the UV region and re-emits in the visible or near-infra-red wavelengths of the spectrum or is capable of donating electrons to appropriate electron acceptors. In that way UV radiation could directly be utilized as an energy source. Various compounds may exhibit that property and should be available under Venusian conditions such as cycloocta-sulfur ($S_8$) and tetrasulfur tetranitride ($S_4N_4$). Also, given the scarcity of water, an alternative solvent may be utilized, possibly an inorganic sulfur compound.

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# Abstract # 12769 - **Applications of Inflatable Solar Arrays in Astrobiology**

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Future commercial and deep space satellites will require solar arrays with higher specific power densities and lower cost to meet mission objectives. The advancements in the technology of flexible thin-film solar cells in conjunction with inflatable structures have made the inflatable solar array very attractive to the next generation of spacecraft. The combination of these two technologies enables the further development of lightweight, low-cost, and small packing volume arrays. Spacecraft could potentially have larger and more powerful solar arrays without the undesirable mass and storage penalty of rigid array systems if these technologies were employed. The inflatable solar array is particularly attractive for missions that demand high power with launch-vehicle size restrictions. Solar arrays were very instrumental in the success of the Mars Rover. Not only were these arrays used to meet the power needs of the rover, but they were also used to collect solar energy. Inflatable solar arrays are on of the most promising candidates for further development to advance satellite structure, especially in the areas of specific power and reduced system cost.

# Abstract # 12770 - **Warming Early Mars with $CH_4$**

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The nature of the ancient climate of Mars remains one of the fundamental unresolved problems in martian research. While the present environment is hostile to life, images from the Mariner, Viking and Mars Global Surveyor missions have shown geologic features on the martian surface that seem to indicate an earlier period of hydrologic activity. The fact that ancient valley networks and degraded craters have been seen on the martian surface indicates that the early martian climate may have been more Earth-like, with a warmer surface temperature. The presence of liquid water would require a greenhouse effect much larger than needed at present, as the solar constant, $S_0$, was 25% lower 3.8 billion years ago when the channels are thought to have formed (1,2). Previous calculations have shown that gaseous $CO_2$ and $H_2O$ alone could not have warmed the martian surface to the temperature needed to account for the presence of liquid water (3). It has been hypothesized that a $CO_2$-$H_2O$ atmosphere could keep early Mars warm if it was filled with $CO_2$ ice clouds in the upper martian troposphere (4). Obtaining mean martian surface temperatures above 273 K would require nearly 100% cloud cover, a condition that is unrealistic for condensation clouds on early Mars. Any reduction in cloud cover makes it difficult to achieve warm martian surface temperatures except at high pressures and $CO_2$ clouds could cool the martian surface if they were low and optically thick (5).

$CO_2$ and $CH_4$ have been suggested as important greenhouse gases on the early Earth. Our research focuses on the effects of increased concentrations of atmospheric greenhouse gases on the surface temperature of early Mars, with emphasis on the reduced greenhouse gas, $CH_4$. To investigate the possible warming effect of $CH_4$, we modified a one-dimensional, radiative-convective climate model used in previous studies of the early martian climate (5). New cloud-free temperature profiles for various surface pressures and $CH_4$ mixing ratios will be presented. This use of climate modeling is important since it is the fundamental way that the magnitude of possible geochemical and biological $CH_4$ sources can be related to predicted $CH_4$ concentrations in the early martian atmosphere.

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# Abstract # 12781 - **Astrobiology at the Martian Hematite Site**

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Defining locations where conditions may have been favorable for life is a key objective for the exploration of Mars. Of prime importance are sites where conditions may have been favorable for the preservation of evidence of pre-biotic or biotic processes. Areas displaying significant concentrations of the mineral hematite (alpha $Fe_2O_3$) have been identified from orbit by thermal emission spectrometry [1]. The largest such deposit, in Sinus Meridiani, is a strong candidate landing site for one of the twin Mars Exploration Rovers, scheduled to launch in 2003.

The Martian hematite site may have significance in the search for evidence of extraterrestrial life. Since iron oxides can form as aqueous mineral precipitates, the potential exists for preserving microscopic evidence of life in ecosystems that deposit iron oxides. Terrestrial hematite deposits proposed as possible analogs for the hematite sites on Mars include massive (banded) iron formations, iron oxide hydrothermal deposits, iron-rich laterites and ferricrete soils, and rock varnish [1]. We are engaged in a systematic effort to document the evidence of life preserved in iron oxide deposits from each of these environments.

<u>Banded Iron Formations:</u> Numerous microfossils are preserved in specimens of the ~2100 Ma banded iron deposit of the Gunflint Formation, Canada. While most of these microfossils are preserved in chert, scanning and analytical electron microscopy reveals that some of the micrometer-scale rods, spheres, and filaments are associated with iron oxides [2]. The detailed relationship between Gunflint microfossils and iron oxide mineralization remains to be determined.

Ferricrete: Several distinct generations of filamentous microfossils, as well as abundant extracellular polysaccharide (EPS), are preserved in a ferricrete sample from the soil surface near Shark Bay, Western Australia [3]. The general state of degradation of these microbial filaments indicates that they were mineralized after cell death and lysis. The intimate relationship among the microorganisms, EPS, and iron oxides suggests that the microorganisms could have influenced mineral formation, either by providing an organic substrate for precipitation or by creating a physico-chemical microenvironment conducive to such precipitation.

Rock Varnish: Bacteria, EPS, and fungi have been found in rock varnish deposits coating granitic rocks from Sonoran Desert sites in Arizona [4], as well as in varnish samples from Hoover Dam, Nevada and the Pilbara region of Australia [5]. In each case the varnish is a complex mixture of clay minerals with iron and manganese oxides. Some of the bacteria and many of the fungal bodies are apparently recent, but the varnish layers also contain evidence showing iron oxide mineralization of these microorganisms.

If the Martian hematite deposits do carry a record of extant or fossil microbes, this record will probably not be revealed by the spacecraft instruments on the Mars Exploration Rovers. Fossil microorganisms in terrestrial rocks are only detectable by optical microscopy of thin sections or by various combinations of scanning, transmission, and analytical electron microscopy. Most such features are significantly smaller than the 30 μm resolution limit of the Mars Exploration Rovers' *Microscopic Imager*. Thus, confirmation of an ancient Martian microbiota via direct fossil evidence will require the return of samples to terrestrial laboratories. A key function of the next generation of Mars landers may be to discover and make preliminary documentation of prime sites for future sample return missions. A hematite deposit may well be among those prime sites.

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# Abstract # 12811 - **Remote Detection of Extremophile Communities Using VNIR Spectra**

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*Background*: It has been argued that life began in hyperthermophile environments on the Earth, and it has been suggested that if life developed on Mars or extrasolar planets it too might have begun in hydrothermal conditions. Most extant extremeophiles are relatively primitive making them useful analogs for fossil organisms on Mars or primitive extant organisms in other planetary systems. The search for evidence of ancient life on Mars or extrasolar planets must be accomplished through remote sensing techniques. Microscopic analysis on Mars, as done on Earth, is difficult and only remote sensing techniques are available for extra solar planets. To assess the value of reflectance data to detect extremophiles in hydrothermal environments and to determine the extent to which characteristic spectral signatures are preserved in a fossil environments, visible to near-infrared (VNIR) reflectance data were collected in Yellowstone National Park. Data have been acquired for organisms in a variety of T and pH conditions. Additionally, spectra were acquired of the siliceous or carbonate sinter.

*Field Methods*: Data were collected with an ASD field spectrometer. The mat samples were measured *in vivo* through the water flow (few mm). Some samples were removed to allow direct measurement. In an effort to achieve consistent illumination and avoid the events of changing atmospheric water content, an artificial light source was used.

*Results*: The data indicate that each major community has a unique spectra resulting from the particular type and concentration of pigment and the manner in which they are bound in the cell. Critical pigments include: bacteriochlorophyll, chlorophyll, carotenoid, and phycobilins which have absorptions easily identified in the VNIR (<1100 nm).

VNIR reflectance data have been obtained for the acidic, relatively low temperature Nymph Creek (61°C, pH 2.7-2.8). Near the source and downstream, biota are primarily *Cyanidium caldarium*-like organisms. At the distal end, a *Chlorella sp*. community is present. Typical spectra of these communities are illustrated in Fig. 1.

Octopus Spring is an alkaline spring (87°C, pH 8.3) with a well developed and extensively studied mat. Major communities begin with *Thermocrinis ruber* at the highest temperature, followed by a green surficial *Synechococcus sp*. mat with an undermat of red *Chloroflexus sp*. At the lowest temperature, orange *Phormidium sp*. occurs. Spectra for each of these communities are illustrated in Fig. 2 and 3. Differences among the spectra are clear.

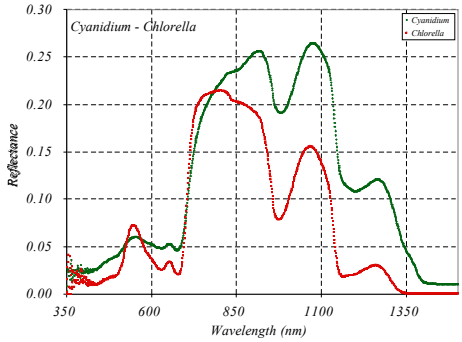


Fig. 1. Comparison of *Cyanidium* (green) and *Chlorella* (red) from Nymph Creek.

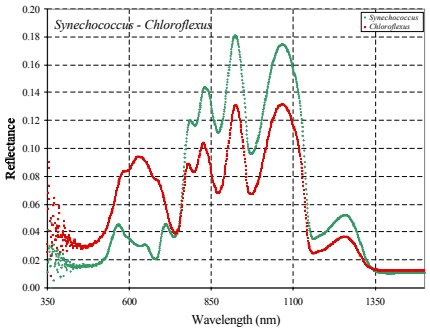


Fig. 2. Comparison of green *Synechococcus* upper mat and red *Chloroflexus* under mat.

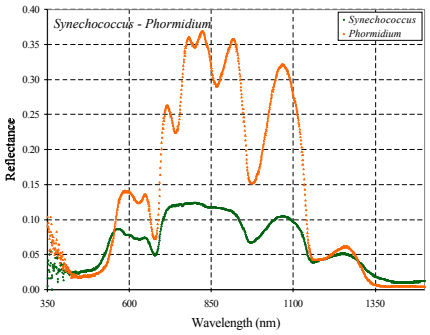


Fig. 3. Comparison *Synechococcus* (green) and *Phormidium* (orange) at Octopus Spring.

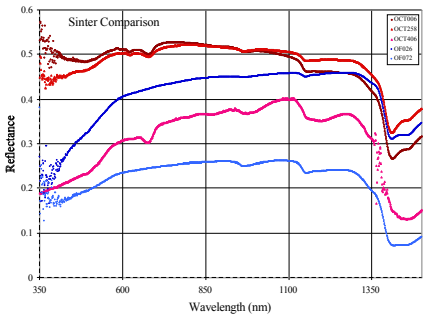


Fig. 4. Comparison of sinter at sites with (reds) and without active mats (blue).

Sinter at geysers which have no visible mat were compared with sinter deposited in association with mats (Fig. 4). Where no mats are present, the sinter has the typical spectra of opaline silica. When a mat is present, absorptions associated with the various pigments are present. The pink line represents unconsolidated / disrupted sinter that retains a well-defined Chl a absorption near 680 nm.

*Conclusions*: VNIR reflectance data can be used to identify the presence of extant hyperthermophiles and differentiate between communities. Preliminary data indicate that some of the spectral signature is retained in the sinter, allowing for remote detection of fossil sinter / extremophile communities on Mars.

# Abstract # 12816 - **Potential Habitats on Europa: Geological Assessment Criteria**

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## Introduction

Mounting evidence for the existence of a liquid water ocean below Europa's icy lithosphere [e.g., 1-3] has increased the potential for the satellite to harbor life, and the future exploration of Europa will need to focus on the identification of sites where signatures of past or present life could be detected and studied. Europan habitats would be sites where environmental conditions allow the survival of organisms, if life ever originated on the satellite. Assuming that life arises quickly under appropriate formative conditions, life could be present wherever it is provided with liquid water, a source of energy, and essential elements. Damaging radiation stemming from Jupiter's magnetosphere poses an additional constraint, although: (a) Jovian radiation is absorbed in the upper 1-10 cm [4] of the surface and (b) possible organisms might exhibit unusual tolerance to transient radiation exposure. Given the presence of organic compounds on Europa and a number of possible sources of energy that could be exploited [5,6], the search for potential habitats should be focused to places where water is liquid. However, the very low temperature at Europa's surface (~80-130°K) prevents the presence of liquid water even at very high salinity levels, and indicates that favorable physical conditions are more likely at depth. Therefore, promising sites for Europa's exploration will include locations where conditions for life are favorable or where bio-signatures from deeper habitats might surface. Future studies will need to focus on surface units where geologic processes have driven: a) the localized warming/melting of ice, b) shielding from radiation, c) the concentration of organic matter and/or nutrients, and d) the ascent of subsurface material.

## Potential Evaluation of Surface Units

Mechanisms proposed for the formation of surface units during the initial interpretation of the Galileo data can be grouped into two scenarios: the thin-shell [7, 8] and the thick-

shell models [9, 10]. Both models postulate different pathways and degrees of interaction between the surface and deeper levels, and so they prescribe different possible conditions and environments for life [9, 11]. However, we here consider a set of model-independent characteristics that could be used for identifying potential habitats from geologic observations. The astrobiological potential (or plausibility for viable or fossil life to be present) of surface units could be evaluated according to the following criteria: (a) evidence for high mobility, indicating possible presence of brines or warm ice during formation; (b) concentration of non-ice components, potential energy sources and likely due to the loss of the icy fraction by a thermal event; (c) relative youth, which increases the chances for finding or preserving bio-signatures; (e) evidence for a stable or gradually changing environment (although rates of processes are hard to determine on Europa) which could allow biological adaptation. This set of criteria is preliminary and incomplete, and additional, unit-specific elements will be considered in the next section.

Following the preceding criteria, we have evaluated the astrobiological potential of the 5 major unit types on Europa: plains, ridges, bands, chaos, and impact structures. Ridged plains are the oldest mappable unit and their potential likely varies depending on the nature and timing of the constituting lineament types. However, the potential of the plains could be enhanced by continuous tidal working of micro-cracks, without producing conspicuous features at the image resolutions available (few m/pixel). Smooth, low-albedo plains show evidence of high mobility, embayment of low-lying areas, and concentration of non-ice components, in some cases associated with geologically recent features. These characteristics make them prime sites for further exploration [12], although they appear to result from single, relatively short events. Recent fractures and doublet ridges may be sites of tidal working and warming of the ice; although the degree of interaction with deeper levels remains unclear, ridges constitute ubiquitous sites of possible upwelling and/or downwelling of crustal material. In this respect, some Europan bands show clear evidence of separation and infilling of inter-plate gaps with mobile, salt-rich material from the subsurface in a progressive fashion. Low-albedo, geologically recent bands are among the most interesting sites for astrobiological studies. Chaos matrix, which can incorporate reworked crustal ice, is comprised of mobile, salt-rich material emplaced by thermal processes at depth. Therefore chaos areas, whether derived from diapirs from the base of the lithosphere or from an exposed and refrozen ocean, are windows to Europa's subsurface, its chemistry, and possible life forms. Large impact structures, which appear to have penetrated deep into Europa's lithosphere, are fairly rare. Although they involve localized heating and exposure of deep levels of the crust, their violent origin undermines their capability for hosting and preserving organisms. However, the gradual isostatic adjustment of large craters may increase their potential as possible habitats.

**Considerations for Future Work**

In the next phase of this work-in-progress, we will expand the criteria for habitat evaluation and ranking. This multi-disciplinary effort will incorporate results from: (a) tolerance of terrestrial sea ice organisms to radiation and investigation of chemical signatures of irradiated cells; (b) investigation of mechanical behavior and possible surface-subsurface pathways by extrapolating results obtained from studies on terrestrial

sea ice; (c) detailed geological analysis, with emphasis on internal morphological and timing variations that may yield additional information on their development; and (d) biospheric modeling, by integrating observations and emerging ideas into possible scenarios that assess the possible evolution, success, and interactions of potential organisms. We expect to produce a series of recommendations, synthesizing the post-Galileo state-of-knowledge regarding astrobiological assessment criteria, possible sites of enhanced potential, required critical measurements, and outstanding issues for future missions to address.

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# Abstract # 12830 - **An Integrated Concept for Imaging and Spectroscopy of ET Materials**

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Traditionally, light microscopy and spectral techniques have been employed with great effect in the study of astromaterials; however, these techniques have had limited spatial resolution. There has been a revolution in light and fluorescence imaging by combining standard optics with Scanning Probe Microscopy (SPM). Instruments that can image using light beyond the diffraction limits of standard light microscopy (i.e., ~0.5µm) have been developed for many years, but they have not been employed to the study of meteoritic materials or IDPs. We propose to develop an instrument concept using a combination of commercially available instrumentation and expertise in spectroscopy design at the Carnegie Institute of Washington, Lawrence Livermore National Laboratories, and Howard University capable of the following:

1. Light Microscopy, both transmitted and reflected.
2. Fluorescence Microscopy, measuring both inherent fluorescence and that from simple or specific stains. The system will include: far field, two photon, confocal and near field (SNOM).
3. Atomic Force Microscopy (AFM), or (in the case of aperture-less glass probes), shear force microscopy (SFM).
4. Chemical Force Microscopy, where the AFM tip is functionalized to allow detection of target molecules.

5. Raman and Infrared Spectroscopy, both confocal and near field.

Although all of these techniques cannot be used at precisely the same time, they can be used sequentially on the same area of a sample, in order to build up a comprehensive picture over time without moving the sample. This is a highly preferable trait in view of increased spatial resolution and the highly heterogeneous nature of the samples. No other instrument allows the gathering of such a suite of information without moving the sample.

While this sounds like an impossible task, there are commercial instruments available that can do all the techniques outlined above, except for coupling infra-red and raman spectroscopy (in the same instrument) and the use of CFM (which requires a liquid cell). An overview of commercial SPM instruments from the main vendors is presented in the Table 1, featuring the most important characteristics. It is clear from this table that commercial instruments use a variety of techniques to gather imaging and spectral data both in confocal and near field modes. None of the commercial instruments is optimized for ET (extraterrestrial) samples, however, so we propose to design and construct a custom-made instrument. The large variety of applications to be combined naturally leads to trade offs in capabilities, since the same probe is used as a wave-guide and a force sensor. The following section will discuss some of the key considerations that will affect the final design of the system.

Table 1. Comparison of the main characteristics of the commercial NSOM products. (Note: All systems can be tailored for raman spectroscopy.)

| **Manufacturer** | **Probe type** | **Reflectivity mode** | **AFM type** | **Feedback** |
|---|---|---|---|---|
| DI(Veeco) | Straight fiber | Angle geometry | Shear force | Tuning Fork |
| Nanonics | Cantilevered | Upright microscope | Contact | Optical Fiber |
| Omicron | Bent fiber | Upright microscope | Shear force | Shear force |
| WITec | Si cantilever | None | Contact | Optical |

We will further develop Raman techniques to gain spectroscopic information at a variety of excitation wavelengths, from ultraviolet to near infrared (229 to 1064 nm). This instrument will be capable of imaging and spectroscopy at a range of resolutions from normal light and fluorescence microscopy to 3-D confocal imaging and spectroscopy (1.4 times increase in resolution over light microscopy) to near-field techniques that routinely achieve sub 100nm resolutions but can theoretically resolve sub 10nm structures. We will test a variety of fluorescence microscopy stains and specific probes using confocal and near field imaging for the elucidation of protocols for the detection of organic material. We will combine this with spectroscopy of the same areas as imaged whilst gaining 3-D information in the form of confocal or AFM images. This will allow direct comparisons of spectral, imaging and fluorescence data both at the micron and sub 100nm ranges and hence help elucidate the composition, structure, and origin of returned ET samples.

# Abstract # 12843 - **Biosignatures and Abiosignatures**

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The search for biosignatures – unambiguous chemical and physical characteristics that point to biological activity – is a key objective of astrobiology. Ongoing debates regarding possible microfossils in Martian meteorite ALH84001 and in the 3.5 billion year old Apex Chert of the Warrawoona Formation in Western Australia underscore the difficulty of establishing beyond a reasonable doubt the physical and chemical traces of ancient biological activity.

A striking aspect of these debates has been the greater burden of proof placed on those who would claim evidence for ancient or extraterrestrial life. Some investigators take Carl Sagan's oft-quoted admonishment that "extraordinary claims require extraordinary proof" to mean that more rigorous evidence is required to prove that a sample is biotic than abiotic. However, the convincing demonstration of an abiotic origin in any ancient terrestrial or Martian specimen with organic carbon would also constitute an extraordinary finding, with possible implications for both the timing of life's origin and its subsequent radiation.

We argue that consideration should also be given to the search for abiosignatures – unambiguous chemical and physical characteristics that point exclusively to abiological processes. A principal difficulty in this effort is that billions of years of diagenesis inevitably degrade physical structures and alter suites of organic molecules (whether biotic or abiotic) to assemblages of molecular fragments that rarely retain morphological information. An alternative approach is to focus on concentration ratios and isotopic characteristics of diagnostic molecular fragments that may provide effective bio/abiosignatures in diagenetically altered ancient specimens. In general, abiotic synthesis produces a suite of energetically similar isomers, whereas biosynthetic processes display a high degree of isomeric selectivity. Consequently, ratios of ubiquitous, stable organic species may serve as bio/abiosignatures.

Three pragmatic selection criteria – ubiquity, stability and detectability – characterize both ideal biosignatures and abiosignatures for ancient specimens.

*Ubiquity:* The most useful signatures are chemical or physical characteristics common to a wide range of circumstances. Thus, abiosignatures should consist of chemical, isotopic

and molecular attributes that point to widespread prebiotic synthetic processes. By the same token, the most useful biosignatures should represent chemical, isotopic and molecular signatures common to all known cellular life. Many cellular functions, including metabolic pathways, membrane transport, protein synthesis and the genetic code, are highly conserved across all taxa. These processes, furthermore, rely on a high degree of molecular selectivity, as displayed by chiral sugars and amino acids, isoprenoids, sterols, biohopanoids and numerous other distinctive biomolecules.

*Stability:* To be useful, a bio/abiosignature must have persisted through geological time. Even the least altered Archaean sediments have been subjected to billions of years of low-grade metamorphic conditions ($T \geq 100^{\circ}C$), which significantly alter the morphological and chemical characteristics of any authegenic suite of organic molecules, whether biotic or abiotic. As a consequence, morphological features of ancient single cells rarely survive and are not generally useful signatures. Similarly, most macromolecules (whether biotic or abiotic) are diagenetically altered and fragmented under such conditions. The criterion of stability, consequently, shifts our focus from characteristic macromolecules to suites of relatively stable molecular fragments, perhaps coupled with their isotopic characteristics. A variety of molecular species, including alkanes and polycyclic hydrocarbons persist stably for billions of years in a relatively benign geological environment and thus serve as a possible basis for identifying bio- and abiosignatures. The predominance of a particular suite of these compounds can be indicative of biology, whereas a more uniform distribution of all possible alkanes and/or PAHs would indicate an abiological origin.

*Detectability:* In the context of astrobiology, a useful bio/abiomarker must be easily detectable in trace amounts by current remote sensing techniques.

Pathways of abiotic and biotic organic synthesis differ dramatically and, consequently, yield dramatically different suites of molecular products. We conclude that life's striking chiral and isomeric molecular selectivity, as compared with the diverse products of proposed prebiotic processes, points to promising new biosignatures and abiosignatures based on ratios of ubiquitous, stable molecular species. Organic matter in rocks – even those in ancient formations altered by billions of years of low-grade diagenesis – should retain characteristic molecular fragments that point unambiguously to biotic or abiotic processes.

The systematic search for biosignatures <u>and</u> abiosignatures will thus contribute to a greater understanding of chemical processes that led to the origin and evolution of life. A great deal of systematic research employing the wealth of new techniques that are available to the astrobiology community must be undertaken to unravel this mix of biogenic and abiogenic signatures preserved in rocks from Earth and other planets.

# Abstract # 12856 *(Oral Presentation)* - **THEMIS Data and the Search for Sites of Astrobiological Interest on Mars**

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The Thermal Emission Imaging System (THEMIS) on board the Mars Odyssey spacecraft currently in orbit around Mars is supplying 9-band thermal infrared (TIR) data that can be used to discern compositional variations on the surface down to 100 m per pixel. In addition, a visible/near infrared camera that is part of THEMIS views the surface at 18 m per pixel in up to 5 bands. After an initial period of data calibration and verification, the THEMIS data set is now poised to provide views of the compositional variations on the Martian surface at spatial scales previously not available. To date, dramatic variations in the composition of volcanic materials in Nili Patera caldera have been observed as well as outcropping units enriched in olivine on the floor of Ganges Chasma. The latter result made use of the higher spectral resolution of the Mars Global Surveyor Thermal Emission Spectrometer (TES) data set to supply the compositional details. In this case, even though the outcrop of interest was smaller than a TES pixel (~3x6 km), the olivine anomaly was readily discernible.

One of the objectives of the THEMIS instrument is to look for sites of astrobiological interest, specifically, locations with aqueous mineral deposits that may have escaped detection by the TES instrument due to small areal extent. For example, while no large (10s of km) occurrences of carbonates have been observed with TES data, it is possible that such deposits occur at smaller spatial scales. TIR data from THEMIS are sensitive to carbonates and many other minerals that are produced in aqueous environments. To date, with only a few 10s of THEMIS multi-spectral images having been analyzed, no new deposits of water-derived minerals have been observed. Yet the initial success with the identification of relatively subtle variations in volcanic composition at small spatial scales bodes well for the potential of THEMIS data to be used to observe the more dramatic spectral variations associated with aqueous environments. The latest results from THEMIS will be presented at the meeting.

# Abstract # 12871 - The Large-scale Surface Flow on HD209458b: A First Look at Atmospheric Circulation Modeling of Planets Beyond the Solar System

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High-resolution atmospheric dynamics modeling using random initial conditions has shown that large-scale circulation on the gas giant planets in our Solar System naturally evolves to the observed states -- banded configuration with east-west jets and persistent vortices embedded between the jets. The evolution to the final configuration is fast (~20 days) and is fundamentally controlled by the rotation rate, size, and (cloud-top) temperature of the planet. Similar numerical simulations of the tidally-locked extrasolar giant planet, HD209458b, show large-scale spatio-temporal flow variability -- in contrast to the naive picture of unchanging hot/cold (day/night) hemispheres, suggesting analogous variability in spectral signatures. The variability is produced by a pair of circumpolar vortices and corresponding few broad jets that undulate in the east-west direction, reminiscent of Earth's winter stratosphere. These large-scale flow features are generic -- arising from many different initially-random flow realizations -- and are dynamically robust -- persisting over many planetary rotations/years, even under intense irradiation from its parent star. Such modeling represents a first -- and necessary -- step in properly characterizing habitability of planets beyond the Solar System, as circulation strongly modifies and interacts with the processes that produce signatures of life.

# Abstract # 12877 - **Autotrophic Sulfate Reduction in a Hydrothermally Formed Ocean on Europa**

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Sulfate in the present-day ocean on Jupiter's satellite Europa may have formed as a result of high-temperature aqueous oxidation of meteoritic-type sulfides [1, 2]. Here we show that the formation of the ocean by quenched hydrothermal fluids provides a source of metabolic energy for low-temperature sulfate-reducing organisms that use dissolved $H_2$ as an electron donor.

High-temperature hydrothermal fluids released at the upper boundary of the silicate mantle during Europa's differentiation are a plausible source for the satellite's ocean. High fluid temperatures, together with mineral catalysis, would have favored equilibration of H-, O-, and S-bearing aqueous (aq) species in the ocean-forming fluids. If so, despite being relatively oxidized, hot sulfate-bearing fluids would have contained a small amount of dissolved $H_2$. Rapid cooling of these fluids to oceanic temperatures (~0ºC) would have prevented re-equilibration of $SO_4^{2-}$ and $H_2$(aq) owing to inhibition of oxidation-reduction reactions. The disequilibrium coexistence of sulfate with $H_2$(aq) in quenched fluids creates a source of free chemical energy (chemical affinity) that could be used by autotrophic sulfate-reducing organisms for their metabolism. In terrestrial anoxic basins and in organic-rich oceanic sediments, thermodynamically-favored sulfate reduction occurs only through biologic activity. Without life, sulfate can coexist at low temperatures with aqueous sulfides at time scales approaching the geologic.

Calculations of chemical equilibria in the S-Mg-$H_2O$ system show that high temperature and reduced conditions of the hydrothermal fluids favor sulfate reduction in quenched ocean-forming solutions. However, that reduction is limited by the amount of $H_2$(aq) available in the original sulfate-rich fluids. Concentrations of $H_2$(aq), and therefore free energy available from sulfate reduction, are constrained by conditions that allow formation of sulfate-bearing solutions in Europa's mantle. These conditions include host rocks oxidized beyond the quartz-fayalite-magnetite buffer and an alkaline pH [2], which typically results from alteration of ultramafic rocks. The redox state of the hematite-magnetite (HM) buffer, which may represent the most oxidized fluids in Europa's mantle, determines lower limits for concentrations of $H_2$(aq). In addition, HM sets a lower limit for the pH of sulfate-rich fluids [2]. In fact, at HM and more reduced conditions, sulfate-rich fluids do not form at acidic conditions.

The amount of chemical energy potentially available (chemical affinity) from sulfate reduction has been evaluated as a function of temperature, pH, and the oxidation state of ocean-forming hydrothermal fluids. Our focus was the $SO_4^{2-}$ to $HS^-$ conversion, for which chemical affinity can develop in an ocean formed by alkaline hydrothermal fluids. The results demonstrate that the chemical affinity is greatest in quenched, high-temperature, reduced, alkaline fluids. The amount of chemical affinity from sulfate reduction increases with increasing $H_2$(aq) concentration in the original hydrothermal fluids. In turn, high temperatures favor higher concentrations of dissolved hydrogen in those fluids. Since alkaline conditions support the formation of sulfate-rich fluids at higher concentrations of $H_2$ (aq) [2], the chemical affinity for sulfate reduction increases in cooled solutions that originally had higher pH. Additional calculations demonstrate that quenching of moderately reduced sulfide-rich fluids, in which the $SO_4^{2-}$ concentration is a few orders of magnitude lower than that of $HS^-$, could provide greater chemical affinity for low-temperature sulfate reduction compared with sulfate-rich fluids. The affinity is greater because the reduced fluids have higher $H_2$(aq) contents but still contain sulfate ions that can potentially be converted to $HS^-$ upon quenching. The amount of energy in these $SO_4^{2-}$ -bearing and $HS^-$-rich fluids is limited by the concentration of sulfate.

The maximum amount of energy available to support autotrophic sulfate reduction is on the order of a few kJ per kg of $H_2O$ and is limited by the abundance of either $H_2$(aq) or $SO_4^{2-}$ in sulfate-bearing fluids that could have formed the ocean. This amount of energy corresponds to potential conversion of about 0.02 moles of $SO_4^{2-}$ per kg of $H_2O$. Although the concentration of $SO_4^{2-}$ in Europa's ocean is unknown, these results demonstrate that the potentially reducible fraction of $SO_4^{2-}$ is not negligible. For a 100 km thick ocean the energy could be as high as $10^{25}$ J. This energy corresponds to potential reduction of ~5 _ $10^{19}$ moles of Europa's $SO_4^{2-}$, which might be a small portion of the oceanic sulfate inventory. This energy might have supported an early autotrophic sulfate-reducing metabolism but is likely to have decreased with time owing to consumption of $H_2$ through sulfate reduction, cessation of igneous and hydrothermal activity, and $H_2$ escape into space. Although the amount of energy could be insufficient to allow sulfate-reducing organisms to persist throughout the ocean's history, periodic supply of abiotic organic compounds into the ocean and/or primary production of biomolecules by methanogens could maintain heterotrophic sulfate-reducing organisms. Biologic sulfate reduction could lead to equilibration between $SO_4^{2-}$, $HS^-$, $H_2S$(aq), and $H_2$(aq). If detected, equilibrium low-temperature relations among these species in Europa's oceanic water would be highly suggestive of the involvement of ancient life.

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# Abstract # 12885 - **Convection and the Potential Habitibility of Titan and Ganymede**

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Ganymede and Titan are believed to contain sub-surface oceans [1,2]. If there were life in these oceans, it is only detectable at the surface. Understanding processes that transport signs of life and/or signatures of interesting ocean chemistry to the surface is key to understanding the astrobiological setting of these moons. Solid-state convection provides a way to move material from the oceans of these moons to the shallow subsurface, where resurfacing events might allow eruption of life/biomarkers onto the surface.

We calculate steady-state thermal models of the interior of Titan and Ganymede using convective scaling laws and numerical convection simulations, and discuss the astrobiological implications of our results. Determination of the stagnant lid thickness allows us to determine how close convection can come to delivering biosignatures/life to the surface and sheds light on the geological setting of the two moons. Determining the convective velocities within the outer icy shells of these moons provides estimates of the time scale over which material from the ocean can reach the shallow subsurface. We show how these convective velocities and the internal temperature structure of these two moons has evolved over time by calculating models applicable today and at two times in the geologic past.

For Ganymede, we use estimates of the mean density and moment of inertia to constrain the physical model and infer the presence of a liquid water layer today (and in the past) based on measurements from the Galileo magnetometer [1]. Our choice of internal structure of Titan is only constrained by the mean density. We present two models of Titan: a fully differentiated Ganymede-like model in which all rock is contained in a core, and a Callisto-like model in which some rock is suspended in the icy mantle.

The Ganymede-like model consists of layers of rock, high-pressure polymorphs of ice, liquid water and ice I. (The thermal effects of the presence of a liquid ocean at the ice I-II or ice I-III phase boundary are beyond the scope of this model and are not expected to significantly alter the results of the model.) We assume that the mantles of the Ganymede-like moons convect as a single layer and ignore the rheological differences

between the high-pressure polymorphs of ice [3]. The steady-state internal temperature in the outer ice I shell is used to determine the location and thickness of the ocean; for the Ganymede/Titan, we use the phase diagram of ammonia-water [4], therefore the expected ocean thickness is greater than on Ganymede, where the ocean will occur at the minimum melting point of ice.

In the Callisto-like model of Titan, we allow a fraction of Titan's rocky component to be suspended within the ice mantle. The presence of rock suspended in the ice merely serves to decrease the radius of Titan's core and increase the size of the ice mantle; the presence of rock does not appreciably affect the rheology.

The parameterized convection model is constructed assuming that the satellite is in thermal equilibrium. The heat delivered to the surface by convection ($F_{conv}$) is thus equal to the heat flux generated by radioactive decay in the interior ($F_r$):

$$F_{conv} = F_r \Rightarrow \frac{k\Delta T}{D} Nu = \frac{R_S}{3} \rho_{rock} \phi H \cdot$$

Here, $k$ is the thermal conductivity, $\Delta T$ is the temperature drop across the layer, D is the thickness of the convecting layer, $R_s$ is the radius of the satellite, $\rho_{rock}$ is the density of rock, $\phi$ is the volume fraction of rock in the satellite as a whole and $H$ is the chondritic heating rate. We consider steady-state solutions at different times in the past by changing values of $H$. Using the Rayleigh number-Nusselt number relation $Nu \sim 0.1\ Ra^{1/3}$, we evaluate the steady-state temperature in the outer ice I shell.

The temperature rise across the boundary layer between the ice I and ice II/III layer is evaluated by assuming that each half-boundary layer has a local Rayleigh number which exceeds the critical Rayleigh number:

$$Ra > Ra_{crit} \Rightarrow \frac{\rho g \alpha \Delta T_b (\delta_1)^3}{\kappa \eta} > 1000 \cdot$$

Here, $\rho$ is the density of ice, $g$ is the acceleration of gravity, $\Delta T_b$ is the temperature rise across the boundary layer, $\delta_1$ is the half-thickness of the boundary, $\kappa$ is the thermal diffusivity and $\eta$ is the viscosity of ice, which is a function of temperature. The half-thickness of the boundary layer is evaluated by setting the heat flux from the interior equal to the heat flux conducted across the boundary layer. A similar analysis is applied to the bottom half of the boundary layer, and thus the interior temperature of the ice mantle can be estimated.

Armed with these estimates of internal structure, we will employ a numerical finite element model of convection (Citcom [5]) to determine the average convective velocities in the outer shells and mantles and to determine their stagnant lid thicknesses.

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# Abstract # 12892 - **Astro-Biotechnology**

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The growth of biotechnology in the last twenty years has been staggering and the sheer number of new techniques and procedures can be disorientating. With the birth of astrobiology a natural interface between biology and therefore biotechnology, space and geological sciences has been formed. For scientists from all of these disciplines the speed of development of new instrumentation has been difficult to keep abreast of. Obviously the development of these techniques would fulfil a unique purpose in exploration terms, the detection and more importantly potential characterisation of life on other solar system bodies. Why use biotechnology? The answer is very simple; the techniques that have been used for solar system exploration (SSE) have been ambiguous or failed completely to detect life. In the case of the debate on relic biogenic activity in the Martian meteorite ALH84001, many traditional techniques all concluded that no life was contained within the meteorite [1,2,3,4]. However, some if not this entire meteorite was colonized by terrestrial microbiota [5]. A further example is the ambiguity associated with the Viking lander results [6]. Within biology, if a patient has an infection or there is a food spoilage problem or a novel organism is sought to answer specific bio(techno)logy questions, the techniques of choice are the wealth of microbiological, molecular and genetic techniques, which are now being refined as biotechnology approaches what is largely regarded as its golden age. Miniaturisation and nano-technology have been integrated with biotechnology in exciting new fields of research towards the goal of "lab-on-a-chip" instruments [8,9]. To put it simply, these techniques have been developed to answer on Earth the questions we wish to address in the rest of the solar system; is there/was there microbial life present, what are its characteristics, how can we detect it in small abundances and what effects is it having on the environment it resides and vice versa. Whether it is a novel microbe in a black smoker or an unknown infection or cancer cell in the human body, the task, goals, methodology and philosophy are the same. To the question "why use biotechnology"?, the answer becomes "because it was developed for this task and need only be modified and applied to  and to solar system exploration". There are several categories of molecules of astrobiological interest: Prebiotic chemicals (and reactions), terrestrial biochemistries and organisms, terrestrial contaminating organics and organisms (in space flight), organic fossil biomarkers, pathogens and human

disease markers, environmental pollutant detection (for use in Manned Space programs), microbial population monitoring, constraining possible extraterrestrial biochemistries, organic chemistry applications and if possible ET biochemistries and organisms. Biotechnology techniques currently exist to screen all or part of these issues. The obvious exceptions are molecules based on non-terrestrial biochemistries, however, as our understanding grows of the possibilities of biochemistry and combinatorial chemistry we may be able to enlarge the search parameters to include a greater detection range of possibilities. However, before exploring this possibility, by far the most useful task of these techniques would be to set a terrestrial base line value that would help to constrain the depth of terrestrial biology. It is only by understanding the range of biomolecules, survival strategies, microbial life, diagenesis and preservation of biomolecules in the geologic record, that we can hope to increase the probability of detecting what has been termed "non-Earth-centric life" [10].

The objective of this proposed NAI Focus Group will be to monitor current and developing biotechnology for direct application to astrobiology research and exploration. Initial focus is expected to be on exploiting biotechnology, lab-on-a-chip and μTAS (micro total analytical systems). The emphasis of the Focus Group is expected to be on;

- Instigating further communication and collaboration between researchers in different astrobiology sub-disciplines, towards refining these techniques for particular applications relevant to their field. To develop a higher profile of these techniques within the community as a whole.
- Defining a number of probes (DNA, RNA, aptamers, proteins, antibodies etc) that could reliably be used in extraterrestrial applications.
- Interest commercial biotech vendors in mission opportunities to ensure fast and efficient use of current technology and its passage into space operations.
- Fostering collaboration and understanding between space flight engineers and biotechnologists and biotech engineers towards defining new instrumentation and flight opportunities.
- Identifying funding bodies both within and outside NASA to apply for investment into new collaborative projects.

If you are interested in possibly participating in such a Focus Group, or in a preliminary workshop to develop plans for such a Focus Group, please fill in the form on www.masse.co.uk for the Astrobiotechnology Focus Group.

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# Abstract # 12893 *(Oral Presentation)* - **Aerosols in Titan's Atmosphere: Implication for Astrobiology**

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Titan provides one of the most interesting extraterrestrial environments for the evolution of abiotic organic chemistry. Khare et al. (1984) have studied the aerosols of Titan in simulating atmospheres (0.10 $CH_4$ and 0.90 $N_2$). The aerosols produced in the experiments reveal amino acids on hydrolysis (Khare et al., 1981) and also contain a range of two to four-ring PAHs, some with one to four alkylation sites, with net abundance ~ $10^{-4}$ grams per gram of tholins on examination by two-step laser desorption/multiphoton ionization mass spectrometry (Sagan et al., 1993). Both amino acids and PAHs are considered important ingredients for the origin and evolution of life. As the optical constants of the aerosols play an important role in controlling the temperature structure of the atmosphere, systematic measurements at various pressure, temperatures and compositions are required.

Voyager's photographs have revealed the presence of several haze layers in the Titan's stratosphere (Smith et al., 1981; Smith et al., 1982) with distinct optical properties (Rages and Pollack, 1983; Rannou et al., 2000). The origin of theses haze layers is unknown, although a chemical origin (Chassefiere and Cabane, 1995) and a dynamical origin (Toon

et al., 1992; Rannou et al., 2002) have been suggested. The effect of pressure on the chemical composition and optical properties of aerosols have not been studied very much before. The altitude profile of aerosols to be obtained by Cassini/Huygens mission cannot be interpreted without laboratory experiments studying pressure effects, etc.

For the first time, we present the chemical and optical properties of aerosols in the Titan's atmosphere at different heights to determine if the variation in the chemical composition of the hazes at different altitudes alone is a major factor in the formation of detached haze layers. Khare et al. (1984) have measured the optical properties of tholin produced from a mixture of 0.10 $CH_4$ and 0.90 $N_2$ subjected to charged particle irradiation at 0.2 mb pressure only. Our results indicate that the properties of tholins produced under different pressure regime within 0.13 mb to 22.4 mb have distinct chemical and optical properties.

Thompson et al. (1991) find less amount of saturated hydrocarbons in gas phase products formed at lower pressure. Infrared absorption measurements showed the decrease in the ratio of aliphatic C-H bonds to N-H bonds in the tholins as the simulated pressure is decreased. Two-step laser desorption/ionization mass spectrometry revealed that the distributions of adsorbed PAHs and hetrocyclic aromatics in the tholins produced at different pressures were distinct. We have not detected PAHs and hetrocyclic aromatics in the tholin formed at higher pressure, but found them in tholins produced at lower pressure. These results indicate that fewer collisions of multiple bonds with hydrogen at lower pressure maintain unsaturated compounds in gas phase products and lead to ring structure in solid products. The pyrolysis elemental analysis revealed an increase in the nitrogen/carbon ratio in tholins produced at lower pressures. These results indicate that the lower pressure condition of plasma may be in favor of forming the nitrogen containing ring structure. This has important implications in making the building block of DNA, such as adenine, effectively at lower pressure. The UV/VIS absorption characteristics showed lower pressure tholin was more reddish. Thus, the haze layers at various altitudes may have different optical properties. These variations, as a function of altitude, will be investigated by the Cassini/Huygens mission.

# Abstract # 12906 - **Humans to Mars: The Political Initiative and Technical Expertise Needed for Human Exploration of the Red Planet**

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We, the 2002 NASA Astrobiology Academy, propose that NASA adopt a human mission to Mars as a clear and articulated goal of the agency. In the past few decades, NASAís focus has shifted from destination-driven missions to research-driven goals. The Astrobiology Academy advocates a return to a more mission-centric NASA, namely a human mission to Mars driven by astrobiological objectives. By coupling science to a human Mars mission, NASA will not only create a unified goal for itself, but it will unite and strengthen the nation and the world.

Our nation currently faces myriad extraordinary challenges, among them the fact that international terrorism has crossed our borders, concern about climate change challenges to our traditional industries, and a decreasing supply of U.S. scientists and engineers. These jeopardize the future of our economic leadership. However, we have also made tremendous discoveries in the past few decades, many in particular of astrobiological importance. The discovery of the ubiquity of life on Earth leads to the obvious question: does life exist on other planets? Human kind now has the ability to explore places in the solar system of which past generations only dreamed, and to find the answers to questions like this.

The time to take action is now. As the current generation of NASA employees retire, they take with them unique knowledge gained during the rapid technology development of the space race. A human Mars mission is an investment, not only in basic scientific knowledge but also in strengthening our nation. Here we outline the benefits of such a mission but also explain why, given the current state of our nation, a Mars mission is a necessity. We also demonstrate the feasibility of a human mission by presenting an overview of existing technology and current research that (when applied constructively) will soon make a mission to Mars not just physically possible, but safe for our astronauts.

This project was created to convey the unparalleled potential of our generation and our desires to no longer simply believe in what we can accomplish, but realize our dreams.

# Abstract # 12912 *(Oral Presentation)* - **Analysis of Areas of High Spectral Variance Detected in TES Data**

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Life on Earth may have originated in areas of hydrothermal activity, where water, energy, and biogenic elements were available. Hydrothermal environments are characterized by the presence of a wide variety of mineral species, which translates into a large amount of spectral variability. Minerals characteristic of hydrothermal systems (both fossil and active) can be identified through their infrared emissivity spectra by instruments such as the Thermal Emission Spectrometer (TES), onboard Mars Global Surveyor. The aim of this study is to determine wether or not there are hydrothermal systems on Mars, using TES emissivity data.
To date, more than 137 million TES radiance spectra of the surface of Mars, which is approximately equivalent to the land surface area on Earth, have been acquired. In order to identify areas of high spectral variance among such a vast data set, a variance index was devised (Martínez-Alonso, 2002). Non-resampled TES single-scan data, selected according to acquisition geometry, surface temperature, atmospheric conditions, and instrument performance were gathered for 5-by-5 degree cells covering the entire planet. The noise-adjusted spectral variance per cell was then calculated. As expected, a positive correlation between variance and number of spectra per cell was found. The outliers in this distribution (cells whose spectral variance is significantly larger than the average) are the focus of this study. The variance index is expressed as the number of standard deviations of the residuals between observed and expected spectral variance per cell. The global distribution of the variance index is consistent with TES-derived albedo and thermal inertia maps. Areas of high variance index coincide spatially with areas of low albedo and high thermal inertia, and vice-versa; low albedo and high thermal inertia are considered indicative of exposed rocky material.

The results of on-going analysis of some of these high-variance-index areas are presented here. The single- and double-scan TES data for such areas are examined using constrained linear mixing models and spectral endmembers extracted from the data themselves. In order to accept that an endmember has spectral significance, repeated

observations (performed at different times in the same location or in adjacent locations) are always required. The data-derived endmembers are then identified by comparison to spectral libraries (ASTER Spectral Library, 2000; Christensen et al., 2000).
One of the high-variance-index areas studied, a 10-by-10 degree region centered at 25ºN, 285ºW, corresponds to Nili Fossae. Analysis of the data-derived endmembers indicates the presence of abundant olivine over an area of at least 2200 $km^2$. Olivine in this area had been previously reported by Hoefen et al. (2000), and Hamilton et al. (2001). Other endmembers identified in this region are most consistent with available library spectra of silica-rich glass (Bandfield, pers. comm.) and/or phyllosilicates. The nature of other TES-derived endmembers identified in this region is still being investigated. THEMIS, MOC, and MOLA data are being analyzed to better understand the significance of the TES spectroscopic evidence.

Another of the high-variance-index regions analyzed is a 15-by-15 degree area southward of Margaritifer Terra, centered at 22.5ºS, 22.5ºW. TES-derived endmembers for this region are consistent with olivine. One particular region of distinct TES emissivity spectra is located in the interior of Kasimov crater. This crater shows intense erosion of its rim as well as younger impact craters. Kasimov was imaged twice (in 1999 and 2000) by the MOC wide-angle camera. Both images indicate that at least one of the small, younger impacts produced a rampart ejecta blanket, suggesting that underground ice may have been present at the time of the impact, although atmospheric conditions have been proposed also to explain this type of morphology (see Carr 1996 for a discussion). A well-defined area of relative high albedo with respect to the average scene albedo inside Kasimov crater and adjacent to the rampart crater is evident in the two MOC scenes as well as in Viking color data and in TES albedo data. This area of relative high albedo coincides remarkably well with a topographically depressed area, as shown by the MOLA-DEM. The TES spectra available for this area are consistent with olivine. THEMIS and narrow-angle MOC data of this region should help establishing the geologic history of Kasimov crater as well as the significance of this olivine occurrence.

The variance index technique applied to the TES data allows for the identification of areas of high spectral variance, which present distinct mineral signatures. High-variance-index TES data, together with higher spatial resolution data (e.g., THEMIS, MOC, MOLA) will enable us to further investigate the surface mineralogy of Mars, and to perhaps determine if hydrothermal systems are present.

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# Abstract # 12924 - **The Importance of Venus in Biocentric Planetary Exploration**

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Venus has not traditionally been considered a likely target in a "biocentric" planetary exploration strategy. We question the wisdom of excluding Venus from a program designed to explore the planets in a way that sheds maximum light on the potential for terrestrial planets to harbor present of past life. We propose that Venus should be central to such an exploration program for several reasons. These include:

1) Putting Earth Life in Context: Venus is the only other Earth-sized terrestrial planet that we know of, and certainly the only one we will have the opportunity to explore in the foreseeable future. Active volcanism is most likely responsible for maintaining the global cloud cover (Bullock and Grinspoon, 2001). Many geological and meteorological processes otherwise active only on Earth at present are currently active on Venus. Given the prevalence of $CO_2$-dominated atmospheres in our own solar system, it is quite likely that at least some extrasolar Earth-sized planets will have atmospheres similar to that of Venus. Understanding the divergence of Earth and Venus is central to understanding the limits of habitability in the inner regions of habitable zones around solar-type stars. Thus, in a comparative planetology sense, Venus presents us with a unique opportunity for putting the bulk properties, evolution and ongoing geochemical processes of Earth in context.

2) The Possibility of Extant Life: Venus almost surely once had warm oceans and an oxygenated atmosphere (Kasting, 1988). The duration of this phase is poorly understood, but it may well have outlasted the Achaean on Earth. During this time, the terrestrial planets were not isolated. Rather, due to frequent impact transport, they represented a continuous environment for early microbial life. On present day Venus, the clouds may represent a habitable niche (Grinspoon, 1997). Though highly acidic, this aqueous environment enjoys moderate temperatures, surroundings far from chemical equilibrium and energetic flows of potentially useful radiation. Knowledge

of widespread acidophilic microbes in hot springs on Earth adds to the plausibility of this habitat, as does recent evidence for a cloud-based microbial ecology on Earth (Sattler et al, 2001). Suggestions of unusual chemistry in the clouds, plus particle populations that are not well characterized, bring to mind that this environment must be explored much more fully before biology can be ruled out. It is possible that life, once established in the early oceans of Venus, migrated to an atmospheric niche (Schulze-Makuch and Irwin, 2002).

3) Unique Planetary Properties of Astrobiological Interest: All of our ideas about extraterrestrial biochemistry are, of necessity, extrapolations from the single example of life which we have been able to study. If we think beyond the specifics of a particular chemical system required to build complexity and heredity, we can ask what general properties a planet must possess in order to be considered a possible candidate for life. The answers would probably include an atmosphere with signs of chemical disequilibrium and active surface geology involving vigorous, cyclic flows of energy and volatile elements between the surface and atmosphere. At present, the two planets we know of which possess these characteristics are Earth and Venus.

After more than a decade of neglect since NASA's fruitful *Magellan* radar mapping mission, several new missions to Venus are being planned or contemplated. These include ESA's Venus Express mission, a Japanese (ISAS) mission scheduled to be launched in 2007, and a Swedish mission to the Venusian atmosphere planned for 2008. In the recently completed planetary science decadal survey by the National Research Council, a Venus *In Situ* Explorer was named as one of 5 high priority missions for a New Frontiers mission to be flown by NASA in the next decade. Measurements of the clouds, atmosphere and surface by this mission can help to shed light on the present and past biological potential of Venus, as well as providing context for increased understanding of the uniqueness of Earth and the likely evolutionary paths of Earth-like planets.

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# Abstract # 12940 - **How to Search for Extraterrestrial Life Without Defining 'Life'**

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In recent work (*Origins of Life and Evolution of the Biosphere* 32(4) (2002)), Christopher Chyba and I argue that it is a mistake for scientists to try to define 'life'. What is needed to answer the scientific question 'what is life?' is not a definition but a general theory of living systems, which we currently lack. In the absence of such a theory, we are in a position analogous to someone from the seventeenth century trying to define 'water' before the advent of molecular theory. No analysis of the seventeenth century concept of water could have revealed that water is $H_20$. Yet this is what is required to answer the question 'what is water?' The upshot is that it is a mistake to design instrument packages for detecting extraterrestrial life around a specific definition of 'life'. But this seems to result in a dilemma: If we don't have a definition of 'life' to guide the design of biological instrument packages, how will we recognize truly alien life if we find it? A strategy for circumventing this conundrum is sketched.

# Abstract # 12991 - **Antibodies to Detect Unambiguous Biomarkers**

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Molecules derived from living cells are diverse. They include large molecules (DNA, RNA and proteins) and small molecules (cholesterol, phospholipids, amino acids, nucleotides and sugars). Unfortunately not all "biomarkers" have an exclusively biological origin, and non-biological processes produce "biological" molecules in abundance (Cooper et al. 2001). Detection of several ambiguous "biomarkers," no matter how many, seems unlikely to lead to an unambiguous conclusion. DNA, RNA and proteins are sufficiently complex not to be produced non-biologically and, if the Martian climate has generally been cold and dry (Golombek 1999), preservation may have occurred (Borja et al. 1997). However, these polymers are generally quickly degraded and further biomarkers should be identified that: (1) are exclusively biological in origin; (2) are derivatives of biological cells; and (3) have a stable structure, i.e., a category 1 biomarker under the new classification system of McKay (McKay 2002). Hopanes and steranes are good candidates. Hopanes are derived from hopanoids, membrane components reported to be biosynthesized by numerous bacteria, including cyanobacteria (Toporski and Steele, 2002; Summons et al. 1999). Steranes are derived from the cholesterol of eukaryotes (Brocks et al. 1999). They have yet to be shown as produced non-biologically, they are present in 2.7 billion year-old rocks (Brocks et al. 1999), and they are structurally stable under high temperatures (Price and DeWitt 2001). We use antibodies to detect category 1 biomarkers. Antibodies may improve sensitivity by as much as 150-fold over GCMS (Li et al., 1999). Immunogold labeling also allows co-localisation of biomarkers with morphological features within a rock section. Hopanes and steranes are small (MW = 300-500) and hydrophobic. This is not ideal for immunization. An antigen must be linked to a carrier protein (Ranadive and Sehon 1967), fused with a liposome (Swartz et al. 1988), or DNA aptamers generated (Li et al. 1996). We report anti-hopane antibodies using a 3-hydroxyhopane-cationized bovine serum albumin (BSA) complex, a technique used previously to generate serotonin antibodies (Ranadive, 1967). Polyclonal serum was obtained at 0, 11, 14 and 23 days following immunization of BALB/c mice. ELISA methods showed hopane-specific immunoglobulin G (especially 3-hydroxy and $\alpha\beta$ forms) increasing to a maximum at day

23. Results will be presented on the use of these antibodies to test hopane levels in terrestrial rocks.

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# Abstract # 13010 - **Protein Detection From Soil Samples by Antibody Microarrays**

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Identification of biochemical compounds from soil samples has both environmental and astrobiological interests. Techniques for biomarker detection (nucleic acids, proteins, lipids or other metabolites) have been extensively developed. Microarrays technology allows the attachment of thousands of probes in a few square centimeters on a solid support. Smaller reaction volumes and higher reaction kinetics, working together with great potential for miniaturization and robotization, make microarray technology a powerful system for *in situ* analysis of biomarkers in astrobiology.

We have already set up this technology for *in vitro* detection of proteins and small peptides using well known antigen-antibody pairs. Application of this approach to environmental samples has several constraints, such as: what kind of biomarker are we looking for, is there already an antibody against it or another capture molecule, sample processing, inmuno-assay sensitivity, antibody stability, detection techniques, etc. Here we will show some preliminary results for the detection of proteins and small peptides from soil samples using antibody microarrays.

# Exploring for Habitable Planets Beyond the Solar System Abstracts

# Abstract # 12557 *(Oral Presentation)* - **Astrobiological Implications of Forming the Solar System in an Ultraviolet-Rich Environment**

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The conventional view of Solar System formation is that the presolar cloud collapsed in a region of low-mass star formation, similar to Taurus-Auriga. In such a quiescent setting, the background UV flux is likely to be low and limited largely to the flux from the protosun once it forms. However, recently a new scenario for Solar System formation has been proposed (Boss, Wetherill & Haghighipour, 2002. *Icarus* 156: 291-295), based on forming the Solar System in a region of high-mass star formation, similar to the Orion nebula cluster. This scenario relies upon a high flux of UV radiation from nearby massive stars to remove the gaseous portion of the solar nebula from Saturn's orbit and beyond, and then to strip the gaseous envelopes from the outermost giant gaseous protoplanets, leaving behind largely ice/rock cores similar to the ice giant planets, Uranus and Neptune. Here we note some of the likely astrobiological consequences of this new scenario for Solar System formation.

Terrestrial planet formation is likely to proceed in a largely unimpeded manner, and may even be somewhat hastened by the gravitational perturbations from a rapidly-formed Jupiter (Kortenkamp, Wetherill & Inaba, 2001. *Science* 293: 1127-1129). Because the inner Solar System is deep within the Sun's gravitational potential well, a halo of hydrogen gas will be retained inside 10 AU, which will protect the planetesimals and gases of the inner solar nebula. Planetesimals and cometesimals outside this distance will be subject to a withering UV flux once the disk gas in their vicinity has been photo-evaporated. However, UV photons will lead to photolysis of the ices on the surfaces of these bodies, producing polycyclic aromatic hydrocarbons and amino acids, i.e., a thick layer of organic compounds that will form an effective sun block (tholins). Beneath this surface layer, the pristine nature of these bodies will be retained. This scenario thus suggests that prebiotic UV-driven chemistry would have been vigorous in the outer regions of the solar nebula even as the planetary accumulation process was underway.

If this scenario can be successfully applied to the origin of the Solar System, then the implications for the frequency of habitable planets are significant. Most stars are believed to form in regions of high-mass star formation, with perhaps only a minor fraction forming in regions similar to Taurus-Auriga. If the Solar System formed in a region similar to Orion, then the prospects for finding and characterizing other Earth-like planets increase several-fold. Future astrobiology space missions such as Kepler will determine the frequency of Earth-like planets and help to determine if this optimistic conjecture is correct.

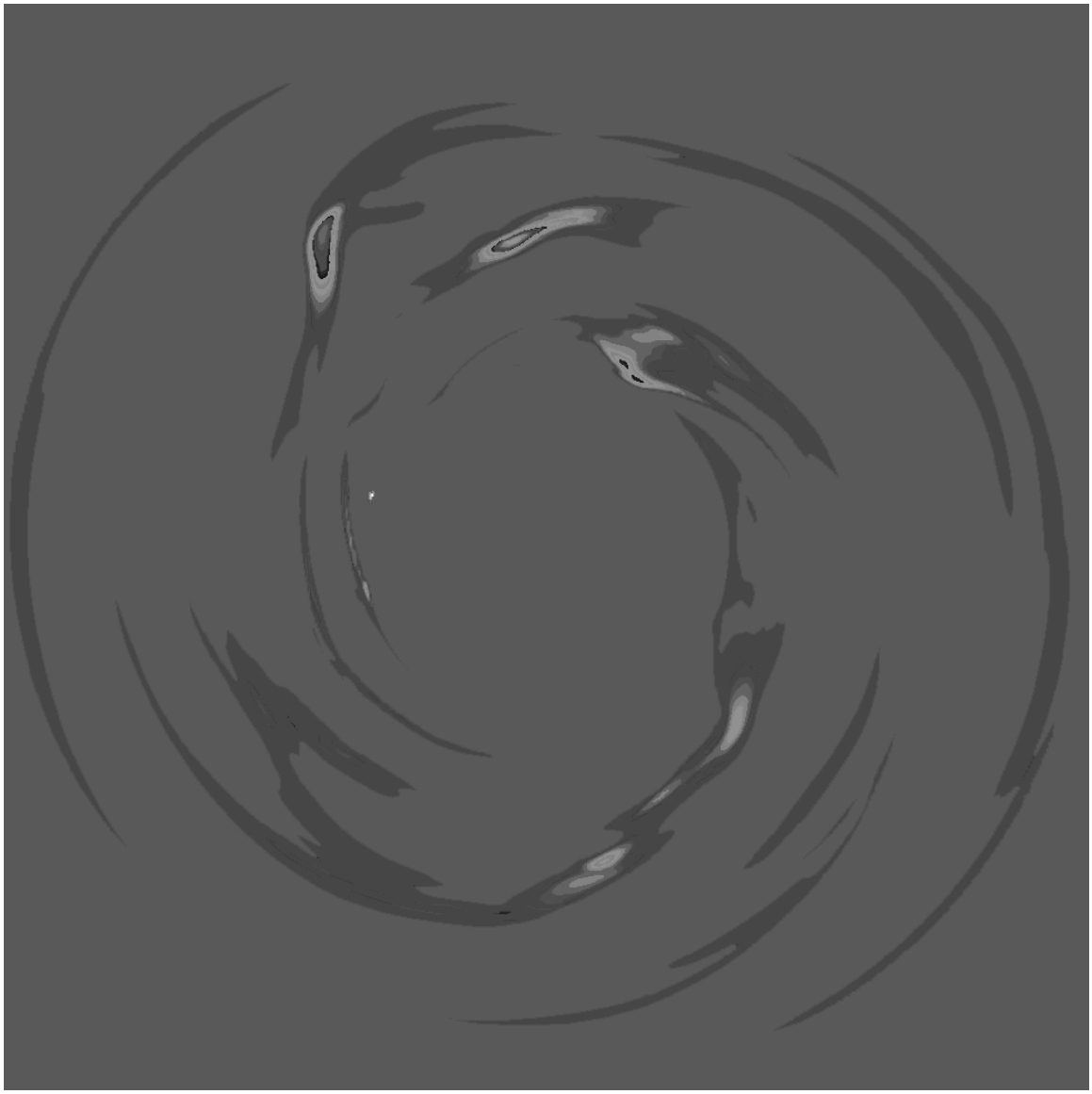

Figure Caption: Equatorial density contours for a three-dimensional radiative hydrodynamics calculation of a disk instability, possibly leading to formation of the giant planets. The region shown is 30 AU in radius, with an inner region of radius 10 AU excised. Four well-defined clumps (cross-hatched regions) have formed after 340 years.

# Abstract # 12603 - **The Diffuse Interstellar Bands as Evidence for Large Organic Molecules in the Interstellar Medium**

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Interstellar space is a very low-density medium of gas and dust, on average much less dense than the hardest laboratory vacuums. Yet stars and planets form from this material, so its composition informs us of the atomic and chemical materials available when planets form and life begins. A variety of evidence, some of it dating back more than 80 years, suggests that the interstellar medium (ISM) is populated by a family of large organic molecules which are very stable and long-lived. Evidence for this conclusion is provided by the unidentified diffuse interstellar bands (DIBs), spectral absorption features spread over the visible and near-infrared wavelength regions, which must represent a very abundant and ubiquitous component of the ISM.

Spectroscopic, chemical, and physical evidence obtained at the telescope and in the laboratory makes it virtually certain that free organic molecules or molecular ions in space are responsible for the DIBs. If so, then these species, whatever they are, probably contain most of the carbon in the universe. Further, the DIBs provide evidence that complex organic species are an important component of the material from which stars and planets form. There are many possible types or families of organic molecules that might explain the DIBs, but available evidence currently favors cyclic compounds such as polycyclic aromatic hydrocarbons (PAHs) or their ions.

In this paper, we review the properties of the DIBs and summarize the evidence that these features are formed by large organic molecules in the ISM. We include recent astronomical results as well as work being done in our laboratory program to study the chemical properties of candidate species. The astronomical data that we present include detailed analyses of the spectral profiles of specific DIBs, while our laboratory data provide insights into the chemistry and viability, under ISM conditions, of various candidate species.

This work has been supported by NASA grants NAG5-10601, NAG5-6758, and NAG5-11487 to the University of Colorado

# Abstract # 12628 - **Identification and Characterization of the Host of Interstellar Deuterium in Interplanetary Dust Particles**

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Some interplanetary dust particles (IDPs) exhibit hot-spots with unusually high D/H ratios. Messenger mapped the spatial distribution of D in an IDP, L2009D11, using Secondary Ion Mass Spectroscopy (SIMS), and we mapped the carbon using a Scanning Transmission X-ray Microscope (STXM). The maps show that D is spatially associated with carbon, and carbon X-ray Absorption Near-Edge Structure (XANES) spectroscopy of the D-rich spot identified C-ring and C=O functional groups, the latter indicating that organic carbon is spatially associated with the D. The C-XANES spectra of D-rich and D-poor IDPs are quite similar suggesting that C-ring material (e.g., hydrogenated PAHs) are not the D-carrier. We performed infrared spectroscopy on one D-rich IDP and one D-poor IDP, and found significantly more aliphatic hydrocarbon in the D-rich IDP, suggesting the D-carrier is an aliphatic hydrocarbon.

Interplanetary dust particles (IDPs), which are ~5 to 35 μm fragments from comets and asteroids, have been collected from the Earth's stratosphere by NASA aircraft since the 1970s. L2011D11 is a D-rich IDP dominated by "track-rich" crystalline silicate, and also containing Fe-sulfide and some carbonaceous material. The presence of solar flare tracks demonstrates that L2011D11 was not significantly heated during atmospheric entry, since these tracks anneal during short heating pulses to ~600° C. Messenger mapped the spatial distributions of D and H in this IDP. The bulk D in L2011D11 is +560 $^{o}/_{oo}$, significantly enriched over the Solar D/H. A spot, about 3 μm in size, shows a D-excess > 1200 $^{o}/_{oo}$.

Keller has developed a technique to embed the SIMS gold mounts in elemental sulfur and prepare ultramicrotome sections for examination by TEM and STXM. We mapped the

carbon spatial distribution in an ultramicrotome section of L2011D11 that showed the 3 μm D hot-spot by comparing transmission images at ~282 eV, an energy where carbon absorbs very weakly, and ~292 eV, just above the C K-edge where carbon absorbs very strongly. The D hot-spot was identified as a carbon-rich region. We then performed carbon XANES spectroscopy on the D hot-spot. The C-XANES spectrum showed two strong pre-edge absorptions: one near 285 eV, characteristic of the C-ring structure, and one near 288.5 eV, characteristic of carbonyl (C=O), as shown in Figure 1. This result demonstrates that organic carbon is spatially associated with the D hot-spot, strongly indicating that the D-carrier is organic. However, we obtained a very similar C-XANES spectrum of the carbonaceous material in a D-poor IDP, L2005*A3, also dominated by crystalline silicate with minor a amount of Fe-sulfide. L2005*A3 has a bulk D of -420 $^{o}/_{oo}$. This suggests that the D carrier is not the material responsible for the C-ring absorption feature detected in both IDPs. L2005*A3 has a magnetite rim and the crystalline silicates exhibit no solar flare tracks, both indicating this IDP was more severely heated on atmospheric entry than L2011D11. L2005*A3 has a large $^{15}N$ excess. The similarity of the C-XANES spectra of these two IDPs indicates that the C-ring and carbonyl are not sensitive to pulse heating to temperatures in excess of 600$^{o}$ C. Further, it appears that the $^{15}N$-carrier is not lost during pulse heating to 600$^{o}$ C.

While the STXM has ~50 nm spatial resolution, both diffraction effects and sample thickness dictate that we cannot obtain good infrared spectra on ultramicrotome sections unless the whole area of the section is analyzed. We obtained infrared spectra of both IDPs and found that, when normalized to the silicate absorption feature at ~10 μm, the aliphatic C-H stretching absorptions (near 3.4 μm) are almost undetectable in the D-poor IDP and at least 5 times as intense in the D-rich IDP (see Figure 2). This result suggests that an aliphatic hydrocarbon is the carrier of the anomalous D, and may indicate that much of the aliphatic hydrocarbon in IDPs is lost or altered during heating severe enough to produce magnetite rims and anneal solar flare tracks. However, we note that although the D hot-spots show large D-excesses, the total amount of D in the particle is small compared to the total H content, thus the carrier of the bulk of the H need not be the same phase that carries the anomalous D.

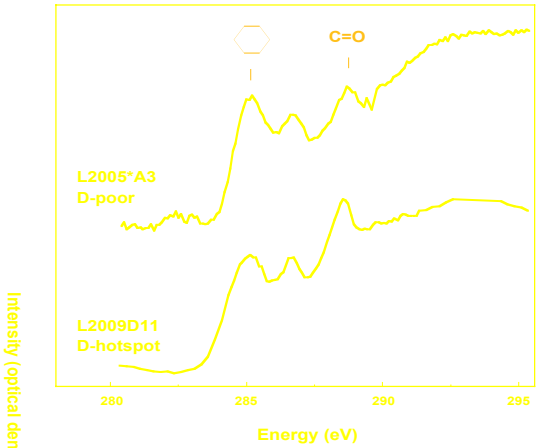


Figure 1: C-XANES spectra of L2011D11 and L2005*A3.

Figure 2: FTIR spectra, normalized to equal 10 μm silicate absorptions, of L2011D11 (bottom) and L2005*A3 (top).

# Abstract # 12739 - **Nearby Young Stars, Proto-Planetary Disks, and Planets**

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Nearby young stars are excellent targets for direct imaging detection of cooling planets because young giant planets are hot in youth; hence they are bright at near infrared wavelengths. Likewise, the dusty disks from which planets form are usually much more prominent around youthful stars. We are involved in a long term project to find the youngest and closest stars to Earth by using X-ray (ROSAT) and astrometric (Hipparcos, Tycho, Supercosmos) catalogs. Once identified, these stars will soon be targeted for warm planets and dusty disks (by our group and others) with ground- and space-based telescopes. On a longer time scale, as appropriate sensitive new systems are developed during the coming decades, we anticipate that these stars will be revisited over and over again by astronomers studying the evolution of forming planetary systems.

From the above catalogs, we generated a list of nearby young star candidates of order 1000. We have observed most of the good targets from the list with the 2.3 m telescope at Siding Spring Observatory in Australia and with the 3 m telescope at Lick Observatory in the USA. To date, we have identified about 150 stars that, indeed, are close to Earth and very young. Our techniques are described in Zuckerman et al. (Astrophys. J. 562, L87, 2001). In particular, we found the closest young association known to date, the beta Pictoris moving group. These ~12 million year old stars share the same motion through our Milky Way galaxy as beta Pictoris, the famous nearby star with a very prominent protoplanetary disk.

Our research has identified co-moving groups of nearby stars with ages in the range from about 8 to about 50 million years. This is the time interval during which planetary scientists believe that the planets of our own Solar System were forming. Thus, by studying the environs of nearby young stars, astronomers will gain a new technique that can shed light on our own origins many billions of years ago.

We currently are collaborating with other astronomers in searches for planetary companions and investigations of dusty disks around the newly identified, young, nearby stars. The planetary searches are with ground-based adaptive optics cameras at Lick and Keck observatories (B. Macintosh et al., in preparation). Dusty disks can be investigated with SIRTF (collaborators include Drs. M. Werner and M. Jura) and with the SCUBA submillimeter array bolometer on the JCMT telescope at Mauna Kea (collaborators include Drs. W. Holland and J. Greaves). In papers on three stars that are somewhat older than the stars we are identifying in our main program, we show (with SCUBA) that Fomalhaut, Epsilon Eridani, and Vega are all likely orbited by substantial planets having large semi-major axes (e.g., Holland et al., 2002, Astrophys. J., in press). The gravity of the planet shapes the orbiting dusty disks. In follow-up observations of these dusty systems (using adaptive optics), we have put upper limits of about five Jupiter masses on any planets in wide orbits that might be present (Macintosh et al., 2002, submitted to Astrophys. J.).

This research was supported in part by the UCLA Astrobiology Institute and by a NASA grant to UCLA.

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# Abstract # 12751 *(Oral Presentation)* - **Astro-Venture: Engaging Students in Grades 5-8 in the Search for Habitable Planets**

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Astro-Venture http://astroventure.arc.nasa.gov is an educational, interactive, multimedia web environment that engages students in grades 5-8 in the astrobiology themes of: "Exploring for Habitable Planets Beyond the Solar System" and "Exploring for Life in the Solar System." This product seeks to foster the development of the next generation of astrobiologists by providing an age-appropriate opportunity for students to role-play NASA occupations, as they search for and design a planet that would be habitable to humans. Astro-Venture is designed to include modules in the areas of astronomy, geology, atmosphere, and biology with a culminating assessment module in which students apply knowledge from all areas to design a planet.

For each core science area, students engage in an online training module in which they isolate variables associated with that area and observe the affects on Earth. They then draw conclusions about which characteristics allow Earth to remain habitable. Following this experience, students engage in several classroom, hands-on activities that teach them core standards-based concepts, which help them to understand why the identified characteristics are vital to human habitability. These concepts include states of matter, flow of energy, chemical properties, planetary geology, plate tectonics, human health, and systems theory. With an understanding of the "whats" and the "whys," students then engage in a mission module for that core science area in which they simulate the methods scientists would use to go about finding a planet with these characteristics. This helps them to understand the "hows." It is important to note that students are given a very simplified version of these methods in which they are evaluated on the standards-based skills of comparing data and drawing conclusions. By meeting education standards, teachers can easily integrate this product into their classroom curriculum.

The Astronomy section of Astro-Venture serves as a model for how each section will be developed. In this section, students focus on the conditions required for liquid water, as a requirement for life. In order to understand these conditions, students first engage in standards-based lessons that teach the different states of matter and factors that change states of matter. This knowledge helps them to understand the conditions necessary for water to be a liquid on Earth's surface and how star type, orbital distance, and atmosphere all work together to determine these conditions. The geology, atmosphere, and biology sections will explore similar requirements for human survival. This theme is an important one in helping students to understand the Earth as a system, which was identified as a need and recommendation in the recent report from the 2001 National Conference on the Revolution in Earth and Space Science Education. This document states, "Students should not experience Earth and space science as a series of topics, but rather as a whole system — the interconnected geosphere, hydrosphere, atmosphere, and biosphere." [1] Astro-Venture is designed to use core astrobiology ideas to provide a context and motivation for understanding Earth and space-related core concepts required in the national education standards.

Astro-Venture best supports the theme of "Exploring Habitable Planets Beyond the Solar System" by engaging students in simulations of some of the search techniques used by astrobiologists including: spectroscopy, Doppler's Shift, photometry, and Kepler's Third Law, which are all simulated in the Astronomy section. The theme of "Exploring for Life in the Solar System" will be a focus of the atmosphere, geology, and biology mission modules in which students will be analyzing moons and planets in our atmosphere to determine their suitability for human life and to draw conclusions about which planets and moons offer the most likely locations for finding other life forms.

Throughout all of the modules and activities, students are engaged in the inquiry process and instructional strategies identified by Project 2061[2] as most effective in science teaching. The lessons use the five "E" approach (Engage, Explore, Explain, Extend, and Evaluate) and models questioning strategies for teachers so that they can guide higher order thinking and help students to form their own learning, instead of lecturing to them. The product also exposes students to a variety of related careers through career fact sheets and trading cards.

Astro-Venture uses the fascinating topic of astrobiology and the search for habitable planets to engage students in an overall scenario that provides the overall purpose, motivation, context and goal for all of the online and off-line instructional activities. In this way, Astro-Venture demonstrates one successful method of teaching core science curriculum concepts while integrating the NASA Astrobiology Institute's research.

[1] Barstow, D. & Geary, E. (2001). Blueprint for Change: Report from the National Conference on the Revolution in Earth and Space Science Education. Cambridge, MA: Terc. (p.13).
[2] American Association for the Advancement of Science Project 2061. (2001). Middle Grades Science Textbooks Evaluation. Washington D.C. [Online] http://www.project2061.org/newsinfo/research/textbook/mgsci/criteria.htm

# Abstract # 12759 - **Laboratory Measurement of the Temperature-Dependent Optical Constants of Water Ice in the Far-Infrared**

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The real and imaginary refractive indices of water ice in the far-infrared are used in the satellite retrieval of cloud properties, as well as to obtain remote sensing information about: 1) planetary surface ices throughout the solar system, 2) ice-coated interstellar dust particles, and 3) perhaps in the future, extrasolar planetary surfaces and atmospheres. However, few measurements of these values exist.

We have measured the real and imaginary refractive indices of water ice in the far-infrared every 10 degrees over the temperature range of 110-180 K. Ice films ranging from 0 to 150 μm thick were grown by the condensation of water vapor onto a cold silicon substrate, and the film transmission was measured in the far-infrared from 650-50 $cm^{-1}$. The thickness of the ice films measured was determined using optical interference from a reflected HeNe laser ($\lambda = 632.8$ nm). The optical constants were then determined by simultaneously fitting the calculated spectra of films of varying thickness to their respective measured transmission spectra with an iterative Kramers-Kronig technique. The results were compared with previously measured data and show large discrepancies at some wavelengths, while good agreement exists at others.

# Abstract # 12810 *(Oral Presentation)* - **Photometric Signatures of Earth-like Extrasolar Planets**

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For the first time in human history the possibility of detecting and studying Earth-like planets is on the horizon. Terrestrial Planet Finder (TPF), with a launch date of 2014, is being planned by NASA to find and characterize planets in the habitable zones of nearby stars. The mission Darwin from ESA has similar goals. The motivation for both of these space missions is the spectroscopic characterization of extrasolar terrestrial planet atmospheres. Of special interest are atmospheric biomarkers — such as $O_2$, $O_3$, $H_2O$, CO and $CH_4$ — which are either indicative of life as we know it, essential to life, or can provide clues to a planet's habitability. A mission capable of measuring these spectral features would also obtain sufficient signal-to-noise to characterize other terrestrial planet properties. For example, physical characteristics such as temperature and planetary radius can be constrained from low-resolution spectra. Moreover, planet characteristics such as weather and rotation rate could be derived from photometric measurements of the planet's photometric variability. Depending on fractional cloud cover, information about the presence of large oceans or surface ice and the existence of seasons may also be derived from photometric data. I will discuss the potential to characterize terrestrial planets by their photometric variability. I will also discuss the possibility to detect strong surface biomarkers — such as Earth's vegetation red edge near 700 nm — that are different from any known atomic or molecular signature.

# Abstract # 12826 - **Predicting New Planets in Known Extra-Solar Planetary Systems**

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Simulations of planetary system dynamics have shown that interacting systems are as tightly packed as possible. In this poster we explore the possibility that separated systems (specifically HD37124, HD74156, HD168443, HD12661, and 55Cnc) may contain additional companions, and hence are also interacting systems. First we fill the region between well separated planets with test particles and integrate for $10^7$ years. We find that the systems HD168443, and HD12661 can hold no more planets. The other systems, however, contain broad zones of stability. Next we test the feasibility of forming terrestrial planets by simulating the late stage of planetary accretion. Planetary embryos are placed on orbits between the giant planets in these systems and allowed to collide. These simulations typically produce 0-2 terrestrial planets. Finally we test the mass upper limit by placing planets up to a Saturn mass in the allowed zones and integrating for $10^9$ years. We find that several systems may support a Saturn, and suggest possible semi-major axes, and eccentricities for these possible planets.

# Abstract # 12858 - **Predicting the Biogenic Methane Concentration in the Archean Atmosphere Using Numerical Modeling**

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Determining the $CH_4$ concentration in the Archean atmosphere (~3.8-2.5 Ga) is important for understanding early Earth's climate and atmospheric composition and could ultimately provide useful information for the search for Earth-like extrasolar planets. Previous studies have attempted to predict Archean $CH_4$ concentrations based on thermodynamic considerations (Kral et al., 1998; Kasting et al., 2001). Here, we take a kinetic approach instead. We are developing a coupled ecological-photochemical model to estimate the level of biogenic $CH_4$ in the Archean as determined by environmental constraints such as nutrient availability.

Our ecological model is partly based on current knowledge of the nutrient dependence of microbial growth in the modern ocean (Tyrrell, 1999). Initially it will simulate a simple ecosystem consisting of $CO_2$/CO-reducing methanogens, acetogenic (acetate-producing) bacteria, and acetoclastic (acetate-consuming) methanogens. The photochemical model we are using is adapted from similar ones used in previous studies of the anoxic Archean atmosphere (Pavlov et al., 2001). Initial analytical calculations with the ecological model showed that CO (hydrated to formate, $HCOO^-$) would have been a more abundant substrate for methanogens than would $H_2$ and $CO_2$. Thus, we have refined the photochemical model to more carefully assess the abiotic production and deposition rates of CO. Analytical calculations also showed that methanogens alone are not likely to have accounted for most of the primary productivity in the Archean ocean, as CO and $H_2$ were both much less available than phosphate. Hence, it is likely that additional primary producers will need to be included to simulate a realistic Archean ecosystem.

Preliminary numerical calculations indicate that the rate of CO deposition into the Archean ocean was dependent on the rate of photooxidation of atmospheric $CH_4$. This suggests that the rate of $CH_4$ photolysis might have provided an upper limit on the productivity of methanogens on the early Earth. Once our coupled ecological-photochemical model is completed, we will further examine whether the biotic $CH_4$

production rate and the abiotic CO deposition rate were indeed interdependent. The coupled model should ultimately allow us to determine whether the level of biogenic $CH_4$ in the Archean atmosphere was regulated more by thermodynamics or by ecological factors.

Fundamentally, our project deals with the influence of life on atmospheric composition. Thus it is also relevant to NASA's planned Terrestrial Planet Finder (TPF) mission, which will attempt to spectroscopically detect biogenic gases in the atmospheres of Earth-like extrasolar planets. Interpretation of the results from that ambitious endeavor will ultimately be based on comparison with known and hypothetical absorption spectra of biogenic gases in Earth's modern and primitive atmospheres. Results from our study can be used to generate hypothetical absorption spectra for the anoxic Archean atmosphere and thus could help determine whether early Earth-like planets could indeed be detected by TPF.

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# Abstract # 12859 - **Was Earth Ever Infected by Martian Biota? Clues from Radioresistant Bacteria**

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High radiation tolerance is hardly necessary for the survival in any natural environment on Earth. Nevertheless, a number of microorganisms (radioresistant bacteria) possess this peculiar ability (*Deinococus radiodurance, Rubrobacter radiotolerance*, *Rubrobacter xylanophilus* ). The radiation background on Earth from any natural sources is many orders of magnitude lower than the lethal dose for these microorganisms. We show that radioresistance can be "trained" in the Martian conditions. We propose that Earth has been infected several times by the Martian biota.

In our experiments, we find that "ordinary" bacteria (*Escherichia coli* and two species of *Bacillus*) can develop radioresistance ability after the multiple cycles of exposure to the high (almost lethal) radiation dosages, followed by recovery of the bacterial population.

We show that natural cycles of this kind could take place only on Mars. Our hypothesis is based on the well-accepted astronomical theory of Martian climate oscillation and our calculations of the radiation levels in the surface layer of the planet. Martian biota would accumulate large radiation dosage during the periods of cold climate, when it would be in the dormant state and would rebuild its population during the periods of warm climate. We demonstrate that hypothetical Martian microorganisms could develop radioresistance in several millions years.

Martian biota could have been transported on Earth several times by meteorites, what in turns would explain the existence of several different types of the radioresistant bacteria in the Earth's biosphere.

We propose that the Martian polar regions (top tens of cm to several meters under the surface) are the most promising place for the Martian life detection by space missions.

# Abstract # 12898 - **On the Enhancement of the Growth-Rate of Planetesimals in the Terrestrial Region of a Non-Uniform Solar Nebula**

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It is widely accepted that planet formation starts by collision and coalescence of small solids in a circumstellar disk. Recent numerical simulations by Inaba and Wetherill indicate that such a planet forming disk is most likely gravitationally unstable. Such instabilities result in formation of non-uniformities where the pressure of the gas may be maximized. In a recent paper, Haghighipour and Boss have shown that when the nebula consists of an ideal and isothermal gas, where the locations of the maximum pressure correspond to local maxima of the gas density, the combination of gas drag and the gravitational force of the nebula, along with the pressure gradients, will cause small objects to migrate in/out toward the location of a local maximum density. Such migrations are of fundamental importance since they have immediate implications on the collision and coagulation of small solids and can enhance the rate of the growth of planetesimals. Haghighipour and Boss have been able to show that for particles ranging from 1 cm to several meters in size, and with densities between 1 to 5 g/cc, the radial migration is quite rapid. Their calculations indicate that such particles can migrate a distance of 1 AU in a few hundred years or less.

In their model, Haghighipour and Boss restricted the motions of small solids to the mid-plane of the nebula and considered a two dimensional density function. In this paper, I present the result of an extension of our previous study to three dimensional motions where a particle can also undergo vertical migrations. The model nebula studied here consists of a turbulence-free and isothermal gaseous disk of pure molecular hydrogen. The scale height of this nebula at any point is equal to one-tenth of the radial distance of that point. In such a nebula, the vertical component of the pressure gradients will balance out the vertical components of the gravitational attraction of the central star. This will impose certain restrictions on the z-dependence of the density of the nebula and causes it to maximize on the mid-plane where z=0. The radial dependence of the gas density is taken to be azimuthally symmetric and with a local maximum at 1 AU. The results of numerical simulations of the motions of particles in such a nebula indicate that they undergo rapid migrations toward the mid-plane of the nebula and at the same time, they migrate in/out toward the location of the maximum density on the mid-plane. Figure 1 shows the inward migration of a 1 m object with a density of 2 g/cc, from 2 AU to the location of the maximum density at 1 AU, in a gaseous disk with a temperature of 300 K. As shown here, vertical migration is much more rapid than the radial migration indicating that particles spend most of their times on the mid-plane migrating toward the location of the maximum density. In this paper, I present the results of a detailed study of such a system and discuss the dependence of the time of migration to the size and the density of

the objects and also to the physical properties of the nebula. I will also discuss the implication of the results to the collision of planetesimals and also to the enhancement of their growth-rate.

**Figure 1.** Three dimensional migration of a solid at radial distance of 2AU from the Sun and vertical distance of 0.2 AU above the mid-plane (black). The bottom figure shows the radial migration of this object on the mid-plane of the nebula. As shown here, vertical migration occurs more rapidly.

S. Inaba and G. W. Wetherill, 2002, to appear in the proceedings of the *Frontiers in Scientific Research on Extrasolar Planets*, Eds, D. Deming and S. Seager

N.Haghighipour and A. P. Boss, to appear in the February 2003 issue of ApJ.

# Abstract # 12907 - **On Stable Resonant Periodic Orbits as Possible Locations of Extrasolar Terrestrial Planets**

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Recent success of the radial velocity technique in detecting more than 100 extrasolar planetary systems has created rich grounds for the extension of the theories of the formation and the dynamical evolution of planetary systems to a broader context several parsecs beyond the boundaries of our solar system. Such an extension allows planetary scientists to explore the possibility of the existence of habitable planets among extrasolar planetary systems. As we expect in analogy to our solar system, such habitable planets are to be Earth-sized. It is therefore of great importance to explore whether such Earth-sized planets can exist on orbits in the habitable zones of their central stars and also whether their orbits will be stable for long enough duration of time to allow the development of life. In multi-body planetary systems, such orbits correspond to mean-motion resonances. When the geometrical configurations of such orbits are periodically repeated, they are known as "Resonant Periodic Orbits."

Resonant periodic orbits are quite common in our solar system. For instance, Jupiter and Saturn rotate around the Sun on orbits that correspond to a (5:2) resonance. With discovery of extrasolar planets, resonant periodic orbits are no longer exclusive to our solar system. There are now 11 extrasolar planetary systems that contain more than one planet and among them, three are believed to be in or near resonances; the planetary system of 47 UMa is in a near (5:2) resonance, GJ 876 is in a (2:1) resonance, and the system of 55 Cnc shows a (3:1) commensurability between its two innermost planets. These all indicate that it is of great value to study the

possibility of existence and also the stability of resonant periodic orbits for different resonances. In this paper, we present the result of our extensive numerical study of the existence and the stability of different resonant periodic orbits and present a methodology for searching the parameter-space of multi-body systems for regions where resonant periodic orbits can be stable. Figure 1 shows such locations for an external (2:1) resonance where an Earth-sized planet is in resonance with a body as massive as Jupiter. The application of our results to the extrasolar planetary system of GJ 876, as a multi-body system in a (2:1) resonance, is also discussed.

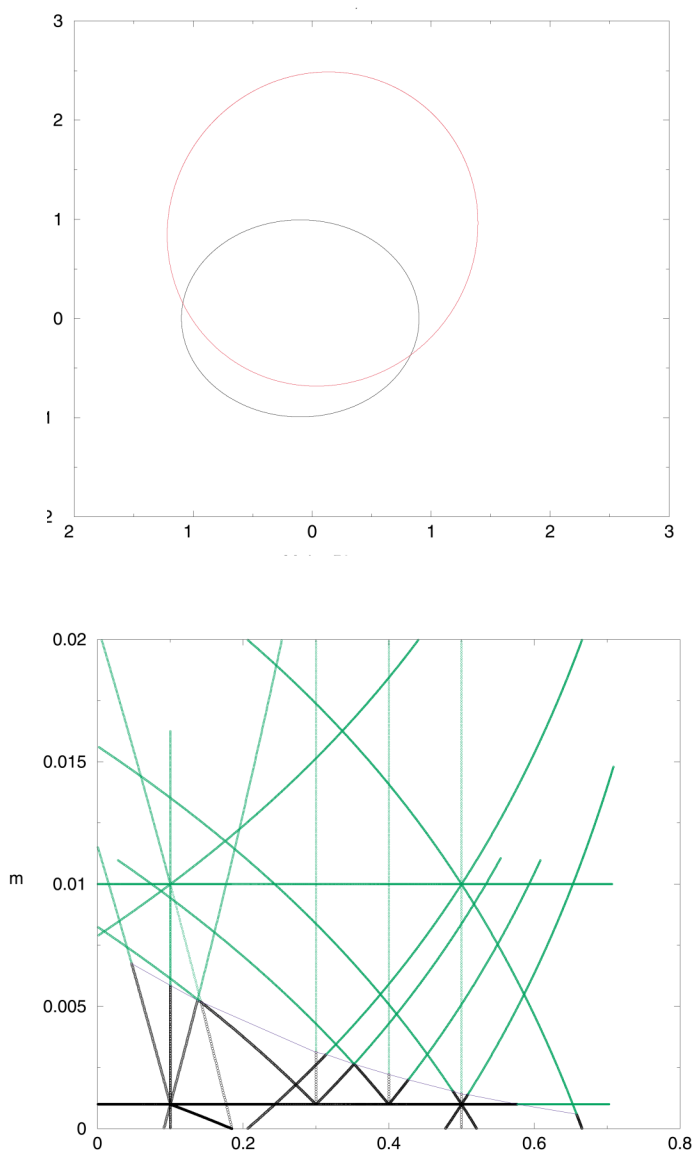


**Figure 1.** A (2:1) resonant periodic orbit (top). The Earth-sized planet is in red, and the inner massive planet is in black. The figure at the bottom shows the regions of stability (black) and instability (green) for the three-body system of the top figure. m and e represent the mass and the orbital eccentricity of the inner massive planet.

# Abstract # 12931 - Self-Shielding of CO and the Oxygen Isotope Anomaly in Meteorites: Unique Clues to Conditions in the Very Young Solar System

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The enrichment of $^{16}O$ in some of the most refractory phases in meteorites, discovered by Clayton et al. (1973) thirty years ago, still defies explanation. What is clear is that the $^{16}O$ enrichment is telling us something about conditions that prevailed in the very young solar nebula. Whether these conditions are relevant to the subsequent development of life on Earth is unknown, but they are almost certain to be central to our understanding of other young planetary systems.

In this presentation I will focus on photochemical processing of CO as a possible source of the oxygen isotope anomaly observed in meteorites. In an $H_2$-rich environment such as a molecular cloud or the solar nebula, photodissociation of CO takes place between 900 – 1100 Å and has a discrete absorption spectrum. Because the spectrum is discrete, absorption lines of the much more abundant $C^{16}O$ become saturated while the corresponding (and shifted) lines of $C^{17}O$ and $C^{18}O$ remain optically thin. When $C^{16}O$ lines are saturated, photodissociation of CO yields an enrichment of $^{17}O$ and $^{18}O$ atoms with respect to $^{16}O$ atoms. This process, termed 'self-shielding', has been observed in cold molecular clouds (e.g., van Dishoeck and Black 1988) and was recently proposed to have occurred in the hot inner solar nebula (Clayton 2002). Yurimoto and Kuramoto (2002) proposed as an alternative that the oxygen isotope anomaly in refractory meteorite phases has its origin in self-shielding of CO in the parent molecular cloud from which the solar nebula formed.

Whether self-shielding of CO occurred in the solar nebula or in the parent cloud, the implications for the solar system are profound. As discussed by Clayton (2002), if nebular self-shielding produced the oxygen isotope anomaly in meteorites, then nearly the entire inner solar system had to have been photochemically processed in the innermost solar nebula, and the sun must have oxygen isotope values very similar to the isotopically lightest meteorite phases. If the oxygen isotope anomaly was inherited from the parent molecular cloud, then the refractory meteorite phases represent original components of the parent cloud, and again the sun would have oxygen isotopes similar to the isotopically lightest phases. The top priority of NASA's Genesis mission is to measure the 3 isotopes of oxygen in the solar wind, which should provide a test of the importance of self-shielding.

My purpose here is to perform a timescale analysis of the chemistry and dynamics implied by the nebular and molecular cloud CO self-shielding mechanisms as a first step toward assessing their plausibility in explaining the oxygen isotope anomalies. The nebular self-shielding scenario of Clayton (2002) requires that CO self-shielding occur at very high temperatures (e.g., ~ 1500 K). Because a great many additional absorption bands become important at high temperatures, band overlap and individual line tail overlap may act to eliminate the self-shielding mechanism (e.g., Navon and Wasserburg, 1985). An evaluation of self-shielding at high temperatures is in progress, but is beyond the scope of the present work; for now I will simply assume that CO self-shielding does occur at conditions relevant to the inner (~ 0.1 AU) solar nebula. Photodissociation timescales are very short due to the enhanced (~ 1000-fold) EUV (extreme ultraviolet) flux present in TTS's (T Tauri stars), and because of the close proximity to the sun. Denoting 'Q' as $^{17}O$ or $^{18}O$, photodissociation of CQ yields Q atoms, which very rapidly react with $H_2$ to produce QH and then $H_2Q$. Thus, nebular $H_2O$ becomes enriched in heavy isotopes while CO becomes depleted. A series of reactions act to isotopically re-equilibrate CO and $H_2O$; at 1 mbar and 1500 K the timescale for equilibration is ~ 1 day. However, photodissociation operates on a timescale of ~ 1 hour, and so can maintain the isotope anomaly between CO and $H_2O$. To form refractory silicates and oxides, reactions between either CO or $H_2O$ and the rock-forming elements must be invoked. One possible reaction (brought to my attention by R. Marcus, pers. comm., 2002) is $SiO + H_2O \rightarrow Si(OH)_2$. Although the rate constants have not been measured for this reaction, the timescale for reaction may be estimated from kinetic theory to be ~ minutes for inner solar system conditions. Similarly, direct O atom exchange between SiO and $H_2O$ may occur, and would likely be even faster. Reactions such as these suggest that the oxygen isotope anomaly in $H_2O$ is readily transferred to SiO, and presumably to silicates. The timescales for formation of silicates will not be considered here, but should depend on X-wind (or some other entrainment) velocity and other disk properties.

In addition to self-shielding in the inner solar nebula, self-shielding of CO will almost certainly occur at the 'surface' of the disk. Temperatures and pressures here are much lower (~100 K at distances ~ 1 AU and greater), so that the analogy to a molecular cloud, where self-shielding is known to occur, is much better than for the inner solar nebula. The extent of CO self-shielding produced at the surface will depend strongly on EUV absorption by dust. Although re-equilibration of CO and $H_2O$ is likely in a warm disk midplane (at distances ~ 1 AU and less), self-shielding at the disk surface should at least create Q atom enrichment in the region of the nebula where small refractory particles are thought to reenter the disk after transport from the inner solar system by an X-wind.

It is very likely that the oxygen isotope anomaly in meteorites offers us a record of a particularly energetic period of time in the history of the solar system, and it may record events that occurred in very close proximity to the young sun, as well as distal processes such as particle entrainment in an X-wind. Such processes are undoubtedly of importance in understanding planet formation.

# Abstract # 12933 - **Search for Evidence of Planetary Engulfment**

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Using the High Resolution Spectrograph on the Hobby-Eberly Telescope, we have taken high-resolution, high signal-to-noise observations of several planet-bearing stars to search for evidence of anomalous abundances of the rare $^{6}$Li isotope. Stellar theory predicts that the lighter isotope of lithium would be completely destroyed in young solar-type stars. Concrete detection of $^{6}$Li in planet-bearing stars (compared with a lack of $^{6}$Li in comparison stars without planets) would present strong evidence for the engulfment of planets by their parent stars, and it would place valuable constraints on planet formation theories.

Several studies have published conflicting results in the search for $^{6}$Li in stars with planets. The major discrepancy comes in the lack of an accurate line list for the lithium region. We have observed several lithium-weak stars (as well as lithium-rich stars), in order to isolate contaminating blends in the region in both planet-bearing stars and comparison stars.

We have also reanalyzed the molecular contribution from the CN molecule, as well as additional atomic lines in the region. Fits to both lithium-weak stars and lithium-rich stars are more fully constrained than in earlier work. There is evidence for asymmetries in the lithium line, but further analysis is necessary.

# Abstract # 12938 *(Oral Presentation)* - **Astrobiology with a Telescope and a Stopwatch**

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For those following the water, Europa provides a tempting target: approximately 100 km of water surrounding a rock and metal body somewhat smaller than Earth's Moon. While the water is important, attention has turned to the more critical problem for life beneath several kilometers of ice: energy. Europa's surface is bathed in energy. So much so that the upper meter or more is completely sterile. The products of radiation chemistry include oxidated species which might survive burial and transport through the ice, if a mechanism for such transport exists. Another energy source may exist at the bottom of Europa's ocean in the form of volcanic activity in the silicate mantle. Hydrothermal circulation is able to transport both thermal and chemical energy from its source in molten rock to the ocean, perhaps powering a biosphere. Both of these energy sources have caused the concept of a "habitable zone" to be modified and expanded.

Since there are several large, icy satellites of the giant planets in the Solar system, it is likely that at least some of the extrasolar planets already discovered have similar satellites and that some of these satellites are in resonances such as that coupling the orbits of Io, Europa, and Ganymede. This resonance is responsible for the powerful tidal heating of Io, making it the most volcanically active body known. It is possible that Europa, too, is tidally heated, driving volcanic activity beneath the ocean. Indeed, without tidal heating, Europa is most likely geologically (and biologically) dead, just like Earth's Moon.

It is possible to place constraints on the amount of tidal heating within Europa by observing the evolution of its orbit, because the energy dissipated within the satellite comes, in part, from the orbital energy of the satellite. The orbital evolution of the satellites can be measured telescopically, by timing eclipses of the satellites with each other (mutual events), with background stars (occultations), or with Jupiter (uncertainty in atmospheric dynamics makes this type of event less useful). Much more accurate estimates could be made by tracking an orbiter or lander.

In order to connect the observations of the satellites made with a telescope and a stopwatch to inferences about the state of Europa's (or some other satellite's) interior, an accurate and physically based theory for the dynamics of dissipating satellites is necessary. The development of this theory requires several intermediate steps, including the development of a coupled orbital-rotational dynamics model, a thermal evolution model, and a model of deformation under tidal potentials. These models are currently being coupled together to create a unified model capable of linking astrometry with astrobiology.

# Abstract # 12951 - **Biosignatures in Visible and Infrared Planetary Spectra**

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The Terrestrial Planet Finder (TPF) is expected to complete a census of extra solar planets down to one Earth mass for stars within 50 light years of Earth. The instrument must null light from the parent star by a factor of >100,000 to permit analysis of spectroscopic signatures of planetary atmospheres for biosignatures indicative of extant life. Currently two architectures are under investigation: an infrared nulling interferometer and a visible light choronograph. Each architecture provides both advantages and significant, but disparate engineering challenges. The interferometry approach requires the launch of multiple small telescopes on a fixed structure or on independent spacecraft flying in a precisely controlled formation. The visible light chronograph approach requires a single large optical telescope with a mirror three to four times larger than the Hubble Space Telescope and requiring an order of magnitude more precision.

Choice of wavelength region to be observed significantly impacts the science capability of the TPF. Both visible and infrared regions offer particular advantages including direct detection of $O_2$ and many other molecules. Observation in near- (NIR) and mid-infrared (MIR) regions can provide significant improvement in the signal to noise ratio between starlight and reflected planetary light, can penetrate cloud cover, and is sensitive to both surface and atmospheric signatures. However, the visible region of the spectrum is quite rich in atmospheric signatures indicative of thermodynamic disequilibrium. Such alterations in atmospheric thermodynamics would be considered a prime signature of biological catalytic activity.

We present data exploring the biosignatures and information content available in visible, NIR, and MIR spectra and the impact on the mission science from choosing one or more of these optical regions. In particular we explore the possibility of employing discrete broadband spectral regions to discriminate biotic and abiotic terrestrial planets. Our strategy involves the segmentation of both

synthetic and real planetary spectra into regions of interest. The information and discrimination power of a variety of band ratios are then explored using multivariate analysis techniques such as principal component analysis (PCA).

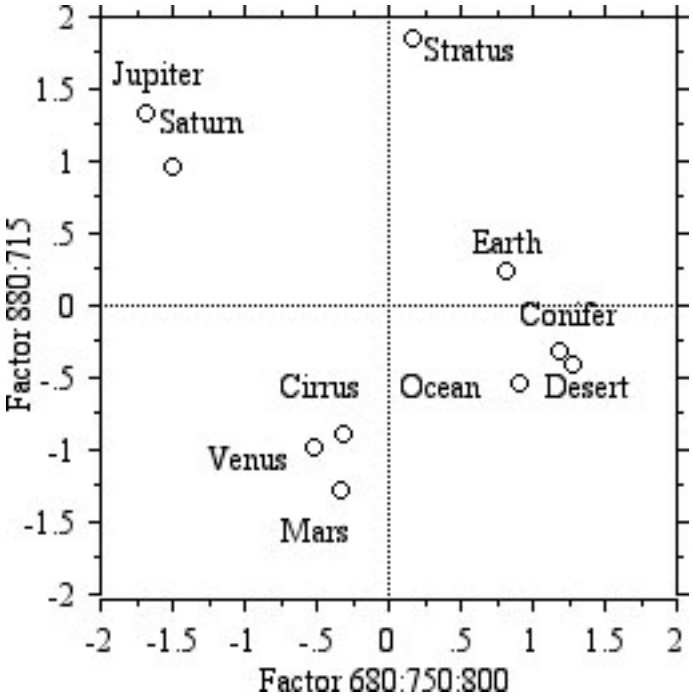


**Figure 1** presents an example of one such analysis at visible wavelengths. In this case ten synthetic spectra were generated using a radiative transfer model (Meadows and Crisp, 1996). Selected bands at 680, 715, 750, 800, and 880 micrometers were combined into weighted factors according to their ability to detect clusters of similar objects using PCA. The technique clustered spectra for Earth as it appears in desert, conifer forest, and ocean regions and distinguished this group from the spectra of the gas giants, Jupiter and Saturn, and the abiotic (apparently) terrestrial planets Mars and Venus. Cloud coverage significantly altered the discriminatory ability for the chosen bands. False negative results such as this can be handled experimentally by either altering band selection choices or collecting data at discrete intervals to detect temporal alterations in cloud cover. The detection of such a dynamic system would provide a significant piece of information concerning the potential complexity of the planetary atmosphere.

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# Abstract # 13034 - **Kepler Education and Outreach: Engaging Students and the Public in the Discovery of Other Worlds**

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The *Kepler Mission* Education and Public Outreach (EPO) program capitalizes on the excitement of discovering Earth-size planets in the habitable zone, stimulating student learning and public interest in astronomy and physics. *Kepler* is a NASA Discovery Mission, selected in December 2001, with launch and the search for extra-solar Earths commencing in 2007. The EPO program started in October 2002, and this poster presents our goals and plans. The EPO program is scoped to build public interest during development, and to engage students as well as the public throughout the initial four-year on-orbit mission, and beyond if an extended mission is conducted.

Are we alone? Are there other worlds like our own? Astronomers are discovering Saturn-size planets, but can smaller planets—new Earths—be found? These are powerful and exciting questions that motivate student learning and public interest in the *Kepler* search for planets. Recent discoveries of extrasolar planets have already sparked broad public interest. During the first year, *Kepler* rapidly detects large planets similar to 51 Peg and smaller Earth-size planets in Mercury-like orbits. By the fourth year, we discover Earth-size planets in habitable zones! The *Kepler* EPO goals are to increase public awareness and understanding of the *Kepler Mission* by embodying key principles set forth in NASA's *Partners in Education* and *Implementing the OSS Education/ Public Outreach Strategy*: involve scientists and contractors in EPO efforts; establish collaborations with planetariums and science museums; build on existing programs and networks that maximize the leverage of NASA EPO funding in this project. The Kepler EPO plan is designed to take advantage of existing collaborations, networks, experience and relationships, to optimize the impact of EPO.

The Kepler EPO team is led by Alan Gould of the Lawrence Hall of Science and Edna DeVore of the SETI Institute; they are working in partnership with Deputy PI, Dr. David Koch of NASA Ames Research Center to take advantage of the skills and experiences of both organizations in developing EPO products and services. *Kepler's* EPO program has ambitious goals for formal and informal education and public outreach. Products and activities are planned to encompass these domains of outreach, and are illustrated in *Figure 1, Kepler's EPO Activities*.

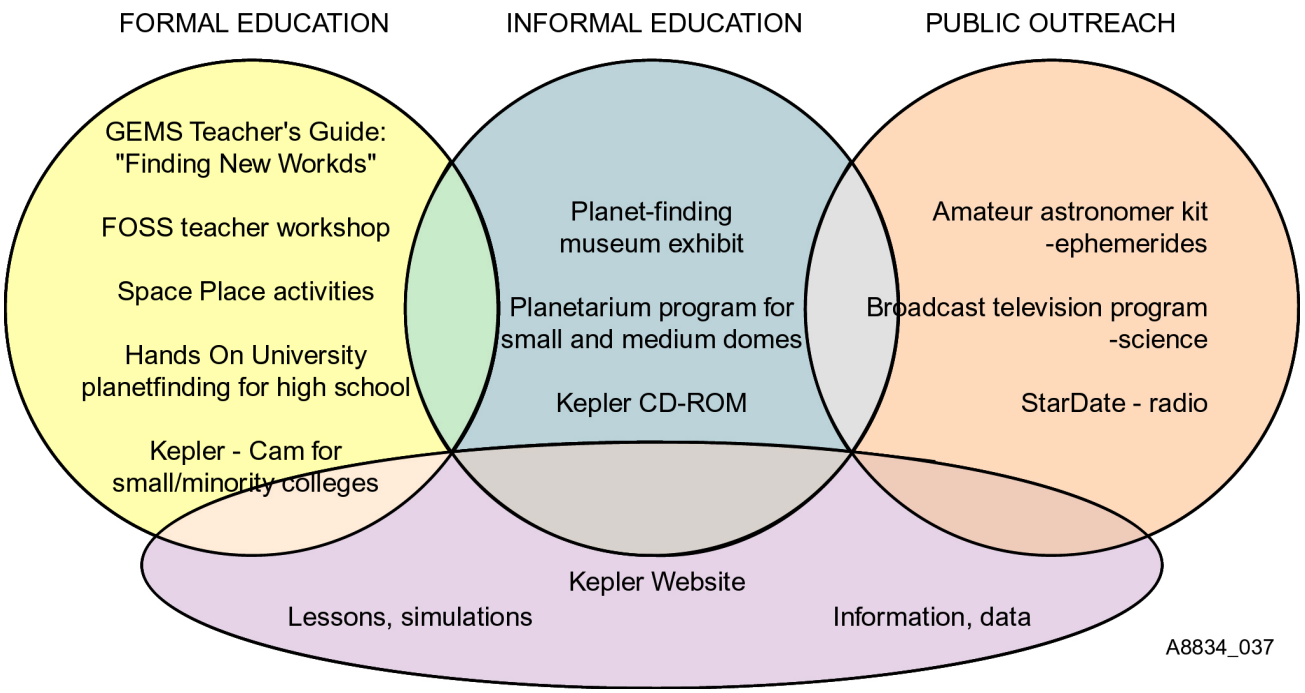
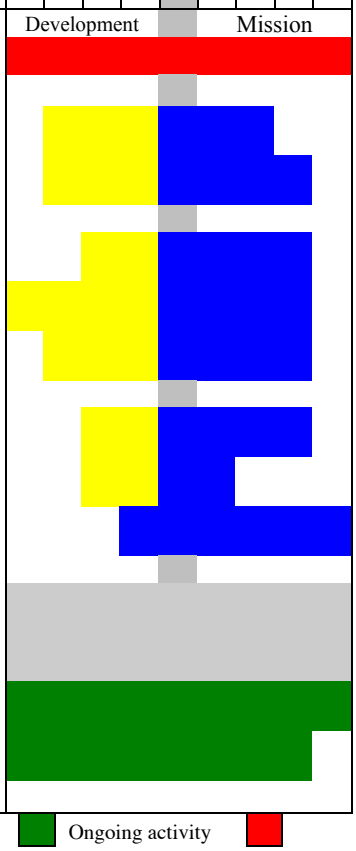



*Figure 1, Kepler's EPO Activities.*

As a space-based research mission, *Kepler* is being developed and will be operated by a consortium led by William Borucki, PI, at NASA Ames Research Center. The consortium includes Jet Propulsions Laboratories, Ball Aerospace, Smithsonian Center for Astrophysics, SETI Institute, Lawrence Hall of Science at UC Berkeley, and Space Telescope Science Institute. In addition, scientists from several US, Canadian and European universities are participating in the *Kepler Mission*. The EPO planning engages these scientists to insure the quality as well as the creativity and best application of *Kepler* results for education and outreach.

The *Kepler Mission,* the EPO program activities, timeline and collaborators are summarized in *Figure 2, Kepler EPO Program Component*. In addition to the EPO program components in *Figure 2,* the *Kepler Mission* plans a unique technology transfer program that will engage college and university undergraduates directly in ground-based observations of extra-solar planets to confirm the space-based satellite data for giant (Jovian-sized) planets. The ultimate technology and methodology is in planning. The *Kepler* program goal is to engage underserved students and institutions by providing *Kepler* data, training, technology and support for observers. A similar program may also be developed for amateur astronomers. As the mission proceeds, scientists anticipate observing transits of Jovian planets on Jupiter-length orbits. To confirm the existence of any planet discovered via transit data, two additional transits need to be observed. The Kepler satellite has a limited life-time; thus, longer-period planets must be confirmed by other telescopes. Many of these observations can be conducted by ground-based telescopes operated by students as well as amateur astronomers.

| ***EPO Program Component*** | *Key Organization* | *NASA Ames* | *Lowell Observatory* | *SETI Institute* | *Space Science Inst.* | *Space Tel. Sci. Inst.* | *UC Berkeley—LHS* | *Univ. Texas at Austin* |
|---|---|---|---|---|---|---|---|---|
| *Multimedia CD-ROM and Website* | LHS | C | C | C | | C | L | C |
| ***Formal Education*** | | | | | | | | |
| • GEMS curriculum material | LHS | C | | C | | | L | |
| • Hands-on-Universe supplement | LHS | C | | | | | L | |
| ***Informal Education*** | | | | | | | | |
| • Theater-type planetarium program | SI + CSSC | C | C | L | | C | C | C |
| • Museum Exhibit | SI+LHS | C | | L | C | | C | |
| • Interactive planetarium program | LHS | C | C | C | | C | L | C |
| ***Public Outreach*** | | | | | | | | |
| • Amateur Astronomers | SI + ASP | C | | L | | | C | |
| • PBS-type video program | SI + Kurtis. | C | C | L | | C | C | C |
| • Stardate series and magazine | SI+McD Obs. | C | C | L | | C | C | C |
| ***EPO Coordination & Management*** | | | | | | | | |
| • Link to NASA educational programs | Ames EPO | L | C | C | | C | C | C |
| • Media contact | Ames PAO | L | C | C | | C | C | C |
| • Project Coordination and Management | LHS | C | | | | | L | |
| • Project Coordination and Management | SI | C | | L | | | | |
| **Total EPO Program Cost** | LHS + SI | | | | | | | |




**L** = Lead Institution C = Contributing Institution Develop & Test Disseminate Ongoing activity

*Figure 2, Kepler EPO Program Component*

A note of credit: William Borucki, the Principal Investigator for the *Kepler Mission* has dreamt of finding Earth-sized planets orbiting distant stars for most of his career. His scientific and personal persistence, plus the evolution of technology over the past two decades, brought *Kepler* to realization. David Koch, Deputy PI, joined Borucki in the early 1990s to work on proposing and now developing *Kepler*. Koch developed the current *Kepler* web site, including a simulation of finding distant planets as they transit their parent stars. Visit http://kepler.arc.nasa.gov

# Extremes of Life Abstracts

# Abstract # 12560 - **Licancabur 2002: Exploring the Limits of Life at the Highest Lake on Earth – An Analog to Martian Paleolakes**

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The Licancabur Volcano (6014m), located at 22°50' S on the boundary of Chile and Bolivia, hosts the highest and one of the least explored lakes on Earth. This environment is especially interesting due to the high-UV flux at altitude in the tropics, which is coupled with low total pressure and concentration of atmospheric oxygen. It is ice-covered most of the year, but the bottom water temperature is warmer than predicted, which may suggest the presence of a hydrothermal system. The Licancabur project aims at exploring and understanding this unique environment, as well as neighboring high-altitude lagunas through two field campaigns in 2002 and 2003. These will provide: (1) critical astrobiological information about the limits of life on Earth; (2) a study of the physiology of modern microorganisms in an environment that may share similarities to those present on early Earth; (3) scientific clues about paleolake environments on Mars; and (4) elements to design science mission strategies for planetary exploration and search for life in the Solar System.

The first field season concluded on 10 November 2002. Here, we present preliminary results from the science team, including a characterization of the physicochemical, geological, and biological environment at the lake and surrounding lagunas. Data on the physicochemical environment include air, water, and soil temperature gradients, as well as water pH, total dissolved solids, and atmospheric relative humidity. The geology includes the reconstruction of the paleolake shorelines from topographical surveys, search for the supply systems, sampling of shore and lakebed sediments, and bathymetry. Microbiological examination of the lakes provides a characterization of the communities present in these environments. Such examination may be used to identify physicochemical controls on the distribution and abundance of microbial life. Results from individual lakes will be compared to illustrate the relationship between basal lagunas (~4000m) and the summit lake (~5900m), as well as sinks and potential sources. Further, this comparison will provide insights into the dependence of the lake environment on altitude- and latitude-dependent UV flux, temperature, and oxygen concentration.

# Abstract # 12607 *(Oral Presentation)* - **Life in Rock: Novel Endolithic Microbial Communities in Yellowstone Geyser Basin**

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The endolith, the pore space of rock, is a ubiquitous habitat for microbes on Earth, and it may offer suitable shelter to life elsewhere in the universe. Microbes establish complex structured communities, protected within the pore space of rock from the harshest climatic conditions on Earth. From polar deserts to hot equatorial deserts, endolithic communities are often the only extant life. The endolithic environment is a micro-habitat that provides microorganisms with a surface to grow on, protection from harmful radiation, mineral nutrients, and more favorable moisture regimes than if exposed directly to the atmosphere. Analogous endolithic habitats likely occur on planets like Mars today, and they could hold evidence for past or present life. Knowledge of life's signature in rock on Earth today, and in the past, is critical to our search for life in the universe.

Despite their global distribution on Earth, endolithic microbial communities remain poorly sampled and understood. Here, we characterize newly discovered endolithic communities that inhabit hydrothermally altered volcanic tuffs in an active geyser basin of Yellowstone National Park, USA. These relatively lush, photosynthetically-based microbial communities inhabit chemically diverse outcrops of geothermally warmed bedrock. In one case, the pore waters extracted from the community measured about pH 1. Molecular phylogenetic analysis of these novel endolithic communities reveals that they are unique when compared to other endolithic communities we have studied from Antarctic sandstone and different rock types in the Rocky Mountain region of the USA. These results contrast previous findings, which show that similar kinds of microbial communities inhabit different types of rock from different settings on Earth.

# Abstract # 12611 - **Microbial Influences on Trace Metal Cycling in Meromictic Fayetteville Green Lake, NY**

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Microorganisms can exist in aquatic environments at very high cell densities of up to $10^{11}$ cells/L, and they can accumulate significant quantities of trace metals. Bacteria actively take up bioactive trace metals, including Fe, Zn, Mn, Co, Ni, Cu, and Mo, which function as catalytic centers in metalloproteins and metal-activated enzymes involved in virtually all cellular functions. In addition, bacteria may catalyze the release of trace metals from inorganic substrates by processes such as the reduction of iron and manganese oxides, suggesting that trace metal distributions within a natural environment dominated by microbial processes may be influenced by microbial ecology. Fayetteville Green Lake (FGL), NY is a permanently stratified meromictic lake that has a well-oxygenated surface water mass (mixolimnion) overlying a relatively stagnant, anoxic deep water mass (monimolimnion). A chemocline separates the water masses at around 20m depth, where oxygen concentrations decrease and sulfate and methane concentrations increase. In addition, previous studies have indicated that trace metals such as V, Cr, Co, Mn, and Fe reach elevated concentrations at the chemocline.

Using fluorescent *in situ* hybridization (FISH) of FGL samples from depths of up to 40m with bacterial and archaeal probes, we have shown that fluctuating redox conditions within the FGL water column correlate with significant variations in the composition and distribution of microbial populations with depth. The mixolimnion is dominated by Eubacteria, with increasing concentrations of Archaea in the lower anoxic zone. Increases in microbial cell densities coincide with increases in trace metals at the chemocline, suggesting microbial activity may be catalyzing trace metal release at this boundary. 16S rRNA PCR cloning techniques are currently being used to identify dominant microbial populations at various levels within the FGL water column. Future studies will focus on the potential for these dominant microorganisms to influence trace metal cycling and bioavailability in the FGL water column.

# Abstract # 12619 - **Characterization of Sulfide-Microbial Habitats in Submarine Hydrothermal Systems**

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Seafloor hydrothermal chimneys provide a unique habitat for unusual microbial and macrofaunal communities. Such environments are believed to have existed throughout much of Earth's history and to have played an important role in the origin of life. Detailed geo-biological characterization of these sulfide-microbial habitats forms the first step in quantifying the interactions between microbes and their environment, and in identification of how such systems might have assisted prebiotic development. To pursue such studies, the University of Washington and the American Museum of Natural History recovered four large intact hydrothermal chimneys (each weighing up to 1816 kg and up to 2 m in length) from the Endeavour Segment of the Juan de Fuca Ridge in 1998. This study focuses on the growth and evolution of one of the recovered diffusely venting hydrothermal chimneys (called Roane) and lays the groundwork for follow-on coregistered microbial investigations.

Roane was approximately 8 m tall prior to recovery. The piece recovered from near the top of the edifice was 176 cm in height and roughly cylindrical with a basal circumference of 287 cm. The venting temperature at the summit of Roane was 179˚C. To investigate the chemical and microbiological gradients within the chimney, the recovered sample was quartered and one quarter was slabbed into 17 sections. All cut surfaces of each slab were mapped in detail. In addition, representative transects from the interior to the exterior of the chimney were selected for thin section and corresponding bulk chemical analyses.

Within Roane there are four major mineralogical and chemical zones that roughly form a radial zonation pattern. Progressing from the exterior to the interior these zones include the Fossil Tube Worm Zone (FTWZ), Silica Zone (SZ), Outer Sulfide Zone (OSZ) and Inner Sulfide Zone (ISZ). The FTWZ is a barite-dominated region with minor amounts of sulfide minerals intergrown within the barite matrix. Amorphous silica ± clay is the second most abundant mineral within the FTWZ, and it helps to solidify and strengthen this friable zone. In this region, numerous hollow, fossillized tubes, which exhibit a wide range of degradation and mineralogical replacement, result in a very high porosity. The SZ is dominated by amorphous silica ± clay, indicating that conductive cooling of hydrothermal fluid was an important process in formation of this region. Sulfides compose the majority of the other half of the mineral assemblage within the SZ, and barite is generally a minor component. The OSZ and ISZ are both sulfide-dominated regions, but they are distinguished by the relative greater abundance of amorphous silica ± clay in the OSZ and an increase in channel size inward. In addition to these zones, which characterize the main trunk of the edifice, the outer walls host parasitic chimneys that exhibit a wide range of mineralogical zoning on a fine scale.

In contrast to many black smokers, which are characterized by through-going high flow through open conduits, Roane lacks a large open centralized channel. Instead it is characterized by an almost sponge-like permeability network that facilitated diffuse flow. The high porosity throughout the interior of the structure may have allowed convection within the walls and promoted moderate chemical and thermal gradients. Episodic fracturing of the less porous, silicified walls likely resulted in influx of seawater and replenishment of nutrients critical to the growth of some microbial communities. This interpretation is supported by microbial analysis, which shows that hyperthermophiles and thermophiles were present throughout Roane. Moderate physical-chemical gradients within the porous, interior walls in diffuse smoker systems may prove to be more hospitable environments for microbial growth than the extreme conditions commonly found in vigorously venting black smoker systems. High cell densities and moderate gradients within a diffusely venting structure provide a unique opportunity to study the progressive fossilization of microbes and macrofauna, which may lead to the identification of useful biomarkers.

# Abstract # 12624 - **Molecular Analyses of Microbial Communities in Rock Coatings and Soils from Death Valley, California**

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Desert varnish is a coating of ferromanganese oxides and clays that coats rocks in Death Valley and in arid and semi-arid regions throughout the world. Wind deposited dusts from surrounding soils probably provide the nutrients for the growth of bacteria and fungal communities. The organic chemistry of the rock coatings has not been well characterized; however, the mineral and inorganic constituents have been well investigated. The Death Valley coatings contain iron, manganese and clays. Manganese ($MnO_2$) is enriched by up to 20 wt. percent oxide in the varnish coatings, but in the surrounding soils is usually less than 0.01%. The coatings are composed of red and black bands. Red layers are rich in hematite and infrared analyses of the black layers suggest they are birnessite. The varnish coatings are chemically and mineralogically distinct from the underlying rock.

We present here the first analyses known to us of the bacterial and archeal communities present in the varnish coatings, found using molecular techniques. DNA was extracted from desert varnish and surrounding soil, and 16S rRNAgene sequences were amplified by polymerase chain reaction (PCR) using primers specific for organisms in domains Bacteria, Archaea, or Eukarya. Clone libraries were constructed from the resulting PCR products and screened using amplified ribosomal DNA restriction analysis (ARDRA). Resulting representative sequences were used to construct a phylogenetic tree of the coating and soil clones. An understanding of the role that microbes may play in the formation of rock coatings and/or sub-aerial biofilms is important not only for the role they play in a weathering environment on Earth but the possible roles they may play or have played on other planets.

# Abstract # 12631 - **Searching for Permafrost Bacteria Relatives in Tropical Soils**

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Permafrost represents a unique ecosystem that has selected for the survival of bacteria at sub-zero temperatures for prolonged periods of time. Since low temperature is a predominant environmental characteristic of our solar system, bacteria isolated from the Siberian permafrost have been selected as models to study the impact of low temperatures on the responses and evolution of organisms.

Vishnivetskaya *et al*. (2000) developed strategies for the isolation of aerobic, oligotrophic bacteria from ancient permafrost sediments. They were successful in the isolation of members of the genera *Arthrobacter*, *Exigiobacterium* and *Psychrobacter* from permafrost samples extracted from diverse depths and geological ages.

Since the bacteria isolated from the permafrost have been exposed to extreme low temperatures for millions of years, it is expected that the traits that have been selected for in the permafrost habitat will not be as frequent in isolates from constantly warm soil environments. To test this hypothesis, we chose to compare various physiological traits of the permafrost strains with nearest relatives isolated from Puerto Rican soil samples. Soil samples were taken from northern Puerto Rico where hot and moist conditions prevail and from the southwestern part of the island where hot and dry conditions prevail. The isolation strategies include the protocols described by Vishnivetskaya *et al*. (2000) as well as media described in the literature for isolating bacteria of the three genera of interest.

The current presentation includes a description of the bacteria isolated to date, their 16S rDNA gene sequences, as well as the results obtained when the soils were probed with primers specific for the 16S rDNA genes designed to amplify the gene of bacteria isolated from the Siberian sites.

Vishnivetskaya T., Kathariou S., McGrath J., Gilichinsky D. and Tiedje J.M. 2000. Low-temperature recovery strategies for the isolation of bacteria from ancient permafrost sediments. *Extremophiles* **4:**165-173.

# Abstract # 12640 - **Biosignatures for Interpreting Life (Past or Present) From Ancient Terrestrial and Mars Rocks**

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An understanding of terrestrial microbial biota, their markers and fossilization processes is important for identifying potential present or past life signs from both Earth and extraterrestrial sources such as Mars meteorites and Mars sample return. Storrs Lake, San Salvador Island, Bahamas, Mono Lake, California, and the Dead Sea, Israel represent marine and nonmarine evaporite sites for comparative investigative studies of potential Mars analogs. Both the Dead Sea and Mono Lake localities, in addition to evaporites, offer opportunities to investigate adjacent springs, all of which can affect microbial abundance, fossilization, and mineral formation. Variations between the sites can be attributed to salinity (absence thereof), pH, water chemistry, and seasonal temperature changes. Storr's Lake (located at sea level, with a pH of 8, and salinity averaging ~70 g/l) has extensive stromatolitic structures composed of biofilm, rods, filaments, cocci and diatoms. The fossilized organic remains are generally composed of magnesium-enriched calcium carbonate with varying levels of silica (Figure 1). The Dead Sea is ~400 meters below sea level, with a pH of 6.3 in the upper water mass, and salinity averaging ~230 g/l. It possesses extensive salt deposits with scant evidence of microbial fossilization (Figure 2), as large carbonate structures such as tufas and stromatolites are absent. Mono Lake is 2100 meters above sea level (with a pH and salinity similar to Storr's Lake), and it displays various evaporite and carbonate deposits including tufa structures that vary in height from less than 1 meter to over 4 meters. Algae, cyanobacteria, diatoms, and other

microbial forms are present and contribute to the formation of evaporite deposits including tufas (Figure 3). Modern investigative tools can identify microbes from all of these environments, but confirming the presence of fossilized microbes and their biomarkers subsequent to burial and lithification is more difficult. The goal of this study is to identify these biomarkers and test their suitability for identifying extraterrestrial microbial remains.

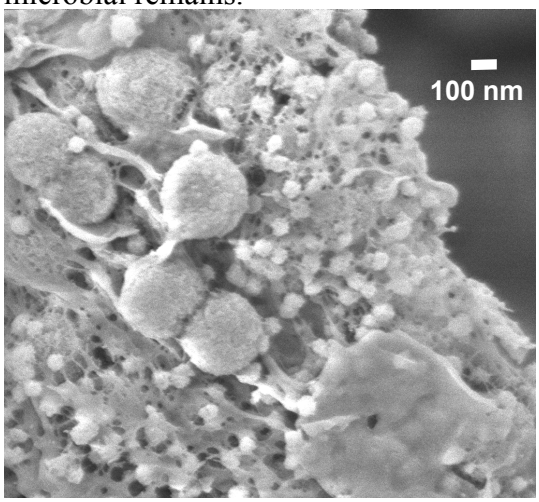


Figure 1. *Storrs Lake, San Salvador Islands, Bahamas.*
Two sizes of spheres enmeshed in biofilm. The larger is probably a fossilized microbe, while the smaller is probably biotically precipitated.

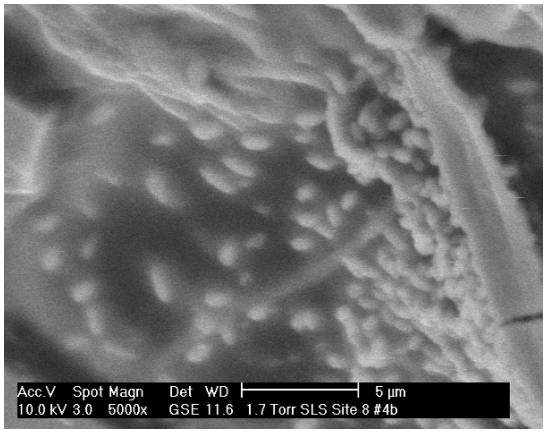


Figure 2. *Dead Sea Israel.*
Rod shaped microbes enmeshed with biofilm. As in Figure 1, microbes are clustered or appear in groups, a typical microbial growth mode.

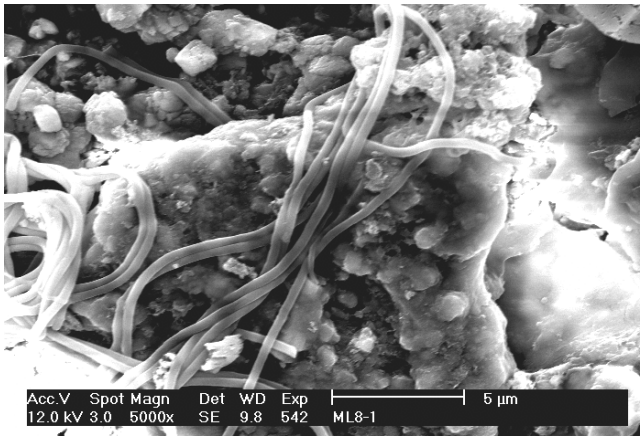


Figure 3. *Mono Lake, California.*
Long, filamentous microbial forms associated with a biofilm covered rock. Enmeshed with the biofilm are spheroidal forms of uncertain origins.

# Abstract # 12656 - **Comparative Analysis of P-type ATPases from Acidophiles and their Neutrophilic Relatives**

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One of the goals of the *NASA Astrobiology Roadmap* is to explore the limits of life on Earth as analogues for environments on Mars, Europa, and other planets that might support life. Our current research centers on such an analogue: the Rio Tinto, a 90 km long river in southwestern Spain, with a pH range of 1.7-2.5, high concentrations of heavy metals, and an iron content that is thought to resemble conditions that may exist on Mars. Our recent small-subunit rRNA-based studies reveal unexpectedly high eukaryotic phylogenetic diversity in the river. These studies identify organisms that live under acid/high metal extremes, but they tell us little about how these organisms have adapted to such environments. We are currently focusing on exploring the alterations in physiological mechanisms that might allow for growth of eukaryotic microbes at acid extremes. To this end we have isolated divergent protists from the Rio Tinto, including *Chlamydomonas* sp., *Euglena* cf. *mutabilis*, *Chlorella* sp., and a lobose amoeba, assigned to the genus *Vannella*. We are currently isolating and characterizing ion-transporting ATPases in the chlamydomonad and euglenid and comparing these genes with those from neutrophilic counterparts obtained from culture collections. We have conducted PCR experiments with primers designed to target the phosphorylation and ATP-binding sites found in members of the P-type ATPase superfamily. After cloning and sequencing these PCR products, we have determined that all of our clones thus far fall into the heavy-metal P-type class but may represent different metal transporters. To date, we have found more diverse sequences in the acidophilic *Chlamydomonas* than in *C. reinhardtii*. We are actively screening additional clones for $H^+$-transporting ATPases. We are planning to conduct similar experiments with other protists already in culture and with new protists obtained on future sampling trips. We will also construct cDNA libraries to obtain full-length gene sequences. We predict that special properties of these ion transporters allow protists to survive in the Rio Tinto's extreme conditions.

# Abstract # 12659 *(Oral Presentation)* - **High Throughput Approach to Study Ancient Microbial Phylogenetic Diversity in Permafrost as a Terrestrial Model of Mars**

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Finding evidence of life on Mars is one of central problems in astrobiology research today. Since Mars is a cryogenic planet, terrestrial permafrost soil (which is inhabited by cold adapted microbes) is a useful model for investigating new approaches to study cryo-adapted microbes.

We examined both Arctic and Antarctic permafrost as well as surface soils. To assess microbes existing in these environments, 16S rDNA genes were amplified from DNA extracted from both the original frozen samples and the same samples incubated at 10 °C for 8 weeks under both aerobic and anaerobic conditions. The latter study allowed us to determine which of the microbes present were alive and capable of growth on the resources provided by the soil. High through-put DNA sequencing was performed on the cloned PCR products to obtain partial 16S rDNA gene sequences. A script was written to automatically compare over 2,000 partial sequences with those rrn sequences in the Ribosomal Database Project (RDP) release 8.1 using the SEQUENCE MATCH. Sequences were grouped into categories from the RDP's phylogenetic hierarchy based on the closest database matches.

Our investigation revealed significant microbial diversity. Two phylogenetic groups were predominant in all samples: Proteobacteria and Gram Positive Bacteria. Microbial community composition within those groups is different from sample to sample. However, similar genera, such as *Arthrobacter, Bacillus, Citrobacter, Caulobacter, Comamonas, Flavobacterium, Nocardioides, Pseudomonas, Rhodocyclus, Rhodococcus, Sphingobacterium, Sphingomonas, Streptococcus*, and *Terrabacter* appeared in both polar regions. Some of these phylotypes have members that are known to live in other cold environments, including ice. The greatest microbial diversity was detected in Arctic surface samples. According to the RDP's phylogenetic hierarchy, those organisms are related to Proteobacteria, Gram Positive Bacteria subdivisions, *Leptospirillum-Nitrospira, Nitrospina-SD, Flexibacter-Cytophaga-Bacteroides, Planctomyces and Relatives*, and *Proteobacteria-SD*. Both the aerobic and anaerobic low temperature soil incubation yielded some microbes not detected in the original samples. The most diverse part of the community, which occurred in ancient Arctic and Antarctic permafrost samples, were different physiological groups of gram negative aerobic non-spore forming bacteria. According to the RDP's phylogenetic hierarchy, microbial phylotypes from those groups related to following bacterial genera: *Chloroflexus, Nitrospira, Flavobacterium, Psychroflexus, Sphingomonas, Flexibacter, Lewinella, Cytophaga, Rhodothermus, Isosphaera, Acetobacter, Rhodopila, Hyphomicrobium, Methylosinus, Methylobacterium, Bradyrhizobium, Sinorhizobium, Agrobacterium, Caulobacter, Sphingobacterium, Blastomonas, Nitrosospira, Pelistega, Bordetella, Comamonas, Rhodoferax, Variovorax, Leptothrix, Oxalobacter, Stenotrophomonas, Methylococcus, Acinetobacter, Pseudomonas*, *Bdellovibrio,* and *Myxococcus*. The bacterial phylotypes identified here will be important for studying their adaptations to cryogenic conditions. Our high through-put techniques allow us to computationally identify clones that are very unique from the database and of high sequence quality. About 170 of such clones were prepared for full 16S rDNA sequencing. The majority of these clones may represent novel bacterial genera or species.

This study of microbial diversity in the deep ancient permafrost can help us to develop the methodology for conducting astrobiological research relevant to the study of microbial life that could be in samples collected from the Martian permafrost by future space missions. The genomic studies done by others on our team could yield other cryo-markers of life. Research on Earth's "extreme environments" could give us indications of what to expect on astrobodies.

# Abstract # 12703 - **Growth and Metabolic Activity of Ancient Permafrost Bacteria in Cold, Low Water Activity Conditions**

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Siberian permafrost, with its continual low temperatures and associated decreased water activity, is seen as a model environment for assessing potential survival mechanisms of life on astral bodies. Physiological characterizations of two ancient permafrost bacteria were performed in laboratory conditions that sought to approximate the low carbon (<1%), low temperature (-10∞C), and low water activity (aw= 0.9) of the Siberian permafrost. The Psychrobacter and Exiguobacterium strains show reduction in cell size and maximal growth rate and an increase in lag time with cold temperature, clearly demonstrating an effect of temperature on physiological activity. The osmotic pressure of the growth media also has a significant effect on the lag time of these two permafrost isolates. However, the maximal growth rate remains constant up to 3.2 osm after no growth was detected in higher osmotic potentials. Despite this lack of demonstrated growth, incubation with a redox dye, cyano-tetrazolium chloride (CTC), revealed that metabolic activity is occurring at 5 osm, the estimated osmolarity of permafrost pore environments. Analysis of membrane lipid compositions and cellular contents revealed further mechanisms that Psychrobacter and Exiguobacterium use to survive permafrost conditions.

# Abstract # 12707 - **Genome Sequencing of *Psychrobacter* 273-4, a Psychroactive Microorganism Isolated from a 20-30 Thousand-Year-Old Siberian Permafrost**

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Low temperature is a widespread characteristic of our solar system, interstellar space, asteroids, and meteors. An understanding of the biological adaptations to low temperatures could provide insights about the possibilities of life elsewhere in the universe. Microorganisms, are among the living forms on Earth that posses remarkable abilities to survive and grow at low temperatures. Current knowledge about adaptations to low temperature primarily comes from studies on mesophilic microorganisms. The objective of this work was to sequence the genome of a psychroactive microorganism to better understand its metabolic capabilities at low temperature.

We have sequenced the genome of *Psychrobacter* strain 273-4, isolated from a 20-30 thousand-year-old Siberian permafrost core [5], which has remarkable abilities to grow at low, even sub- zero temperatures. *Psychrobacter* is a member of the gamma *Proteobacteria* family. This genus is commonly isolated from cold or saline environments, including soil, sea-water [1], and the skin and gills of fish [2]. It has also been associated with food spoilage and is often resistant to irradiation used for food preservation [3]. *Psychrobacters* have also been identified from a variety of human sources [4]. Besides growth at sub-zero temperatures, this strain also grows at low water

activities. Preliminary analysis indicates that the size of this genome is ~ 2.5-megabases and has a GC content of 42%. DOE's Joint Genome Institute, as part of our NAI team, has provided 10X sequence coverage of *Psychrobacter* genome, and the bioinformatics group at Oak Ridge National Laboratory has provided the initial pipeline annotation. This analysis indicates that this strain's genome encodes approximately 2,065 predicted open reading frames (ORFs), with 14% of them classified as poorly characterized proteins, i.e., of hypothetical or unknown function. Furthermore, 21% of the ORFs have no homologs in the GenBank database indicating that the function of a major portion of the genome is yet unknown. Some of the genes identified that could be related to cold adaptation include four cold shock proteins, six proteins with known cold-induced expression and 12 stress-associated proteins. Interestingly, 45 transposases from other microorganisms were identified on *Psychrobacter's* genome suggesting that horizontal gene transfer could have affected the evolution of this genome. DNA microarrays are being constructed to recognize cold and desiccation (salt) induced genes.

Acknowledgements: Funding for the genome sequencing was jointly sponsored by NASA's NAI Program and DOE's Microbial Genome Program. We thank Trevor Hawkins of JGI, and Frank Larimer and Lauren Hauser of Oak Ridge National Laboratory for their contributions to the sequencing and annotation, respectively.

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# Abstract # 12716 - **Tolerances of Hydrothermal Vent Archaea to Deep Subsurface Conditions**

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We explored the ecophysiology of hyperthermophilic archaea from hydrothermal vent sites, to understand their tolerance to environmental stress factors that characterize deep-sea hydrothermal vent and hot, deep subsurface environments. Growth and survival of four phylogenetically distinct archaea were tested under high temperature and pressure, low pH, and high concentrations of sulfide. The test organisms consisted of 2 heterotrophic sulfur reducers (*Pyrococcus sp*. strain GB-D and *Thermococcus fumicolans*), which grow optimally at 95°C and pH 7.3, and at 85-90°C and pH 8; one autotrophic methanogen (*Methanocaldococcus jannaschii*), which grows optimally near

85°C and pH 6.0; and one mixotrophic sulfate reducer (*Archaeoglobus profundus*), which grows optimally at 82°C and pH 6.0. Members of these archaeal genera are frequently found in hydrothermal fluids, in hot oilfields, or during diking events and undersea eruptions at mid-ocean ridges (Kelley et al. 2002), indicating that these archaea inhabit deep marine subsurface environments under the hydrothermal vent seawater/rock interface that is commonly sampled.

We found synergistic effects between high pressure and the other variables. At 845 atm, the sulfur reducer *T. fumicolans* grew well down to pH 4.5 and 90°C, and P. strain GB-D grew at pH 5 and 90°C. At 1000 atm and 100°C, both strains are incapable of growth at less than pH 5.5. In contrast, neither the methanogen nor the sulfate reducer ever exhibited growth at high pressure, possibly due to the difficulty of supplying adequate $H_2/CO_2$ energy and carbon sources without the availability of hyperbaric bioreactors.

In the dynamic environment of the hydrothermal vents and the vent subsurface, prokaryotes require strategies to survive in the temporary absence of carbon and energy sources. We therefore measured the survival of all four archaea in the absence of carbon and energy sources; heterotrophic substrates for *Pyrococcus* strain GB-D and *T. fumicolans*, hydrogen for *M. jannaschii*, and both for *A. profundus*. Under these survival conditions, the sulfur reducers were more susceptible to pressure than they were while actively growing. At 1000 atm and100°C, only *Pyrococcus* strain GB-D was capable of short-term survival for 4.5 hours. At 845 atm and 90°C, survival of *Pyrococcus* strain GB-D and *T. fumicolans* improved significantly, with no decline after 16 hours at pH 7, but survival generally declined after 5-10 hours at pH 4.5 - 5. For *M. jannaschii*, survival at 735 and 850 atm was limited to short time intervals (5 - 10 hours at pH 5 - 6). The *A. profundus* data are problematic; *A. profundus* did not survive high pressure, in contrast to later tests that combined high sulfide concentrations and high pressure.
High sulfide concentrations were tolerated by the two heterotrophic sulfur reducers. No measurable decline in survival was observed for *Pyrococcus* strain GB-D and *T. fumicolans* in as high as 30-35 mM sulfide over 18 hours at 845 atm, 90°C and pH 7. At 100°C, the sulfide resistance of *T. fumicolans* reached 50 – 70 mM, whereas the viability of *Pyrococcus* strain GB-D decreased with increasing sulfide concentrations over time. *M. jannaschii* and *A. profundus* did not tolerate high sulfide concentrations as well as the sulfur reducers. For *M. jannaschii*, exposure to 10 – 30 mM sulfide at 82°C and 88°C and 1000 atm led to increasingly faster die-off over 10 – 24 hours. *A. profundus* appeared to show a small increase in sulfide tolerance with higher sulfide levels (up to 30 mM, at 82°C).

These metabolically diverse archaea can tolerate the high pressures associated with the deep subsurface. Actively growing cells tolerated stresses better than cells that were surviving during depletion of electron and carbon sources. Survival tolerances decreased when high pressures were combined with the stresses of acidity, high temperature, and high sulfide concentrations.

Kelley, S., Baross, J.A., and Delaney, J.R. 2002. Volcanoes, fluids and life at Mid-Ocean Ridge spreading centers. *Annu. Rev. Earth Planet. Sci.* **30**, 385-491.

# Abstract # 12728 - **The Protective Roles of the Antioxidant Enzymes Superoxide Dismutase and Catalase in the Green Photosynthetic Bacterium *Chloroflexus aurantiacus***

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Living organisms are constantly bombarded by cell damaging reactive oxygen species (ROS). Sources of ROS include ionizing radiation, normal cell metabolism, and metal catalyzed oxidation systems. Modifications of proteins, DNA, and lipids caused by ROS are lethal, and cells have had to evolve efficient defense mechanisms to survive.

The antioxidant enzyme superoxide dismutase (SOD) in the thermophilic photosynthetic green bacterium *Chloroflexus aurantiacus* is the focus of this study. Catalase activity and its source are also being investigated since a catalase gene in the *Chloroflexus* genome has not yet been found. *Chloroflexus aurantiacus* is an evolutionarily significant organism since it groups in the first branch of the eubacteria, which are capable of photosynthesis. This organism is found growing in mats beneath cyanobacteria in the shallow runoff of the alkaline hot springs in Yellowstone National Park. This environment is both hyperoxic and high in ultraviolet radiation, a potent source of ROS.

The SOD gene from *Chloroflexus aurantiacus* has been cloned and expressed in *Escherichia coli* as an easily purifiable fusion protein with maltose binding protein. These two proteins were then separated with a protease and SOD was purified by isoelectric focusing. This SOD is a dimer with a monomeric weight of 23,153 kDa by mass spectrometry. SOD from *Chloroflexus aurantiacus* is a manganese type SOD, both by sequence and by activity assay experiments. However, metal analysis and EPR experiments demonstrate that this SOD contains both iron and manganese cofactors. Further characterization of the nature of this possibly active iron atom as well as other biochemical studies of this cambialistic Fe/Mn SOD are underway.

The patterns of activity of SOD and catalase in natural *Chloroflexus aurantiacus* containing microbial mat samples have been profiled. These enzymes were shown to exhibit inhibited activity under conditions of oxidative stress such as natural UV radiation and hydrogen peroxide exposure. Enzymatic activity was also shown to recover and to be sustainable during the day when exposure to oxidants occurs early, suggesting gene inducibility. These oxidative stress experiments will be repeated with an axenic lab culture of *Chloroflexus aurantiacus*. Patterns of enzymatic activity, as well as levels of SOD transcript and protein, will be compared to the natural samples. This approach will give a clear picture of the role these enzymes play in the ability of this organism to tolerate oxidative stress in its extreme environment.

# Abstract # 12753 - **Consolidation of Serial Analysis of Ribosomal RNAs (SARS) as a Unique Molecular Biology Method for Sampling Microbial Diversity In Natural Environments**

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Recent observations of extra-solar system planets and the discovery of microbial life in extreme environments heightens our expectations that life will likely be encountered beyond Earth. A better understanding of the microbial ecology of extreme environments on Earth may: 1) enlighten us about the origins and full diversity of life, 2) provide insights into the limits of the adaptability of life, 3) redefine the environmental boundaries that are compatible with the search for life on other planets and 4) provide new information about the remote possibility that panspermia (transfer of life from one planet to the another) [1] is/was a significant factor that contributes to the distribution of life in the universe.

Historically, culture-dependent methods and morphological identification of microorganisms have been the only way to unambiguously identify a distinct microbial species. With the availability of molecular genetic techniques, scientists developed novel ways of identifying microorganisms. Through the lens of molecular biology, we have expanded our view of microbial diversity on Earth. The sequence analysis of ribosomal RNAs (rRNAs) isolated from natural populations of microorganisms has led to new ideas about the origin, evolution, and possible distribution of life [2]. Despite these advances, our understanding of microbial diversity is constrained by data sets that are too small to adequately inventory the kinds of microbial forms in a particular study site. The inherent expense and limited throughput of individual sequencing reactions has led to the widespread use of terminal restriction fragment length polymorphisms (T-RFLP, [3]) or denaturing gradient gel electrophoresis (DGGE, [4]) to characterize products of polymerase chain reaction (PCR) experiments. But these techniques provide very low levels of information about microbial diversity and the results are difficult or impossible to compare between different sites.

To address these deficiencies, we have developed a new sequence-based strategy to obtain quantitative estimates of natural diversity. Serial Analysis of rRNAs (SARS) is a new, high-throughput technique that can sample at the sequence level short species-specific regions of PCR amplified rRNAs genes from many microorganisms in a single reaction [5]. Modeled after serial analysis of gene expression (SAGE, [6]), SARS provides a means to rapidly and efficiently enumerate relative numbers of rDNA templates in a nucleic acid population extracted from a microbial community. In this communication, we describe the application of this technique to an extreme environment, the hydrothermally active sediments of the Guaymas Basin (Gulf of California, Mexico). Funded through the NASA Astrobiology Institute, molecular-based studies of hydrothermally active sediments of the Guaymas Basin have reported microbial diversity inventories for several core samples [6]. We have applied SARS to the same biological samples. Using bacterial universal primers that amplify a hyper-variable region of prokaryotes 16S rRNA gene we obtained hundred of sequences in samples of core A1 of the Guaymas Basin. The information content of these sequences eclipses our previous studies based upon partial rRNA sequence comparisons supporting SARS as a powerful technology to investigate microbial population structures in unexplored environments. We believe that a broad application of SARS technology will accelerate astrobiology studies that seek to define environmental boundaries that are compatible with the search for life on other planets, as well as the conditions conducive to life's origins and evolution. We plan to continue the application of SARS to quantitatively assess the microbial diversity and population structure of other extreme environments of astrobiology interest.

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# Abstract # 12757 - **Circumneutral Iron Oxidizing Bacteria: Habitats, Metabolism, and Biosignatures**

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Circumneutral iron oxidizing bacteria (FeOB) have been isolated from groundwater, hydrothermal vents, and the wetland plant rhizosphere. The isolates are obligate lithotrophs that grow by oxidizing Fe(II) at mesophilic temperatures (30 ºC). To compete against the rapid chemical oxidation of Fe(II) that occurs at a pH >4, FeOB tend to occupy microaerobic habitats. We are currently working on methods to definitively demonstrate carbon fixation by a groundwater isolate. In culture studies, FeOB grow with bicarbonate as the sole carbon source. In addition to carbon metabolism, we are investigating the method by which FeOB obtain fixed nitrogen. Studies of carbon and nitrogen metabolism will provide insight into the constraints on life in an environment with limited substrates, such as early Earth and Mars. A marine isolate, PV-1, produces a characteristic filamentous iron oxide. Filamentous iron oxides are common at hydothermal vent sites and are suggestive of the utility of distinct morphological structures as biosignatures of past life on Earth and Mars.

# Abstract # 12782 - **Characterization of Novel Subseafloor Isolates from a Deep-Sea Volcano in the NE Pacific**

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Molecular phylogeny and culturing data show that the subseafloor at mid-ocean ridges hosts a diverse community of thermophilic and hyperthermophilic bacteria and archaea [1, 2]. These organisms are ejected from oceanic crust following a deep-sea volcanic eruption and continue to be detected in diffuse-flow fluids having temperatures 20-40 °C below their minimum temperature for growth. Since these microbes cannot grow in cold, oxygenated seawater, they are considered to be indicator organisms of the subseafloor. Unfortunately, little can be inferred about the physiology of these indicator organisms from molecular phylogeny data. To understand the physiological diversity, it is necessary to isolate and characterize representative subseafloor organisms. This requires culturing conditions that reflect known characteristics of the subseafloor environment. The chemistry of hydrothermal systems provides carbon and energy sources for life to exist without photosynthesis. The abundance of electron acceptors $CO_2$, $SO_4^{2-}$ and Fe (III) and electron donors including $H_2$, $H_2S$, $CH_4$ and Fe (II) support metabolic processes such as methanogenesis, sulfate reduction, and iron reduction. One of the important unsolved questions about the ecology of the subseafloor is the sources of organic compounds that are required to support the diverse community of thermophilic and hyperthermophilic heterotrophs that are commonly isolated from these environments. Is the source of organic material from abiotic or biotic processes? The physiological properties of subsurface microbes may provide a partial answer to this question. One of the key characteristics of microbes isolated from the subseafloor is the ability to attach to mineral surfaces and produce biofilms. In almost all cases biofilm-forming microbes produce extracellular polysaccharides that form the matrix of the biofilm. These extracellular products may also be a primary carbon source for some subsurface heterotrophs.

Here, we present some preliminary data on the isolation and characterization of two novel thermophilic microorganisms isolated from low temperature fluids at a deep-sea volcano in the northeast Pacific. Isolate Ax99-59 is a strictly anaerobic chemolithoautotrophic bacteria that uses hydrogen as an electron donor and sulfur compounds as an electron acceptor. Additionally, this isolate produces copious amounts of exopolysaccharide in

culture and is a model organism for studying biofilms on mineral surfaces. Ax99-59 is related to a *Desulfurobacterium* species and is deeply rooted in the order Aquificales. The second isolate, Ax00-33, is an anaerobic heterotrophic archaea that uses organic compounds as an electron donor and acceptor. Unlike many chemoorganotrophs isolated from deep-sea hydrothermal vents, this isolate does not require sulfur compounds for growth. Ax00-33 is most closely related to *Palaeococcus* species, a newly described, deeply rooted genus within the Thermococcales. However, the DNA guanine + cytosine ratio and physiological characteristics indicate that Ax00-33 may be a new genus. An impetus for this study is the prediction that microbes unique to the subseafloor at mid-ocean ridges could provide insight into metabolic processes and strategies for growth and survival of life forms in the subsurface of other volcanically active solar bodies.

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# Abstract # 12784 - **Community Structure and Diversity of Cyanobacterial and Bacterial Populations in Intertidal Microbial Mats Along a Desiccation Gradient**

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We sought to investigate the effects of desiccation frequency on diversity and community structure on microbial mat populations. For this, we characterized both cyanobacteria and (eu)bacteria in a mat consortium exposed to varying degrees of desiccation depending on their position in the tidal range. Community fingerprints were obtained by separating PCR amplified 16S rRNA genes via denaturing gradient gel electrophoresis. Clear shifts in community structure were detected along the gradient. Shannon-Weaver diversity and richness estimates for both bacteria and cyanobacteria decreased with increasing desiccation. Benthic microbial mats from an environmentally stable evaporitic pond were also studied to compare the spatial variability in mats not subject to gradients. The community fingerprints for both cyanobacteria and bacteria were uniform along the sampling transect in the latter mat. The environmentally stable pond samples also had lower diversity estimates for both populations, compared to the intertidal samples. These results indicate that environmental gradients (when present) can account for spatial variation in microbial community structure, and that both extreme and very stable conditions tend to decrease diversity in microbial mats.

# Abstract # 12792 - **Changes in Gene Expression in Response to Low Temperature in Two *Psychrobacter* Isolates from Arctic Permafrost**

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Cold temperature is a predominant characteristic of much of our solar system. We are interested in understanding biological adaptation to environments common in space, in this case low temperature; our focus is on microbial adaptation. We are using microorganisms isolated from permafrost core samples on Earth that have survived freezing for thousands of years as a model system to study how life forms might adapt and live in inhospitable conditions such as those found elsewhere in the universe. In order to understand how organisms can survive and even metabolize and grow at low and sub-zero temperatures, we are undertaking a study of genetic changes that occur in response to these low temperature conditions. Specifically, two isolates of the genus of gram-negative bacteria, *Psychrobacter*, that were isolated from 20-30 thousand year old permafrost samples are being examined for genes that are up-regulated at low temperatures. Two approaches are being taken. The first approach is to develop a transposon mutagenesis system in which a reporter gene, *luxAB*, is inserted randomly into the genome and is used to clone genes which are up-regulated in the cold when it inserts downstream of the promoters of such genes. A second approach is to examine the protein profiles of extracts from *Psychrobacter* grown at normal and low temperatures and to identify by mass spectrometry proteins which accumulate in the cold. Progress on the two aspects of this project will be presented.

# Abstract # 12809 *(Oral Presentation)* - **Intrinsically and Pleomorphically Dwarf Bacteria and Archaea in a Semiarid Soil**

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Extremely small microorganisms have been of interest to astrobiologists since the report of "nanofossils" in Martian meteorite ALH84001. Microscopic studies have shown that most microbes exist in soils as dwarf cells that are thought to be an adaptation to nutrient limitation. Most dwarfs are uncultured by current approaches and have not been identified phylogenetically. A few dwarf bacteria have been isolated in culture, but dwarf archaea have not been studied previously. We selected a semiarid creosotebush shrubland at the Sevilleta Long Term Ecological Research Site for studying dwarf microorganisms because arid and semiarid soils are generally nutrient-poor. Soils were collected beneath creosotebush canopies and in open areas between shrubs. Cells were eluted in sodium pyrophosphate and filtered with a 0.45-$\mu$m pore-size filter. Filtrate DNA was extracted, PCR-amplified using universal bacterial and archaeal 16S rDNA primers, cloned, RFLP-screened, and sequenced. The eluted cell filtrates were also inoculated into R2B medium. After incubation, cultures were filtered to select against populations of dwarfs that formed large cells in the presence of nutrients (pleomorphic dwarfs) and to select for populations that retained dwarf size (intrinsic dwarfs). Dwarf archaea and bacteria were present in the initial filtrate and in the cultures. A single dwarf archaeon (SevArch 01) that is related to other nonthermophilic soil Crenarchaeota sequences was found in the initial filtrates and in subsequent filtrate cultures, indicating an intrinsically dwarf archaeon. Phylogenetically diverse dwarf bacteria were detected in the initial filtrates. Intrinsically dwarf bacteria in enrichment cultures fell into the $\alpha$- and ß-Proteobacteria, but they were not closely related to any previously cultivated species. Dwarf bacteria related to *Arthrobacter*, *Propionibacterium*, and other Actinomycetales were detected. Many sequences showed no close relationships to any microorganisms that have been grown in culture.

# Abstract # 12839 *(Oral Presentation)* - **Global Rates of Sulfate Reduction in Deeply-Buried Marine Sediments**

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Evidence of microbial activity up to 800 meters below the sea floor (mbsf) was first documented via geochemical profiles from Deep Sea Drilling Project (DSDP) sediment cores (Claypool and Kaplan, 1974). Deep beneath the sea floor, sulfate reduction appears to be the principal terminal metabolic step (D'Hondt et al., 2002). At steady state, the sulfate reduced by respiration is typically replaced by diffusion of sulfate from the overlying ocean.

The flux of dissolved sulfate from the overlying ocean to the sediments can be calculated from the sulfate concentrations of sedimentary porewater and the physical properties of the sediment. Fortunately, sulfate concentrations and relevant physical properties have been routinely determined for sediment cores collected by the DSDP and the Ocean Drilling Program (ODP) over the last 30 years. We examined porewater chemical data from over 1,100 DSDP/ODP sites and calculated the sulfate flux to the subsurface biosphere (>1.5 meters below sea floor) at 436 sites that had sufficient data quality and density to warrant consideration. These results were then regressed against oceanographic variables (most derived from satellite measurements) with complete geographic coverage to provide estimates of the total global sulfate flux to the deep subsurface. As a quality control measure, we repeated the process with what we deemed to be 85 "highest quality" sites from a variety of environments and geographic locations. The combined approach balances the limitations of using lower quality data with good geographic coverage and using high-quality data with poor geographic coverage.

The best predictor of sulfate flux is a combination of distance from shore and chlorophyll concentration in the overlying water column. For the case of 431 sites (gridded to 5° longitude by 5° latitude), the regression explains 44 percent of the variance in the sulfate

flux. For the 85 "highest quality" sites the regression explains 60 percent of the variance in the sulfate flux. The regression coefficients for the two cases are indistinguishable at the 1–sigma level and the residuals are normally distributed. Additional oceanographic properties that were considered include water depth, primary production and sea surface temperature. The strong correlation between sulfate flux and distance from shore is not surprising if one considers distance from shore to be a proxy for organic carbon flux to the sediment surface and total sedimentation rate.

Our calculations indicate that approximately $1.0 \times 10^{14}$ mol$SO_4^{2-}$/yr diffuses from the ocean into sediments deeper than 1.5 mbsf. Of this flux, 75 percent occurs in the open ocean in water depths greater than 4000 meters. Although sulfate reduction rates are much higher in shelf settings, these areas comprise only about 5 percent of the sea floor. Our estimate of sulfate reduction rates on the shelf is 2.0-2.2 $\times 10^{13}$ mol$SO_4^{2-}$/yr, in close agreement with Ivanov's (1978) estimate of $2.8 \times 10^{13}$ mol$SO_4^{2-}$/yr. Our global total far exceeds Ivanov's estimated because he did not consider the open ocean.

The removal of sulfur from the ocean via pyrite formation in sediments has been estimated as $1.2 \times 10^{12}$ molS/yr (Berner, 1982). This is far less than our estimates of the total sulfate flux to the deep subsurface. In shallow-water settings, approximately 90 percent (Jørgensen, 1978) of the downward sulfate flux is balanced by the release of $HS^-$ (a product of sulfate reduction). Extending the release of $HS^-$ measured in shallow-water settings to the shelves, our estimate of net sulfur flux to the deep subsurface is $8 \times 10^{13}$ molS/yr. This flux is still far larger than the estimated removal via pyrite.

Our results indicate that subsurface metabolic activity has a large impact on the marine sulfur cycle. They also suggest that the marine sulfur cycle is not yet fully quantified.

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# Abstract # 12861 - **The Effects of Environmental Factors on the Resumption of Photosynthetic Activity of Cyanobacterial Mats Following Rehydration**

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Microbial mats dominated by cyanobacteria occur extensively in the intertidal regions near Guerrero Negro, Baja California Sur. These mats are periodically exposed to desiccation stress between tidal flows and rains, although most of the time they are metabolically inactive. Therefore, periods of hydration are extremely important for growth as well as for repair of cellular damage from desiccation and ultraviolet radiation (UVR) accrued when the mat is dry. Excised microbial mat, used in our experiments, was determined by microscopy to be composed primarily (~95%) of the cyanobacterium Lyngbya sp. PAM fluorometry in conjunction with carbon fixation assays were used to determine the effects of UV radiation, salinity, and solar light intensity on the recovery of photosynthesis in these mats after an extended period of desiccation. PAM fluorometry was used to observe photosynthetic recovery during the first 30 minutes after rehydration whereas the carbon fixation assays focused on more long-term recovery between the first 30 minutes to 2 hours after rehydration. Based on readings taken using these two methods, it appears that photosynthesis in these Lyngbya mats recovers in at least two stages: 1) the initial recovery of photosynthesis from desiccation which varies between 10 and 30 minutes and 2) acclimation to the environmental conditions which takes from 30-60 minutes. The time course of photosynthesis recovery for these mats is perhaps even more rapid than that found in terrestrial Nostoc sp. (see Dodds and Gudder, 1995).

Across all salinity and UV treatments, initial recovery of photosynthesis from desiccation was slower under low rather than high irradiance. After the initial response, differences in photosynthetic recovery rates between treatments depended on the method used. Using PAM fluorometry, mats under low light reached higher rates of photosynthesis than under high light but this result was reversed for carbon fixation rates. This

inconsistency may be caused by differences in the two techniques, since PAM fluorometry collects only data from the surface of the mat whereas the carbon fixation assay incorporates rates from deeper in the mat where light attenuation is greater.

Lyngbya mats initially recovered from desiccation much faster when rewetted with freshwater as opposed to higher salinities (55 and 75 ppt) under both high and low light intensities. However, long term carbon fixation rates were lowest in mats recovering in freshwater and higher than freshwater in salinities of 55 and 75 ppt. The effects of UVR under high and low light conditions were only studied in 55 ppt seawater, but no significant differences between UV plus and UV minus treatments were observed using PAM fluorometry. There were also no differences in long term carbon fixation rates between UV plus and minus treatments. Similar UV results were obtained with Calothrix mats which endure even longer periods of desiccation than mats dominated by Lyngbya. However, previous work with Lyngbya mats conducted in October of 2001 showed a decrease in carbon fixation rates when the mats were acclimated to high solar irradiance without UV for more than one day and then exposed to high solar irradiance plus UV for the duration of the assay.

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# Abstract # 12880 - **NEPTUNE: A Submarine Network of Interactive Laboratories at the Scale of a Tectonic Plate – A New Paradigm in Ocean and Earth Sciences**

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NEPTUNE's goal is to enable real-time, long-term, plate-scale studies in the ocean and earth sciences. The NEPTUNE project will deploy a submarine cabled network on the Juan de Fuca tectonic plate off the U.S. and Canadian west coasts. Using fiber-optic/power cable and junction boxes, this plate-scale ocean observatory will establish a linked array of undersea observatories by providing significant amounts of power (100Kw) and a high-speed Internet communications link (10 Gbits/sec) to sensors and sensor networks on, above, and below the sea floor. The network may also serve as a unique test bed for sensor and robotic systems designed to explore other oceans in the solar system.

NEPTUNE will focus on a broad range of scientific inquiries including the relationship between oceanic-crust microbial productivity and the deformation and volcanic eruptions within a plate tectonic framework. Other research will address a broad array of earthquake and tsunami-related issues, fish migration, sediment transport, carbon fluxes related to air-sea exchange and primary productivity in the upper ocean, and earthquake-generated outgassing of subduction complexes.

Hard-wired to the Internet, NEPTUNE will enable a new paradigm where ocean and earth investigations can be conducted for decades from instrument arrays immersed in the dynamic environments within and beneath our oceans. The network will also bring real-time data and imagery into laboratories, classrooms and living rooms, and will enable the public to watch electronically over the shoulders of oceanographers and geoscientists as they explore the time domain, from seconds to decades, within one of our planet's most dynamic ocean basins.

# Abstract # 12920 *(Oral Presentation)* - **Investigation of Steep Thermal and Chemical Gradients in Submarine Microbial Habitats**

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Organisms living in submarine hydrothermal systems survive in extremely dynamic environments. Conditions within hydrothermal chimneys range from hot (>300ºC) and reducing to cold (2ºC) and oxidizing. However, little is known about the interaction between microbial life and the mineral/chemical environments in which they live. To study these environments in detail, the University of Washington and the American Museum of Natural History collected four large intact hydrothermal chimneys in 1998 from the Endeavour Segment of the Juan de Fuca Ridge. The thermal and chemical gradients were steepest within Finn, the highest temperature venting chimney. Characterizing these gradients and correlating them to the abundance and diversity of organisms living within chimneys such as Finn is important in the understanding of where the high-temperature limits to life might be in hydrothermal environments.

At the time of recovery, Finn was vigorously venting ~ 302ºC fluids through a large central conduit, 12-32 cm in diameter. Post-recovery examination of a ~1.6 m section of Finn shows that the conduit is lined with a chalcopyrite layer 0.2 to 10 cm thick. In places, the conduit has thick clay (smectite) and anhydrite deposits, indicating that substantial seawater entered the conduit through fractures in the wall rock and that it underwent variable mixing with hydrothermal fluid.

Detailed mapping and petrologic investigation of Finn show that the walls supported steep thermal and chemical gradients, which dramatically affected the microbial populations inhabiting the walls. Wall thicknesses range from only 5 cm up to 42 cm.

Where the walls are thinnest, Finn exhibits a fairly straightforward progression in mineral and thermal gradients. The chalcopyrite-lined conduit, which hosted vigorously flowing 302ºC hydrothermal fluids, transitions into a 1-3 cm wide zone rich in chalcopyrite, pyrite, zinc sulfide, and anhydrite. Outward from this, anhydrite and chalcopyrite disappear, and pyrite, zinc sulfide, barite, amorphous silica, and interstitial clay dominate. The exterior wall in contact with the 2ºC seawater exhibits a brown layer of Fe-oxide minerals.

In areas where the walls are thickest, multiple generations of chalcopyrite-lined parasitic chimneys are present. The formation of these smaller chimneys helped the structure grow in diameter, and several examples of pre-existing exterior walls (indicated by fossil tube worms) are now incorporated well within the structure. Closer to the central conduit (within 20 cm), the parasitic chimneys commonly contain thick pockets of anhydrite, showing that these smaller conduits also suffered from fracturing events that allowed seawater into the channels, possibly choking off their supply of vent fluid. Strontium isotopic analyses of anhydrite from several individual pockets demonstrate that the anhydrite deposits are sea-water dominated, with seawater-hydrothermal fluid ratios ranging from 48:52 to 98:2, with an average of 77:23. In places where these parasitic chimneys exist, the chalcopyrite/zinc sulfide-rich zone is much thicker, up to 15 cm wide.

Further from the central conduit, parasitic chimneys are lined with zinc sulfide, barite, and amorphous silica. The presence of barite indicates that seawater was able to enter the channels, yet the abundance of amorphous silica signifies that conductive cooling of hydrothermal fluid was an important process during the infilling of these channels. The amorphous silica also exhibits a distinctive filamentous habit, and it is possible that this morphology represents the fossilization of microbial communities living within the channels. Preliminary SEM analyses support this interpretation.

Initial geochemical analyses show significant enrichment in many trace elements near the outer wall of Finn. These enrichments are associated with the highest microbial concentrations measured. The correlation between high cell counts and enrichment of some trace metals near the outer walls may reflect: (1) a high energy environment where hot reducing hydrothermal fluids and cold oxidizing seawater mix, and/or (2) an area where microbial populations may mediate metal deposition.

In addition to representing the steepest gradients in temperatures, Finn exhibits a complex history of fluctuating physical and chemical conditions. Multiple mixing events between the hot hydrothermal fluid and cold seawater are recorded in its walls. Microbial investigations of the various regions within Finn show that communities are able to survive and even thrive in this dynamic environment. Physical and chemical gradients within microbial habitats are likely to have played key roles in the evolutionary path of organisms over geologic time. On a larger scale, gradients similar to those present in sulfide chimneys are present within the oceanic crust beneath mid-ocean ridge crests. These physical and chemical gradients could support a subsurface microbial community on Earth and other solar bodies such as Mars.

# Abstract # 12921 *(Oral Presentation)* - **Ecosystem Diversity in Yellowstone National Park**

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Our search for life beyond Earth will be facilitated by accurate predictions about the "ecosystems" that we can expect to find, using Earth environments as templates. Mars and Europa may house possible havens for life in the form of hydrothermal systems that supply requisite water, energy and sources of carbon. Chemotrophic organisms in hydrothermal systems on Earth are an excellent example of the intricate relationship between biological and geochemical processes. These thermophilic organisms thrive on chemical energy and mineral precipitates created by water/rock reactions and the cooling or mixing of hydrothermal fluids, processes that often result in chemical systems out of equilibrium (10). A model astrobiological ecosystem, one operating independent of sunlight, requires the consideration of chemosynthetic life as candidate occupants. It is logical to look first to the hydrothermal environments on Earth as working templates for astrobiological models.

Work continues towards our greater understanding of Earth's hydrothermal ecosystems; much thermophilic diversity has been discovered in recent years as various exciting communities are probed (3, 4, 6, 7, 11). Our understanding of the direct interaction of thermophilic organisms with their geochemical environments remains largely unexplored, however. Extreme ecosystems on Earth make better templates for astrobiological ecosystems if the environments are characterized along with the organisms that inhabit them.

In an effort to further characterize thermophilic organisms in the context of their geochemical environments, we have chosen three distinct habitats in Yellowstone National Park. We have completed extensive analyses of geochemical samples collected

in the field in 1999, 2000, and 2001 from hydrothermal environments across the park. To determine the relationship of geochemical and biological diversity in this study, three springs were chosen for their similarity in temperature (80 ± 2°C), but differences in pH and chemical composition. One hydrothermal feature, Obsidian Pool, has a pH of 7.0 ± 1 and is already known for its great diversity of thermophilic organisms as determined by culture-independent studies (1, 2, 9). These studies revealed 86 separate 16S rRNA signatures, few of which are represented in pure culture (5, 8). A second location, Sylvan Springs, where the average pH is 5.5, represents a more acidic example of thermophilic habitats. This spring is among a group that changed from alkaline to acidic about 30 years ago. The last study location is an alkaline spring (pH 8.1) in the Lower Geyser Basin, "Bison Pool".

In conjunction with culturing thermophiles from these environments using location-specific and geochemically-relevant media, we are employing culture-independent methods to detect thermophilic community diversity. Culture-independent methods have revealed an amazing spectrum of diversity in other similar environments (2, 3, 7, 9), consistent with our preliminary results, specifically clone libraries and FISH analyses, for these three locations To date, we have obtained 52 mixed cultures from Obsidian Pool, 18 mixed cultures from Sylvan Spring, and 23 mixed cultures from "Bison Pool" using our location-specific media. With a serial dilution method, seven thermophiles have been isolated from Obsidian Pool, three from Sylvan Springs, and three from "Bison Pool". Our success with culturing thermophiles from these environments reflects the importance of accurately representing the geochemical environment in culturing studies. Because these isolates were obtained in the context of their natural environment, we are able to link them directly to the geochemical processes which govern these hydrothermal ecosystems.

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# Abstract # 12922 *(Oral Presentation)* - **Geochemical Habitats of Deeply-Branched Lineages**

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Representatives of the *Aquificales* and the *Korarcheota* (the deepest Bacterial and Archaeal branches in the 16S rRNA tree, respectively) populate hot springs at Yellowstone National Park. In some cases they are present in the same spring (1, 2, 3). The reasons why these settings are particularly conducive to these microorganisms are unknown, owing to the lack of geochemical data from these locations, as well as the primitive understanding about the metabolic and micronutrient demands of these organisms. As a first step toward linking these organisms and their environment, we have sampled and analyzed water, sediments and gases from several hydrothermal habitats in Yellowstone National Park.

Field measurements include temperature, pH, and aqueous concentrations of oxygen, total sulfide, nitrate, nitrite, total ammonia, and ferrous iron by spectrophotometry conducted within minutes of sample collection. Gas samples are analyzed in the lab by gas chromatography yielding mole fractions of hydrogen, carbon dioxide, hydrogen

sulfide, carbon monoxide, methane, oxygen, and nitrogen. Additional lab analyses include major inorganic species by ion chromatography (Na, K, Mg, Ca, F, Cl, sulfate, phosphate), trace element analyses by high-resolution inductively-coupled plasma mass spectrometry (Li, B, Al, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Sr, Mo, Cd, Ba, W, Hg, Tl, Pb, U) and mineralogy of silicates and iron- and sulfur-bearing phases by X-ray diffraction.

These measurements provide a framework for characterizing the geochemical habitats of the deep microbial lineages. These results are also input for speciation calculations that permit conversion of concentrations into thermodynamic activities of individual aqueous species, and consequent assessment of chemical affinities for hundreds of potential metabolic reactions (4). At Obsidian Pool, which hosts both the *Aquificales* and the *Korarcheota,* reduced constituents like hydrogen sulfide, ammonia and methane are far from equilibrium with their oxidized counterparts such as sulfate, nitrate and carbon dioxide, as are $H_2$ and $O_2$. The latter two constituents are used in the knallgas reaction by members of the *Aquificales* to obtain energy. The chemical affinity for the knallgas reaction at Obsidian Pool is not particularly unusual for Yellowstone springs based on our analytical data. Therefore, if these deep-branching organisms are not present elsewhere with similar energy supplies, nutrient supplies or other geochemical variables may be responsible. At Obsidian Pool, carbon dioxide and $H_2$ are out of equilibrium with methane, making methanogenesis a plausible energy source, while in the same samples methane and $O_2$ are out of equilibrium with $CO_2$, which means that energy is available from methanotrophy as well. These are just two examples of numerous potential energy-yielding reactions in these hydrothermal habitats, and suggests that consortia of organisms may be required even when the deepest-branching organisms are involved.

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# Abstract # 12928 - **Sulfur Geochemical Evidence for Enhanced Sulfate Transport by Vestimentiferan Tubeworms**

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The characterization of biota inhabiting extreme environments is a major focus of the NASA Astrobiology Institute. Furthermore, life isolated from photosynthetically fixed carbon dioxide is often alien and fascinating in its unusual adaptations. *Lamellabrachia* c.f. *luymesi*, a vestimentiferan tubeworm found at cold seeps in the Gulf of Mexico, is able to acquire sulfide from anoxic sediments using posterior extensions of its body. Sulfide feeds the symbiotic bacteria on which tubeworms depend. Models indicate that sulfide uptake will outpace sulfate reduction rates if the reduction rates are limited by diffusion. It is proposed that *Lamellabrachia* facilitates the metabolism of nearby consortia of archea and bacteria by pumping sulfate into the sediments, thus enhancing the production of sulfide necessary for their symbionts.

In June of 2002, ten push-cores were collected by the Johnson Sea-Link submersible in proximity to two tubeworm aggregations. Extracted pore waters from these cores were analyzed for sulfate and sulfide isotope composition. Additionally, rates of sulfate reduction were measured in four cores using $^{35}S$ labeled sulfate. Enhanced transport of sulfate in excess of that replaced solely by diffusion will lead to model estimates that underestimate the measured rates of sulfate reduction. Light isotope compositions of sulfate and sulfide suggest the injection of sulfate into the sediments, and the rate data are used to examine the activity of the bacterial consortia fueling this unique syntrophic relationship.

# Abstract # 12934 - **Tungsten Extraction from Basalt at 100ºC by Hyperthermophilic Archaea**

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Leaching of trace metals by an assortment of microorganisms has been shown to be an important process in many environments. In the deep ocean there is significant interaction between basaltic rocks and hydrothermal fluids concentrated in trace metals. If required, hyperthermophilic microbes will scavenge these metals from hydrothermal fluids, but it is not known if they also need to leach micronutrients from basaltic rocks. The aim of our study is to investigate this issue.

Our study employed the use of the trace metal, tungsten (W). Due to the scarcity of tungsten in crustal rocks, we have tested whether tungsten-dependent hyperthermophiles will leach this trace metal from basalt. Several hyperthermophiles require tungsten for growth, including the facultative aerobe *Pyrobaculum aerophilum* (Afshar et al., 1998) and the strict anaerobe *Pyrococcus furiosis* (Roy and Adams, 2002). Initial results from aerobic growth experiments involving *Pyrobaculum aerophilum* and excluding iron and tungsten, show enhanced release of tungsten from basalt powder. Concentrations of about 3 ppb were obtained after 15 days, with an abiotic control experiment releasing only 0.1 ppb. This enhanced biological leaching is not observed when growth is in the presence of powdered synthetic basaltic glass enriched in tungsten, in which abiotic tungsten concentrations were as high as 270 ppb at 15 days. Leaching is not observed in parallel experiments with *Pyrobaculum aerophilum* under anaerobic conditions, while the strict anaerobe *Pyrobaculum islandicum* demonstrates moderate tungsten leaching, with levels reaching 9 ppb in 15 days and an abiotic control experiment releasing 3 ppb. During all of these experiments, no significant microbial leaching above background was observed for Fe, Ni, or Cr suggesting a high degree of metal specificity in this process.

This study has implications for the origins of life and microbial-rock interactions in hydrothermal environments, as well as in similar environments that may have been present on the early Earth.

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# Abstract # 12936 - **Distribution of Metabolic Activity Within a Deep-Sea Sediment Column**

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ODP Leg 201 Shipboard Scientific Party

It is usually assumed that most metabolic activities in deep-sea sediments occur near the sediment surface. For example, the reduction of oxidized manganese is assumed to occur in relatively shallow sediments below the depth of nitrate reduction and above the depth of sulfate reduction. To test these assumptions and document the distribution of some important microbial reactions at a representative open-ocean site, we calculated net reaction rates of dissolved sulfate reduction, dissolved sulfide production, and dissolved manganese (Mn) production throughout the sediment column at Ocean Drilling Program (ODP) Site 1226. Site 1226 (Leg 201) provides high-resolution measurements of porewater chemicals and is chosen for the study. This site is located in the eastern equatorial Pacific at a water depth of 3297 meters. Its sediment thickness is 420 meters.

Porewater sulfate, sulfide, and $Mn^{2+}$ concentrations, plus formation factor (FF) and porosity ($\phi$) were measured at high resolution at this site (Shipboard Scientific Party, 2002). Assuming steady state conditions and no significant advection, we used the one-dimensional (downhole) mass conservation equation to model the biogeochemical reaction rates. The variation of diffusivity (D) with temperature (T) and viscosity ($\eta$) was considered in the model according to the Stokes-Einstein relation ($D \propto T/\eta$). FF and $\phi$ data were smoothed with LOWESS and then interpolated to the chemical data sampling depths. The chemical profiles were fit with polynomials by using least squares regression

before calculating the gradients. A finite difference approximation was used to calculate reaction rates in the model.

Dissolved sulfate in the sediment at this site has two sources: a downward flux from seawater and an upward flux from formation water in the igneous basement. The model results reveal that most sulfate reduction occurs above 100 meters below sea floor (mbsf) with the consumption rate decreasing from $10^{-11}$ mol/cm$^3$-yr at about 10 mbsf to $10^{-12}$ mol/cm$^3$-yr at about 100 mbsf. From 100 mbsf to the basement, the consumption rate is an order of magnitude smaller. Sulfide is the product of sulfate reduction. Net production of dissolved sulfide starts at about 10 mbsf with a rate of $10^{-12}$ mol/cm$^3$-yr and decreases gradually to $10^{-14}$ mol/cm$^3$-yr at about 200 mbsf. At greater depth, net loss of dissolved sulfide occurs. Throughout the sediment column net sulfate reduction exceeds net production of dissolved sulfide. This discrepancy between net sulfate reduction and net dissolved sulfide production indicates that dissolved sulfide is lost to a solid phase (presumably metal sulfide) throughout the sediment column.

Dissolved Mn is produced by the reduction of oxidized manganese (e.g. $2MnO_2 + CH_2O + 3CO_2 + H_2O \rightarrow 2Mn^{2+} + 4HCO_3^-$). At this site there are three zones of dissolved Mn production. As usually expected, one zone occurs in relatively shallow sediments (between 0 and 12 mbsf). In this interval, the net Mn reduction rate is approximately$10^{-12}$ mol/cm$^3$-yr. Another zone is between 202 mbsf and 240 mbsf with a net Mn reduction rate ($10^{-15}$ mol/cm$^3$-yr) that is 3 orders of magnitude lower than in the near-surface zone. The third zone is from 272 mbsf to 310 mbsf. Its Mn reduction rate ($10^{-13}$ to $10^{-15}$ mol/cm$^3$-yr) is 1 to 3 orders of magnitude lower than in the near-surface zone.

Sinks for dissolved Mn and dissolved sulfide coincide at about 1 to 3 mbsf and 246 to 270 mbsf. The sink for both dissolved phases may be formation of solid manganese sulfides. If so, manganese sulfide precipitation accounts for a few percent of the sulfide disappearance within this sediment column. Formation of iron sulfides may be the likeliest sink for the rest of the sulfide that disappears within the sediment.

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Shipboard Scientific Party, 2002. Leg 201 Preliminary Report. ODP Preliminary Report, 201 [Online]: http://www-odp.tamu.edu/publications/prelim/201_prel/201PREL.PDF

# Abstract # 12948 *(Oral Presentation)* - **The Tinto River, A Model System for an Iron World**

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Extreme ecosystems have recently attracted considerable interest, not only because they prove that life is robust and adaptable, but also because their existence increases the probability of finding life elsewhere in the universe. Most of the best characterized extreme habitats on Earth correspond to geophysical constraints to which opportunistic microorganisms have adapted. However, some extreme acidic environments are unique in that they are the product of biological activity (chemolithotrophy).

The Tinto River (Huelva, Southwestern Spain) is an unusual acidic ecosystem (100 km long, mean pH of 2.3) containing a high concentration of heavy metals and an unexpected level of microbial diversity (1,2). In the past, the extreme conditions of the river were considered the result of intense mining activity. The geomicrobiological analysis of the Tinto ecosystem strongly suggests that these conditions are the result of the metabolic activity of chemolithotrophic prokaryotes, mainly iron-oxidizers (3). The system seems to be controlled by iron, which is not only used as an electron donor, but also as an electron acceptor, allowing a full iron cycle to operate. Furthermore, ferric iron is responsible for

the maintenance of the constant pH of the ecosystem and can protect the different organisms thriving in its waters from radiation.

Laminar, iron-rich stromatolitic formations are generated by the precipitation of different iron minerals on the surface of the biofilms that cover most of the rocks in the river and the riverbed. These structures are similar to ancient massive bioinduced laminated iron bioformations formed long before the first mining activities started in the area 5000 years ago. The existence of these ancient iron-rich deposits formed prior to any known mining activity, under hydrochemical conditions similar to modern deposits, is considered a strong argument in favor of a natural origin of the river (4,5).

Given these characteristics, we postulate that the Tinto River, and other natural acidic environments, are relics of an iron world, in which the basic metabolism of iron-chemolithotrophic organisms control the conditions of the system.

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# Abstract # 12975 - **Microbial Hyperdiversity in CuatrociÈnegas Coahuila**

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The study of Bacteria communities is an exciting new field of ecology, where new molecular techniques are helping to answer some long standing questions regarding community structure. Our first task was to develop the correct biochemical methods for isolation and identification of this very diverse array of Prokaryotes given the particular characteristics of CuatrocienÈgas (CCB) environments. Multivariate statistical analysis was applied to classify information from ca. 3000 different isolates.

DNA was isolated from 250 isolates that represented the biochemical diversity of these microbes, and the gene 16S was amplified using general primers (515FPL and 1492 RPL). RFLP analysis was done using 5 enzymes (SauIII, AluI, HinfIII, HhaI, and HaeIII). All the 250 analyzed strains proved to be distinct. DNA sequences were obtained for some the extreme halophytes. It is interesting that some of the halophytic bacteria were identified with the DNA 16S sequences as generalist bacteria that can survive a wide range of salinity, while others are similar to marine Eubacteria found previously in hydrothermal vents (Halomonas elongata, Chromohalobacter canadensis, and Marinococcus halophilus). A massive sequencing effort of 500 representatives of the

cultivable bacteria is being conducted to gain further information regarding these microbes.

The cultivable microbial diversity in CCB was so enormous for our samples that we decided to characterize the community structure before choosing a specific group of bacteria for population genetic analysis. We collected 10 water samples across a gradient in salinity, pH, and temperature of superficial water as well as 8 samples from deep springs and 3 samples of deep subterranean water (more than 200 m below the valley). DNA was extracted in situ using specific kits. Also, water and sediment samples were plated in situ using 12 different media; total DNA of the microbes that grew in the plates was also extracted. Bacteria and Archaea did grow in the selected media, and a salt range has been established for each clone in order to determine its environmental tolerances. The ribosomal gene 16S was amplified using PCR for both total DNA and cultivable DNA, and TRFLP data were obtained for each site for both types of samples. Comparative analysis of the community patterns will tell us not only differences among sites and how much of the diversity we are losing by growing the prokaryotes on plates, but it will tell us also the abundance of the main OTUs in each site.

# Abstract # 12992 - **A Summary of NAI Field Expeditions**

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Field work is an important part of the research of the NASA Astrobiology Institute. It brings together scientists from a myriad of disciplines though shared scientific interests. Field work can also be very interesting to the general public. The efforts by a multidisciplinary team of field scientists can result in discoveries that combine to construct a more complete understanding of the world. This is of particular interest for the general public, whose exposure to astrobiology is often limited to the reporting of discoveries in the popular media. Also, the reporting of discoveries made in the field may serve to draw more people, scientists and non-scientists, into astrobiology.

For these reasons and more, NAI Central has been soliciting information about field expeditions as part of the NAI annual report. The data collected from NAI Year 2, 3 and 4 have been analyzed to summarize NAI field expeditions and to answer the following questions:

Which sites around the world are being visited?
Which sites are of particular interest to astrobiologists?
What is being researched?
What have they found?
Which sites are, or can be, highlighted to the general public?

To date, NAI scientists have made over 200 expeditions on all seven continents plus the oceans. Field work has been conducted at Yellowstone National Park, Western Australia, the Antarctic, the Rio Tinto in Spain, and hydrothermal vent fields on the Endeavour segment of the Juan de Fuca Ridge. These are good examples of sites important to astrobiologists, and they may be interesting to a broader audience. These sites are highlighted on the poster with photographs and research summaries.

# Abstract # 12994 - **A Comparison of 16S rDNA Sequences from Cyanobacteria That Build Thalassic Teepees and Athalassic Mats in Evaporitic, Gypsiferous Environments**

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Halotolerant cyanobacteria can form vertically stratified communities in both thalassic (marine) and athalassic (non-marine) hypersaline environments. Such communities are also known to have formed in old (> 1,000 years b.p.) sedimentary evaporites. Using denaturing gradient gel electrophoresis (DGGE) separation of PCR-amplified 16S rDNA alleles from cyanobacteria, we compared two microbial communities from geographically separated, hypersaline environments in which gypsum is precipitating. One occurs as vertically stratified endolithic communities in gypsum "teepees" of thalassic ponds (150-180‰ salinity) in Guerrero Negro, Baja California Sur, Mexico. The other forms benthic microbial mats in athalassic ephemeral ponds (75-360‰ salinity) in the Cuatro Ciénegas Basin, Coahuila, Mexico. Our comparison showed that members of the Halothece cluster represented the virtual totality of the cyanobacterial diversity found in both the thalassic and the athalassic hypersaline environments. These results indicate that this cyanobacterial cluster represents a potential biomarker for ancient surface-lit evaporitic communities where gypsum precipitated (> 120‰ salinity).

# Abstract # 12997 - **Microscale Analysis of Microbial Nitrogen Cycling in Biological Soil Crusts of the Colorado Plateau**

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Biologically crusted desert soils, the terrestrial equivalent of microbial mats, cover up to 70% of the Earth's arid lands. These crusts, constructed by cyanobacteria, provide for thin (1cm) microbial communities. Such communities may easily be considered extreme, as the average yearly precipitation occurs in 60 short-lived storms per year (17 - 23cm annually), and summer soil temperatures routinely exceed 50ºC. Nitrogen cycling in this environment is poorly understood, as high rates of nitrogen fixation are often found, but well developed soil crusts do not display a proportionately high nitrogen reservoir, indicative of rapid biogeochemical cycling.

Microbial and chemical characterization utilized various techniques, including: microbiological culturing, colorimetric analyses, microscopic analyses, DNA based molecular techniques, and microsensors. Our results, taken together, indicate a complex community stratified on the millimeter scale with the ability to rapidly cycle nitrogenous compounds. Particular microbial types and processes were found to peak in specific microhorizons of the crust. These results indicate that to uncover the intricacies of the nitrogen cycle in desert soils, one must consider the architecture of the microbial population and its biogeochemical functioning.

# History of Planetary Habitability Abstracts

# Abstract # 12572 *(Oral Presentation)* - **Modeling the Response of the Late Ordovician Climate System to Different Forcing Factors**

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The Ordovician was a time of extensive diversification and radiation of marine life. However, at the end of the Ordovician (ca. 443 Ma), a major mass extinction occurred that is the second most devastating extinction to marine life in Earth history. This mass extinction is generally attributed to environmental perturbations associated with an extensive yet short-lived glaciation; evidence for extraterrestrial causes is lacking.

In order to better understand the climate dynamics during this crucial time period for the evolution of life, we used numerical models to investigate the response of the Late Ordovician climate system to different forcing factors. Specifically, we evaluated the impact of changes in paleogeography, atmospheric $pCO_2$, solar insolation cycles (obliquity), poleward ocean heat transport, and sea level.

We performed sensitivity experiments with the atmospheric general circulation model GENESIS on two stages of the Late Ordovician (Caradocian, ~454 Ma; Ashgillian, ~446 Ma) under a range of atmospheric $pCO_2$ values (8-18x PAL; pre-industrial atmospheric level), high and low sea level, and two values of poleward ocean heat transport in order to determine the importance of these variables on long-term global cooling during the Late Ordovician. We then coupled a 3-dimensional ice sheet model to GENESIS in order to investigate the necessary boundary conditions for ice sheet formation. All simulations with a high sea level and normal heat transport remain free of ice sheets, even with $pCO_2$ levels as low as 8x PAL. In the Caradocian simulations, ice sheets form in three scenarios: (1) with $pCO_2$ of 8x PAL and a low sea level and normal poleward ocean heat transport, (2) with $pCO_2$ of 8x PAL and a high sea level and reduced (50% of normal) poleward ocean heat transport, and (3) with $pCO_2$ of 15x PAL and a low sea level and reduced poleward ocean heat transport. In the Ashgillian simulations, ice sheets form in only two scenarios: (1) with $pCO_2$ of 8x PAL and a low sea level and normal poleward ocean heat transport, or (2) with $pCO_2$ of 8x PAL and a high sea level and reduced poleward ocean heat transport. Assuming that $pCO_2$ did not fall below 8x PAL, a minimum value for this time period based on geochemical modeling and geochemical data from paleosols, a drop in $pCO_2$ and the paleogeographic evolution coupled with an

ice-albedo feedback can therefore be regarded as only preconditioning factors for the Late Ordovician glaciation. In order for ice sheets to form in the Late Ordovician, other factors must have changed, such as a drop in sea level from its generally high Late Ordovician levels and/or a reduction in poleward ocean heat transport. A lower sea level along with paleogeographic change lead to more exposed land area where ice sheets can grow.

We also used the ice sheet model in order to investigate the sensitivity of the Late Ordovician climate system to orbital forcing at the obliquity timescale (30000 to 40000 years). Our simulations indicate that large ice sheets, grown during periods of low $pCO_2$ (8x PAL), can subsequently be sustained during periods of higher $pCO_2$ (9-10x PAL). Thus, if atmospheric $pCO_2$ was one of the main drivers of climate during the Late Ordovician, then atmospheric $pCO_2$ must have risen to greater than 10x PAL to melt the ice-sheets in the higher southern latitudes and end glaciation.

Because of the absence of a dynamical ocean in GENESIS, atmosphere-ocean interactions and potential climate feedbacks of the global ocean cannot be investigated. We therefore used the output from GENESIS as forcing boundary conditions and initial conditions for a ocean general circulation model (MOM v.2.2) in order to investigate oceanic feedbacks to the climate system. In particular, we looked into changes in ocean heat transport in response to continental drift, plus changes in atmospheric $pCO_2$ and sea level. In all simulations, a drop in sea level led to a reduction in poleward ocean heat transport. This indicates a possible positive feedback that could have led to enhanced global cooling in response to pre-glaciation sea level drop during the Late Ordovician. Alterations in poleward ocean heat transport linked to changes of atmospheric $pCO_2$ also indicate that there is a threshold of 10x PAL, above which ocean current change cannot be held responsible for glaciation in the Late Ordovician. Continental drift could explain the observed global cooling trend in the Late Ordovician through a combined poleward ocean heat transport feedback and increased ice-albedo effect, if atmospheric $pCO_2$ was low during the entire Late Ordovician.

In summary, our numerical models show that ocean-atmosphere interactions played a crucial role in this glaciation. While changes in paleogeography and atmospheric $pCO_2$ mainly preconditioned the global climate system for glaciation through global cooling, changes in sea level or solar insolation were responsible for initiating and sustaining the glaciation.

# Abstract # 12604 - **The Oxygen Isotopic Composition of Trace Sulfate Associated with a Neoproterozoic Cap Carbonate from Namibia**

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Significant variations in the sulfur isotopic composition of trace sulfate bound in post-glacial carbonates suggest that sulfur cycling in the late Neoproterozoic may have been strongly influenced by global glaciations. Here, we present the oxygen isotopic composition of trace sulfate from the Maieberg cap carbonate in Namibia in order to assess variations in the oxygen cycle that may have accompanied the snowball Earth events.

The oxygen isotopic composition of seawater sulfate is controlled by processes associated with the delivery and export of sulfate to and from the oceans. Modern $\delta^{18}O$ of seawater sulfate is 9.35 ‰ (VSMOW), as opposed to 0‰ for $\delta^{18}O_{H2O}$. Sulfate is delivered to the oceans via the oxidative weathering of pyrite and dissolution of calcium sulfate minerals. Sulfate is removed from the oceans primarily by two mechanisms: (1) calcium sulfate precipitation (evaporates, ridge flank hydrothermal systems) and (2) bacterial sulfate reduction and formation of sedimentary pyrite. There is essentially no isotopic fractionation associated with the weathering of evaporites, therefore, both the $\delta^{18}O_{sulfate}$ and $\delta^{34}S_{sulfate}$ delivered to the oceans represents what was previously deposited in

marine sediments. Additionally, there is a negligible sulfur isotope fractionation associated with sulfide oxidation. By contrast, the oxygen incorporated into sulfate during the bacterial oxidation of sulfides is derived from both ambient $H_2O$ and $O_2$. This is significant because atmospheric $O_2$ has a heavier isotopic signature than fresh-water $H_2O$. This difference would have become most pronounced with the advent of terrestrial transpiration and respiration, forcing the $\delta^{18}O_{O2}$ to more enriched values. Therefore, different processes govern the isotopic composition of sulfur and oxygen during the production of sulfate via sulfide oxidation and may provide independent evidence for or against global glaciation in the late Neoproterozoic.

$\delta^{18}O_{sulfate}$ of precipitated sulfate minerals in evaporites is enriched by ca. +3.5 ‰. A larger kinetic isotope effect prevails during bacterial sulfate reduction as $^{16}O$ is preferentially dissimilated in the production of $HCO_3^-$ and $CO_2$. Additionally, there appears to be an oxygen isotope exchange between sulfate and water during bacterial sulfate reduction. The combination of these effects produces fractionations between 4 to 29 ‰ at Earth-surface temperatures.

We analyzed the $\delta^{18}O_{sulfate}$ for 30 samples from two separate localities of the Maieberg Formation (Namibia). In the first locality (G2008), the Maieberg Formation contains approximately 30 meters of cap dolostone (Keilberg Member) followed by 95 meters of limestone and then 80 meters of dolostone. $\delta^{18}O_{sulfate}$ values are low at the base of the section (ca. –2 ‰) and rise sharply to values ca. 9 ‰. The transition from cap dolostone to limestone attends a sharp increase in siliciclastic input and a negative shift in $\delta^{18}O_{sulfate}$ to values ca. 0 ‰. $\delta^{18}O$ then rises abruptly to >10 ‰ in the overlying dolostone. In the second locality (P4017), the Maieberg Formation contains approximately 15 meters of cap dolostone, followed by 60 meters of limestone. $\delta^{18}O_{sulfate}$ values are low at the base (ca. 2 ‰) and rise abruptly to 16 ‰ within 5 meters and then level off around 12 ‰ through the rest of the section. P4017 does not appear to have the sharp increase in siliciclastic input relative to the first locality.

The preliminary results indicate that the large shifts in $\delta^{18}O_{sulfate}$, coupled with large variations in $\delta^{34}S_{sulfate}$, reflect a complex interplay between riverine inputs, oceanic upwelling and the post-glacial transgression of an ocean with low sulfate concentrations. Additionally, offshore-onshore trends illustrate the importance of fluvial influence on surface waters in post-glacial ocean.

# Abstract # 12612 - **Chemostratigraphy of Neoproterozoic 'Cap' Carbonates from the Volta Basin, West Africa**

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The Neoproterozoic Era includes some of the most extreme ice ages in Earth history. The exact number of glaciations is unknown, although there were at least two events of global reach and possibly an equal number of lesser advances. Neoproterozoic glacial deposits in West Africa have proven particularly difficult to correlate with better-constrained successions elsewhere. In most West African successions, only a single glaciogenic deposit occurs, generally as part of a stratigraphic 'triad' consisting of tillite, carbonate, and bedded chert; the age of these deposits and their synchroneity across the craton remain controversial. We report isotopic data from carbonates that cap tillites in the Volta Basin (Sud-Banboli Group). In the three sections measured, δ13C (ppm v. PDB) begins at ~–2 to –3 and drops to –5 to –6, correlated with a drop in both δ18O and a transition from dolomite to limestone. This pattern – both the drop in δ13C and the correlation between δ13C, δ18O, and lithology – has been observed in Neoproterozoic 'cap' carbonates on other cratons, suggesting that it reflects primary depositional variations. In addition, the strong positive correlation between lithology, δ13C, and δ18O suggests that lithological variation may be controlling isotopic variation, implying that the dolomite is either primary or very early diagenetic, precipitating in equilibrium with seawater. This would require low levels of sulfate, consistent with available S-isotopic data, the conditions of seawater chemistry hypothesized in the aftermath of a 'snowball Earth' and the presence of barite crusts in association with some cap carbonates (e.g., Hoffman et al. 2002, abstract: ABSciCon 2002)

The pattern of carbon isotope variation in the Volta Basin 'cap' carbonates suggests that underlying tillites may be Marinoan in age. This interpretation is supported by distinctive lithological characters observed in Volta Basin 'cap' carbonates and other Marinoan correlatives. Tillites elsewhere on the craton have been suggested to be latest Precambrian or Early Cambrian in age. Either the basis for these proposals requires reexamination, or West African tillites record more than one glacial event, and the 'triad' is diachronous.

# Abstract # 12617 - **The Origin of Hematite Crystals Associated with Archean Redbeds in the Lake Shebandowan Area, Canada — A Preliminary Study From Chemical Compositions and Oxygen Isotopes**

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The 2.7Ga "redbeds" in the Shebandowan greenstone belt have been suggested by Shegelski (1980) as the oldest redbeds formed under an oxygenated atmosphere. However, these redbeds are not like normal redbeds that developed in fluvial arkosic sandstone. The Shebandowan redbeds are typically ~30 to ~100m thick conglomerate units. They are composed of poorly sorted red-colored clasts with sizes ranging from ~10 to ~50cm; the matrix varies from red to gray-green in color. Because of these unusual characteristics, some researchers have disputed whether they are "true" redbeds, in which the goethite/hematite crystals formed by $O_2$-rich groundwater during early diagenesis of the sediments. Some previous researchers have suggested that hematite crystals in the Shebandowan redbeds may have formed by reaction with oxidized volcanic gas at high temperature or by low temperature oxygenated groundwater several hundred million years after sediment accumulation. We have initiated this study to determine the origin of hematite crystals in the Shebandowan redbed area by examining its physical, chemical, and isotopic characteristics.

The clasts are composed mostly of andesite and arkosic sandstone with rare gabbro. The matrix is also composed of smaller fragments of the same rock types. Both the andesite and sandstone are comprised of fine grain crystals of feldspar, quartz, magnetite, hematite, and chloritized mafic minerals (hornblende and biotite). Typically hematite crystals in the clasts are very fine-grained (1 to 5μm) and occur as dissemination along grain boundaries of feldspar and chlorite. High accumulation of hematite crystals is

observed around the chlorite crystals. The chloritized phenocrysts sometimes contain inclusions of larger hematite crystals (20 to 50μm). These occurrences of hematite crystals suggest they formed after chloritization events. The chloritization probably occurred by hydrothermal processes.

Electron microprobe analysis of the hematite crystals indicates variable contents of $TiO_2$ ranging from ~0 to 1.8 wt%.

The oxygen isotopic composition of individual grains of hematite was determined with a Cameca-6f secondary ion mass spectrometer (SIMS). The $\delta^{18}O$ values range from 13 to 15 ±2‰. Hematite crystals that formed at T > 200ºC typically possess $\delta^{18}O$ values less than +3‰. The $\delta^{18}O$ values around +14‰ suggest these hematite crystals formed (or re-equilibrated) at low temperatures.

The mineralogical, chemical, and isotopic data obtained on hematite crystals in our samples are consistent with the following model for the history of the redbeds:

(1) Conglomerates and sandstones, comprised mostly of chloritized andesite, accumulated on land (i.e., fluvial sandstones) prior to ~2.7Ga.
(2) These conglomerate/sandstone beds reacted with $O_2$-rich groundwater to form hematite-rich redbeds.
(3) The redbeds were mechanically disintegrated by tectonic activity, and fragments of the redbeds were transported to and re-deposited on the ocean floor in areas of active submarine volcanism about 2.7Ga.

Our preliminary study, therefore, supports the idea proposed by Shegelski (1980) that the Shebandowan redbeds contain evidence that the atmosphere was oxygenated by 2.7Ga.

# Abstract # 12622 - **Were Ocean Impacts an Important Mechanism to Deliver Meteoritic Organic Matter to the Early Earth? Some Inferences from Eltanin**

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Several workers have addressed the potential for extraterrestrial delivery of volatiles, including water and complex organic compounds, to the early Earth. For example, Chyba and Sagan (1992) argued that since impacts would destroy organic matter, most extraterrestrial organics must be delivered in the fine-fractions of interplanetary dust. More recent computer simulations (Pierazzo and Chyba, 1999), however, have shown that substantial amounts of amino acids may survive the impacts of large (km-sized) comets and that this may exceed the amounts derived from IDPs or Miller-Urey synthesis in the atmosphere. Once an ocean developed on the early Earth, impacts of small asteroids and comets into deep-ocean basins were potentially common and may have been the most likely events to deliver large amounts of organics.

The deposits of the late Pliocene impact of the Eltanin asteroid into the Bellingshausen Sea provide the only record of a deep-ocean (~5 km) impact that can be used to constrain models of these events. This impact was first discovered in 1981 as an Ir anomaly in sediment cores collected by the USNS Eltanin in 1965 (Kyte et al., 1981). In 1995, *Polarstern* expedition ANT XII/4 made the first geological survey of the suspected impact region. Three sediment cores sampled around the San Martin seamounts (~57.5S, 91W) contained well-preserved impact deposits that include disturbed ocean sediments and meteoritic impact ejecta (Gersonde et al., 1997). The latter is composed of shock-melted asteroidal materials and unmelted meteorites. In 2001, the *FS Polarstern* returned to the impact area during expedition ANT XVIII/5a. At least 16 cores were recovered that contain ejecta deposits. These cores and geophysical data from the expedition can be used to map the effects of the impact over a large region of the ocean floor.

One of the most remarkable characteristics of this impact deposit is the high concentrations of melted and unmelted meteoritic material. We estimate the total amount of meteoritic materials by measuring bulk Ir concentrations in the sediment (using 187 ng/g as the concentration of Ir in the meltrock and the precursor asteroid; Kyte, 2002), and by measuring the amount of meteoritic ejecta in the coarse fractions of the sediment.

These analyses have led to an estimated minimum diameter for the projectile of ~1 km. High Ir concentrations and abundant unmelted fragments of basaltic meteorites have shown that this object was a differentiated meteoroid, likely a low-metal mesosiderite. Although this particular object was not a volatile-rich carbonaceous chondrite, we can be relatively certain that it was derived from the asteroid belt. We have now established that high concentrations of meteoritc debris can be found across over 80,000 $km^2$ of the ocean floor. The ejecta deposit probably occurs over a much larger area. Observed fluxes of coarse (mm-sized) particles range from ~0.2 to 8 $g/cm^2$ over this region. Although 90% of this debris is shock-melted asteroid, the remaining 10% is unmelted meteorite material.

Because this is the only known impact deposit of its kind, it is not possible to know how representative it is of deep-ocean impacts in general. But it is reasonable to assume that meteorite survival may be a common result of this type of phenomenon and that carbonaceous asteroids may produce localized deposits of very organic-rich sediments. However, whether or not this organic matter is ever available to play a role in the development of life on the early Earth may depend on its ability to actually get dissolved in the early oceans. In the case of the Eltanin impact, the localities with the most concentrated fluxes of meteoritic debris were also those where it was most rapidly buried. The impact severely disturbed sediments of the ocean floor and fine-grained sediments that were dispersed in the water column also buried much of the ejecta near ground zero. Thus, if large amounts of organic matter surviving small ocean impacts is concentrated in coarse, unmelted meteorites, these organics may be rapidly sequestered from the hydrosphere.

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# Abstract # 12626 - **Investigating Isotope Exchange Between Dissolved Aqueous and Precipitated Amorphous Iron Species**

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Isotope exchange between amorphous Fe oxyhydroxides (ferrihydrite) and dissolved aqueous Fe is critical to understanding global cycling of Fe. Ferrihydrite is the primary Fe phase to precipitate from aqueous Fe solutions, and it is a precursor to many diagenetically produced minerals, such as hematite and goethite. Understanding the possible role of Fe isotope exchange between ferrihydrite and associated dissolved aqueous Fe species will increase our understanding of abiological Fe isotope fractionations, and this will ultimately further our ability to recognize biological signatures through the detection of Fe isotope fractionations induced solely by biological processes.

Determining if there is Fe isotope exchange between dissolved aqueous Fe and precipitated ferrihydrite will allow for inferences about Fe isotope compositions in many aqueous systems. For example, the isotopic composition of Fe delivered to the world's oceans from dissolved riverine loads has yet to be measured, and its impact on the overall isotopic composition of Fe in seawater is not well constrained. If there is large fractionation between aqueous Fe and ferrihydrite at the time of precipitation with no subsequent isotopic exchange, the dissolved load should show significant isotope variations that could ultimately impact the Fe isotope composition of seawater. If, however, the precipitated Fe isotopically exchanges with surrounding fluids, particularly in places such as estuaries where ferrihydrite is known to flocculate and be deposited,

isotopic "back reaction" will buffer the dissolved and precipitated Fe load components to an equilibrium value. These possible differences in the behavior of Fe isotopic exchange will have a major impact on Fe isotope compositions of modern oxic seawater, where the bulk of Fe is oxidized to ferric iron.

Isotopic exchange between ferrihydrite and Fe in solution could also impact diagenetic processes. Ferrihydrite precipitated from solution has been shown to subsequently form hematite and magnetite through diagenetic mechanisms. The potential ability for these precipitated Fe phases to "back react" isotopically with diagenetic fluids could mean that Fe isotopic compositions of hematite measured from the rock record do not record the Fe isotope composition of the fluid that initially precipitated them. For example, the Fe isotope composition measured in hematite from Archean banded iron formations may not represent the Fe isotope composition of Archean seawater, but rather the isotopic composition of diagenetic fluids.

Tracking Fe isotope exchange between aqueous Fe(III) and ferrihydrite is an experimental challenge because the rate of isotopic exchange between solid and dissolved species is typically very slow at low temperatures (<300ºC). In order to promote isotopic exchange between aqueous Fe(III) and ferrihydrite, a 3nm sized ferrihydrite (NANOCAT Super Fine Iron Oxide) is used, with 35% of the Fe at the surface of each grain. Using this ferrihydrite, if isotope exchange occurs, even only between atoms at the surface of ferrihydrite particles, the total amount of exchange will be quite high. The kinetics of isotope exchange between ferrihydrite and dissolved Fe is being studied using a $^{57}$Fe tracer approach. Initially, we expect there to be rapid isotope exchange between the dissolved $^{57}$Fe tracer and aqueous Fe(III) dissociated from the ferrihydrite with a normal Fe isotope composition, followed by slower exchange between the ferrihydrite and aqueous Fe.

Previous studies from our group have investigated Fe isotope variations in naturally occurring ferrihydrite. In one study, the suspended sediment loads from several major North American rivers, shown to contain as much as 50% poorly crystalline Fe oxides, were analyzed for their Fe isotope compositions. In all cases, the suspended river loads were shown to have Fe isotopic compositions comparable to the Bulk Earth Fe isotopic baseline measured in all terrestrial igneous rocks. In a separate study at Chocolate Pots Hot Springs in Yellowstone National Park, we investigated isotopic variations seen in ferrihydrites formed as aqueous ferrous Fe from an anoxic hot spring source is exposed to the atmosphere. These ferrihydrites were shown to have highly variable isotopic compositions. Heterogeneity was even more evident in partial dissolution studies of the same samples. It is predicted that these differences in Fe isotope composition of naturally occurring ferrihydrites may be representative of residence time in their surrounding fluids. If there is isotopic exchange between precipitated and dissolved Fe phases, the longer residence time of ferrihydrite in suspended river loads may allow the necessary time for isotopic exchange to occur, buffering the measured isotope compositions to baseline values.

# Abstract # 12637 - **Stress Mechanisms and the Evolution of Europa**

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**Introduction:** Understanding the astrobiological potential of Europa requires an understanding of its history of deformation, including: origin of its surface features, possible changes in geological style over time, and means of material exchange between the surface and interior. We have embarked on a study that integrates these themes. The present study addresses how Europa's lineament patterns constrain the stresses that have shaped its surface over time. Here we discuss the orientations of lineaments near Europa's leading point of motion in light of the possibility that lineament patterns in Europa's equatorial regions resulted from failure in shear (due to nonsynchronous stress), rather than tension (due to diurnal or nonsynchronous stress) [8,9]. The shear failure hypothesis is supported by comparison of the stratigraphy and orientation of lineaments to the relevant stress fields. These lineaments suggest that Europa's shell has rotated nonsynchronously by <90° during the period of lineament formation recorded in the study area, suggesting that Europa's geological style may have changed with time.

**Background:** Nonsynchronous rotation stress patterns have swept across the surface of Europa by an uncertain amount, with principal stresses represented as orthogonal directions of least and greatest compression [1-4]. Many researchers have assumed that lineaments formed as tension cracks, perpendicular to the least compressive stress direction (hence their orientations should rotate systematically through time) [3,5,6]. The assumptions of this model break down in two antipodal football-shaped zones in the equatorial region of Europa, in which both principal stresses are compressional [1,2,4] (i.e., in which the least compressive stress is compressional, rather than tensile). Within each such Equatorial Compressional Zone (ECZ) [9], nonsynchronous rotation stresses cannot form lineaments as tension cracks. Although diurnal stresses can be tensile in the ECZs, the orientation of tensile stress in these zones is limited to nearly N-S (predicted to produce E-W lineaments) and does not rotate systematically [4].

Due to nonsynchronous stresses, lineaments in the ECZs may form as conjugate pairs of strike-slip faults, with predicted orientations ~30° from the greatest compressional stress direction [9]. Conjugate fault formation has important implications for the amount of nonsynchronous rotation that has occurred through time.

**Mapping Methods:** We have mapped >50 lineaments near the leading point of Europa (lat 0-30°, lon ~80°) in the Galileo E15REGMAP02 observation at ~235 m/pixel [cf. 5]. This region is predicted to be just emerging from an ECZ, as carried by nonsynchronous rotation. Near-simultaneous formation of structures with conjugate orientations is predicted, as is a lack of N-S and E-W lineament orientations. Cycloidal lineaments [10] are not included in the data set. Determination of a precise stratigraphy of individual Europa structures is challenging, and ideally requires application of Geographical Information Systems (GIS) techniques. We have adopted an objective, semi-quantitative method of stratigraphy based on the number of times each mapped lineament is overcut and undercut by other lineaments.

**Preliminary Results:** We find that the predicted dominant E-W orientation of lineaments if due to diurnal stress patterns is completely lacking in the mapped area, suggesting that this model is of unlikely application to the majority of structures in the region (with the probable exception of cycloidal features [7]). This result is consistent with the fact that diurnal stresses are about one tenth the magnitude of nonsynchronous rotation stresses [2,10]. We infer that the diurnal stress model has not been significant in creation of structures in the ECZ. We note that in each neighboring Equatorial Tensile Zone (ETZ), E-W structural orientations are also expected to dominate. The absence of E-W structures in the mapped area suggests that ETZ stresses did not contribute to lineament formation. Because the mapped area is predicted to be just emerging form an ECZ, this places an upper limit of ~90° of nonsynchronous rotation for the icy shell during the recognizable period of lineament formation.

Lineament orientations in the study area are best fit by the predicted pattern of conjugate shears resulting from nonsynchronous rotation in an ECZ. The lineament orientations of N-S and E-W are expected to be particularly absent from the study area, in agreement with the orientations of the mapped lineaments. Notable departures from the predictions are the youngest and oldest features mapped, which cannot be easily explained by either diurnal or nonsynchronous stress patterns. Some evidence is found for NE-NW interweaving of lineaments based on our semi-quantitative stratigraphy, which may support the hypothesis of near-simultaneous or successive lineaments formed as conjugate shear fractures. Predicted differential stress magnitudes in the ECZ [4] are sufficient to cause failure in shear if lithospheric strength is frictionally controlled.

**Conclusions:** We have re-evaluated the stratigraphy of lineaments near Europa's leading point, based on the hypothesis that lineaments formed in an ECZ may be conjugate shears. Comparison with observed lineament orientations and stratigraphy is a good match to the nonsynchronous stress model predictions and a poor match to the predictions of diurnal stressing. A lack of E-W structures in the study area provides an upper limit of ~90° for the amount of nonsynchronous rotation that has occurred during the period of lineament formation recorded in the study area. This is significantly less than some recent interpretations [5-7], but consistent with earlier studies [1-4], and suggests that Europa’s geological style may have changed over time. We infer that the bulk of Europa's recognizable surface deformation may have occurred during finite nonsynchronous rotation of the ice shell, rather than multiple rotations. It is plausible that

changes in geological style correlate to changes in the astrobiological potential of the satellite, and in mechanisms of transport between the surface and subsurface.

A truly quantitative analysis of the hypothesis of near-simultaneous or successive lineaments formed as conjugate shear fractures necessitates use of GIS techniques to confidently determine whether a successive interweaving of individual lineament orientations is present in this and other equatorial regions. These orientations can be quantitatively compared to the stress predictions from nonsynchronous and diurnal stresses.

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# Abstract # 12639 - **Distinctive Carbonates in Five Martian Meteorites: Search for Water on Mars**

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Recently published results from Mars orbital data strongly support both the idea that large bodies of water were present at the surface in the past (1) and the possibility that significant amounts of water ice are currently present in the regolith just below the planet's surface (2). These new findings increase the significance of the evidence in martian meteorites that some low-temperature aqueous alteration and secondary mineral deposition occurred on Mars.

Carbonates are especially important because they are associated with the possible signs of martian biologic activity in meteorite ALH84001 proposed by McKay *et al*. (3). Most of the martian meteorites examined for secondary phases have been found to contain carbonates, and some of these carbonates are demonstrably from Mars. Carbonates in different meteorites are not all alike, however. The concentrically zoned carbonates in ALH84001 are unique among the martian meteorites analyzed in detail thus far; petrographically similar carbonates have not been described in the other martian meteorites. Carbonates in the other

meteorites commonly occur as irregular vein fillings or as small subhedral to euhedral crystals. Calcium carbonate seems to be the most common, and has been described in the observed falls Nakhla, Shergotty, and Chassigny along with Antarctic meteorite EETA79001. Sideritic carbonate is present in Nakhla, while magnesian carbonates have been described in Chassigny and EETA79001. It is likely that carbonates in the martian meteorites can help us answer a number of questions. For example, did they all result from deposition by relatively low-temperature aqueous fluids? Is it possible to obtain information about the fluids from which the carbonates precipitated? Based on textures and compositions of the carbonates, what can we infer about the near-surface history of each rock on Mars? Were some carbonates mobilized and re-precipitated after the meteorites landed on Earth? If so, is it still possible to determine anything about the pre-terrestrial history of the phases? These comparative studies should provide a basis for further studies of the meteorites and should also help increase background knowledge for sample return missions.

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# Abstract # 12644 *(Oral Presentation)* - **Aeolian Processes and Long Period Climate Change on Mars**

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Wind deflation and deposition are powerful agents of surface change in the present Mars climate regime. Recent studies indicate that, while the distribution of regions of potential deflation (or erosion) and deposition is remarkably insensitive to changes in orbital parameters (obliquity, timing of perihelion passage, etc.), rates of eolian surface modification may be highly sensitive to these parameters even if the atmospheric mass remains constant. But atmospheric mass is likely to be sensitive to obliquity, especially if a significant mass of carbon dioxide can be stored in the regolith. Deflation and erosion are highly sensitive to surface pressure, so feedback between orbit variations and surface pressure can greatly enhance the sensitivity of Aeolian modification rates to orbital parameters. We use statistics derived from a 1 Gyr orbital integration of the spin axis of Mars, coupled with 3-D global circulation models at a variety of pressures, to explore this feedback. A 1-D energy balance model is employed to illuminate the gross characteristics of long-term wind erosion and deposition on Gyr timescales. Finally, surface textural features in high resolution images from the Mars Global Surveyor Mars Orbital Camera (MOC) are examined in the light of the orbital integrations and model results. The ability to couple geological information to orbital forcing and climate change, and the resulting distribution of wind erosion and deposition will guide future exploration, analysis of aqueous mineral deposits, and the search for life.

# Abstract # 12665 - **Growth of *Methanopyrus kandleri* during Serpentinization of Olivine**

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Hydrothermal systems in the early Earth were likely hosted by olivine-rich ultramafic igneous rocks. In such systems, the most important silicate-hydrolysis reaction is the serpentinization of olivine. Because this reaction involves significant production of hydrogen gas, actively serpentinizing ultramafic rocks should represent favorable environments for chemoautotrophic organisms in the early Earth. We are investigating this hypothesis by conducting experiments on serpentinization in the presence of microorganisms.

We are using the methane producing microorganism "*Methanopyrus kandleri*" because its molecular phylogeny suggests minimal evolution away from the hypothesized universal ancestor of all life on Earth. Further motivation for studying the interaction between methanopyrus and serpentinization is based on two observations. First, *M. kandleri* – which thrives at 100˚C and inhabit oceanic hydrothermal vents – require hydrogen gas, $H_2$, for metabolism. Its metabolic pathway is one in which carbon dioxide, $CO_2$, is reduced by $H_2$ to produce methane, $CH_4$. The chemoautotrophic reaction produces energy for growth. $H_2$ is abundant during serpentinization because natural olivine is a solid solution between forsterite ($Mg_2SiO_4$, ~90%) and fayalite ($Fe(II)_2SiO_4$,~10%). Because serpentine incorporates <10% Fe(II) olivine hydrolysis produces magnetite ($Fe(III)_2Fe(II)O_4$) by oxidizing the fayalite component of olivine. The second reason to examine M. kandleri is that the organism facilitates reduction of aqueous Fe(III)-bearing organic compounds (Lovely et al., 2000; Vargas et al., 1998). The reduction of Fe(III) from magnetite would release $O_2$ and could create a positive feedback for additional fayalite oxidationl.

We conducted biotic and abiotic experiments with natural forsterite (San Carlos olivine), fayalite, and magnetite perchased from Ward's Natural Science and serpentine obtained

from the UCLA mineral collection. All minerals were crushed in a steel mortar and pestle and sieved to size fraction 110-250$\mu$m. The crushed minerals were ultrasonically cleaned in acetone, rinsed in Millipore water, then dried in a 110°C oven. Mineral assemblages (forsterite only, forsterite + magnetite, fayflite + magnetite, serpentine only, serpentine + forsterite) were placed in glass, batch reactors filled with 20 ml growth medium and a 3 bar $H_2/CO_2$ head space both with and without *M. kandleri* cells. Two types of growth medium were used; a standard growth medium for M. kandleri and an Fe, Ca free medium.

A "healthy" experiment is one in which the population density as measured by number of cells per microscope field is large *relative* to other biotic experiments; therefore "health" is a relative term. In standard growth medium, serpentine-only and serpintine + fosterite experiments were healthiest; fayalite + magnetite were least healthy, possibly due to a weathering product of oxidized iron on the surface of fayalite (Fe(III) oxide, hematite) which may have poisoned experiments by increasing the $fO_2$ in the bottle. *M. kandleri* require a strict anaerobic atmosphere for survival. Forsterite only and forsterite + magnetite experiments health was average.. In Fe, Ca free growth medium forsterite + magnetite experiments health was average.

The concentration of aqueous Fe was determined by inductively coupled plasma-mass spectrometry (ICP-MS). In all but two experiments, biotic systems had higher concentrations of iron in aqueous solution relative to abiotic experiments, regardless of growth medium or mineral assemblage. It is likely that an increase in Fe concentration in biotic experiments with magnetite indicate Fe(III) reduction, as Fe(II) is much more soluble than Fe(III)> The remaining 2 biotic experiments had identical Fe concentrations to abiotic experiments. Pyrite ($Fe(II)S_2$) was observed by SEM as a precipitate on magnetite in forsterite + magnetite experiments. The pyrite may be a product of Fe(III) reduction carried out by methanopyrus.

The concentrations of aqueous Mg and Si were also determined by ICP-MS. In standard growth medium experiments with forsterite + serpentine, biotic activity clearly increased aqueous Si and Mg, whereas in forsterite only and serpentine only experiments the influence of *M. kandleri* is unclear. This suggests that rather than a single mineral phase, an experimental system needs to be buffered by a reasonable geologic mineral assemblage in order to reach equilibrium.

Our results demonstrate that *Methanopyrus kandleri* can be cultured during active serpentinization of olivine. The olivine-rich ultramafic-hosted hydrothermal systems that were likely abundant in the early Earth are favorable environments for this ancient microorganism.

# Abstract # 12678 - **Oscillations of $\delta^{18}O$ in Cambrian Carbonates from the Siberian Platform and Their Utility as Paleoenvironmental Proxy**

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The Early Cambrian record of stable carbon isotopes in carbonates can be remarkably conserved (Kouchinsky et al. 2001). The behavior of the $\delta^{13}C$ curve in its Tommotian–Atdabanian part is nearly identical in north Siberian sections investigated (Fig.1). Oscillations of $\delta^{13}C$ are very close in their trends and amplitudes, despite natural variation in sedimentation rate and lithology on regional scale. Correlation of the curves is also supported by biostratigraphic and sequence stratigraphic markers. Simultaneous analysis of stable isotopes of oxygen is often considered a way to evaluate diagenetic alteration of samples. Co-variation of $\delta^{18}O$ and $\delta^{13}C$ is therefore regarded a sign of diagenetic perturbations, which alter both carbon and oxygen isotopic signals. Moreover, patterns of $\delta^{18}O$ oscillations are often less reproducible from one section to another and are not as distinct as those of $\delta^{13}C$. The greater alteration of the oxygen isotopic record makes it hard to apply as a paleoenvironmental indicator, especially for Paleozoic rocks.

The available data from northern Siberian platform shows that both types of curves vary consistently in sections studied. The source rocks are continuous successions of clayey limestones, of mostly micritic composition. Co-variation of carbon and oxygen is especially noticeable in the prominent peaks of $\delta^{13}C$ oscillations (Fig.1). Co-variation of $\delta^{13}C$ and $\delta^{18}O$ profiles is regarded herein as a primary phenomenon. In agreement with Veizer *et al*. (2000), detrended $\delta^{18}O$ oscillations may be explained mainly by variation of sea surface temperatures. Thus, the ~2‰ amplitude during the Tommotian (*D. regularis*) – Botomian (*B. micmacciformis*) interval (Fig.1) may correspond with up to 9ºC range of sea surface temperatures. A possibility of the ice-volume effect on shifting $\delta^{18}O$ must not be excluded though (Eerola 2001). The overall range of variation of $\delta^{18}O$ does not exceed 3‰, if samples from the underlying pre-Tommotian carbonates of the Early Cambrian age or the overlying partly bituminous Early-Middle Cambrian carbonates (with a few depleted and possibly greater altered end members) are included.

Data from southern Siberian sections, upon which the Early Cambrian carbon isotopic reference curve is based (Brasier *et al*. 1994), show almost twice as high range of $\delta^{18}O$ oscillations. Carbon isotopic records from southern and northern parts of the Siberian platform, however, permit precise correlation (Fig.1). Oxygen isotopic oscillations of higher magnitude from the southern sections may not be readily explained by the factor of temperature or other primary nature. The sections belong to the transitional facies belt, a setting more prone to diagenesis than carbonates of adjacent normal marine facies belt, where northern sections are situated. Diagenesis is the most likely cause of $\delta^{18}O$ values

depleted to ca. –9.5 ‰ (Brasier *et al.* 1994), but the upper level of $\delta^{18}O$ variation is in good agreement with that of less altered samples from northern Siberian platform. Hence it seems realistic to expect primary co-variation of $\delta^{18}O$ and $\delta^{13}C$ from well-preserved Cambrian carbonates and to explain it by the influence of climate on the primary production and burial rate.

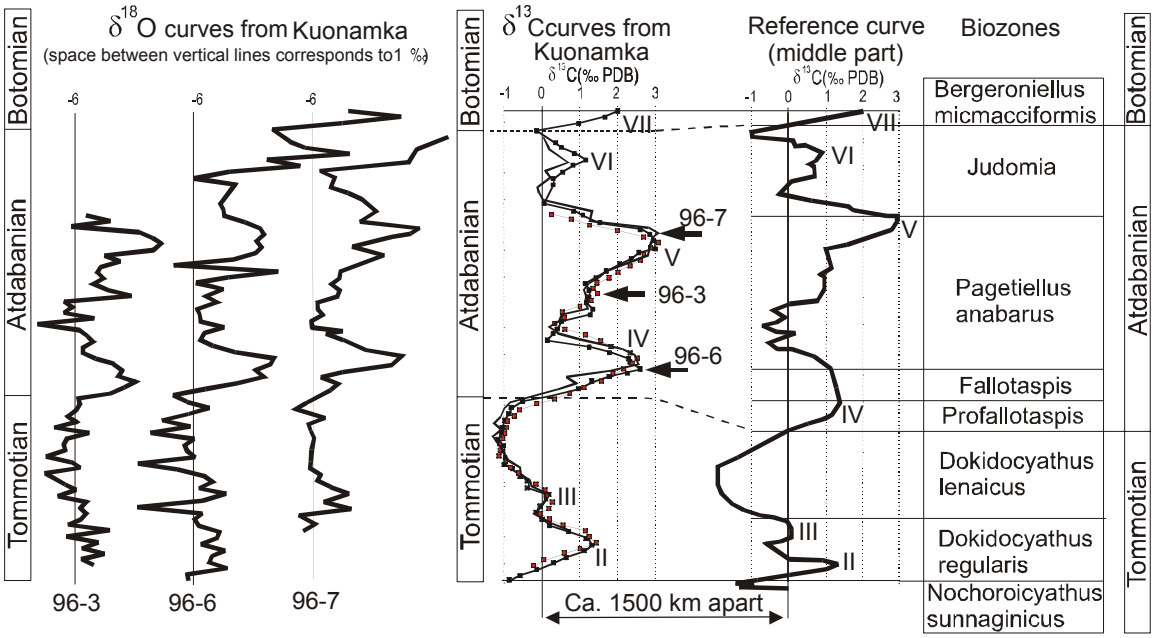


Fig.1. Proposed correlation of Tommotian-Botomian $\delta^{18}O$ and $\delta^{13}C$ curves from the Malaya (96-3) and Bol'shaya (96-6, 7) Kuonamka with the reference curve from the south of Siberia

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# Abstract # 12681 - **What Caused the Second Rise of $O_2$ in the Late Proterozoic? Methane, Sulfate, and Irreversible Oxidation**

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Several hypotheses have been suggested for a rise of oxygen at 2.2-2.4 Ga, in the early Proterozoic. These include temporary and secular increases in organic burial rates (Karhu and Holland, 1996; Des Marais et al., 1992), oxidation from hydrogen escape to space via biogenic methane (Catling et al., 2001), and a shift in the redox state of volcanic gases (Kasting et al., 1993; Holland, 2002). However, despite evidence that $O_2$ levels increased a second time in the late Proterozoic, few ideas have been presented to explain why such a second event would occur. Sulfur isotopes suggest that $O_2$ increased from about 1-3% to greater than 5-18% of present levels around ~0.8 Ga (Canfield and Teske, 1996). At this time, sulfides are found with $^{34}S$-depletions exceeding the fractionation threshold of sulfate-reducing bacteria. This can be explained if sulfide was re-oxidized at the sediment-water interface to $SO_4^{2-}$ and reduced again by microbes, cyclically increasing the isotope fractionation. Possibly, $O_2$ increased to the point where it penetrated marine sediments, making the deep ocean aerobic for the first time. Such a second increase cannot be explained by the evolution of fecal pellets giving a greater flux of carbon to the seafloor (Logan et al., 1995) because the fecal pellets are found near the Cambrian boundary (Walter, 1995), well after ~0.8 Ga.

We suggest that over the course of Earth history, atmospheric $CH_4$ concentrations have basically reflected the inverse of concentrations of atmospheric $O_2$ and ocean $SO_4^{2-}$. Today, upward diffusion of $CH_4$ from seafloor sediments is in approximate steady-state balance with $SO_4^{2-}$ reduction at the $CH_4$-$SO_4^{2-}$ transition zone (D'Hondt et al., 2002). In the low sulfate Archean ocean, the $CH_4$ flux would have been less impeded in reaching the atmosphere. In the Mesoproterozoic, sulfate levels were probably only a few mM, compared to 29 mM today (Shen et al., 2002). Thus a substantial flux of $CH_4$ to the atmosphere likely occurred throughout the Mesoproterozoic. Since $CH_4$ concentrations vary quadratically with methane flux to the atmosphere (Walker, 1977, p.90), $CH_4$ was likely an important greenhouse gas not just in the Archean (as argued previously (Catling et al., 2001)), but also in the Proterozoic, when tens of ppmv were likely sustained.

The redox consequences of abundant $CH_4$ are obvious. Today, biogenic $CH_4$ contributes about half of the hydrogen atoms that escape to space. With an elevated concentration of $CH_4$, the $CH_4$-induced hydrogen escape rate is proportionately greater. When hydrogen escapes from Earth, the Earth must be oxidized. We propose that methane-induced hydrogen escape oxidized the Proterozoic Earth. This oxidation caused a shift in Earth's sulfur cycle towards a sulfate-rich ocean. In the Neoproterozoic, the loss of $CH_4$ and increased $O_2$ likely precipitated global cooling and "Snowball Earth" glacial episodes, analogous to those of the Paleoproterozoic.

If the Proterozoic ocean was deeply sulfidic as proposed by Canfield (1998), it is also likely that biogenic sulfides were permanently subducted from the Proterozoic ocean into the mantle, given the highly refractory nature of sulfides. This would also have been a net reductant loss from the atmosphere-ocean-crust system, analogous in its effect to hydrogen escape to space. Thus, the Proterozoic environment was prone to oxidize both from methane-induced hydrogen escape and sulfide subduction.

An interesting question is the regulation of the $O_2$ content of the Proterozoic atmosphere. With Mesoproterozoic $O_2$ levels only 1-3% of present, the microbial biosphere would be close to the Pasteur point where a fall in $O_2$ levels would cause a switch to anaerobic metabolism. Thus it is possible that the biosphere behaved as an important negative feedback on Proterozoic $O_2$ levels. Today, this control no longer exists because the amount of organic carbon in the biosphere is $\sim 10^2$ times smaller than the atmospheric reservoir of $O_2$ so that respiration and decay can modulate no more than 1% of total amount of present-day $O_2$.

In summary, we propose that the redox history of the Proterozoic was one of secular oxidation enabled by methane-induced hydrogen escape and/or sulfide subduction. Oxidation resulted in a second rise of $O_2$, which was a critical influence on subsequent biology.

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# Abstract # 12683 - **A Quantitative Definition of Habitability**

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Life does not only require liquid water, an energy source, and biogenic elements. It also requires a suitable environment or habitat. The availability of liquid water has been considered as an indicator of habitability in planetary environments. However, life is more diverse or replicates better at certain liquid water environments than others. Therefore, a quantitative definition of habitability may be more appropriate to compare the compatibility of different physical environments with life.

This works proposes a new quantitative definition of habitability. The Habitability Equation estimates how suitable an environment for life is, provided the other requirements for life are present (i.e., an energy source and biogenic elements). The equation is formed by the product of Habitability Functions for each physical or chemical environment variable. A simple form of the Habitability Equation for microorganisms (which easily measures physical environment variables) is this:

$$H(T,P,w) = T(T)P(P)w(w)$$

where $T(T)$, $P(P)$, and $w(w)$ are empirically determined Habitability Functions for temperature, pressure, and water content, respectively. Each Habitability Function represents the normalized relative growth rate of microorganisms as a function of a physical variable. A Habitability of one ($H = 1$) represents a maximum replication rate where zero ($H = 0$) represents no growth. The Habitability is related with the growth rate as $\mu = \mu_O H(T,P,w)$, where $\mu_O$ is the maximum growth rate (usually measured in the laboratory at high nutrient concentrations) and $\mu$ is the environmental growth rate.

A Habitability Equation can be constructed for a particular species, genera, or domain from local to global scales. In a global sense, most microorganisms growth better at temperatures close to 37°C (310 K), but the mean global temperature of our planet is about 15°C (288 K). This means that the current state of our planet has a Habitability of less than one for its microbial diversity as a function of temperature. It is possible that past higher global temperatures contributed to a larger global diversity at all levels because many microorganisms are primary producers or live in symbiotic relations with other primary producers. In fact, this is mostly responsible for the higher diversity of life in the tropical regions of our planet. The Habitability Equation was used to compare past and present Habitability States and Planetary Habitable Zones of our planet and other planetary bodies (i.e., Mars).

# Abstract # 12709 - **The Habitability of Mars Meteorites**

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Interpretations of Mars Viking and Surveyor orbital images have built a strong case that Mars had surface water during its past geological history. New neutron spectrometer data from Mars Odyssey show that poleward of 60 degrees North and 60 degrees south, significant hydrogen, likely as ice or permafrost, is present in the upper meter or so of the martian regolith. Here, we present a summary of independent data from the Mars meteorites showing that liquid water was present in the upper few meters or tens of meters as early as 3.9GY and continuing throughout most of Mars history. The evidence from the meteorites shows that the subsurface environment of Mars was favorable for life throughout the past 3-4GY.

Currently, about 25 martian meteorites are available in collections on Earth. These meteorites have formation ages ranging from 4.5GY to 165MY. Some (and perhaps all) of these meteorites also show evidence for aqueous alteration on Mars. Estimates of formation depths and depths before ejection from Mars range from the upper meter to 100 meters or so. All of the meteorites recovered so far are igneous rocks and would not be expected to contain information on sedimentary or low temperature processes. Yet, many of these meteorites contain cracks and pores formed on Mars that display clear evidence of secondary alteration, weathering, and mineral precipitation from a water

phase. This alteration and precipitation occurred on Mars, but after the original igneous rocks cooled and became fractured.

Within these meteorites, the evidence for aqueous alteration includes: 1) abundant weathering and corrosion textures; and 2) the production of secondary water-precipitated minerals including smectite, carbonate, magnetite, hematite, Fe-sulfides, Ca-sulfate, and very thin clay-rich layers deposited in cracks and pores. Amorphous $SiO_2$, probably originally a gel, is also present in some meteorites. Many of these secondary minerals likely formed at relatively low temperatures; all apparently formed from liquid water. Examples of meteorites showing extensive secondary alteration by water include ALH84001, Nakhla, and Lafayette. Indigenous organic carbon is also present in many Mars meteorites. Nakhla, for example, has at least 300pppm organic carbon, 75% of which lacks terrestrial $^{14}C$ signature and is therefore from Mars.

Additional features favorable to making these meteorites habitable to microbes include abundant readily water-extractable phosphate (including apatite and whitlockite), iron in both ferrous and ferric oxidation state (hematite, magnetite, siderite, pyroxene, olivine, smectite), and sulfur as both sulfates and sulfides. These minerals could readily provide energy for iron or sulfur oxidizing and reducing microbes. They provide evidence for a significant redox gradient in the shallow subsurface.

Furthermore, some of these meteorites contain features that can be interpreted as biosignatures. While some of these potential biosignatures may be derived from terrestrial processes, many are demonstrably martian. Such potential biosignatures include minerals such as magnetite and carbonate, which may have been formed by bioassisted precipitation, micrometer-size ovoid biomorphs of various composition, ovoid molds, complex etching textures, possibly bioetching, and features that are possibly fossilized biofilms.

In summary, all of the requirements for a habitable environment on Mars are present as revealed by the meteorites: the presence of liquid water, significant organic carbon, microenvironments in cracks and crevices suitable for sheltering microbes, energy sources provided by reduced and oxidized iron and sulfur mineral, chemical disequilibria between the water and the enclosing rocks, and the presence of abundant labile minor and trace elements such as phosphorous important to life. It is clear that at least some of the shallow martian subsurface, as sampled by these martian meteorites, has been a hospitable place for life throughout most of all of Mars history.

# Abstract # 12748 - **The Formation of the Pulsar Planet System**

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The planets orbiting the Pulsar B1257+12 are the only known extrasolar planets of the terrestrial class. We present constraints on the age of the system based on the pulsar's kinematics and likely origin. This suggests that the system is relatively young, less than a hundred million years old. Thus this may be a system that is still in the process of clearing out the debris associated with the planet formation process and may provide a glimpse into the early stages of our own terrestrial planet system. We investigate the likely dynamical state of such a young planetary system and compare our predictions to potential future observations, especially in light of recent reports of additional timing signatures observed from this system.

# Abstract # 12771 - **The Sources of Water in SNC Meteorites: Clues from Hydrogen Isotope Measurements**

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Measurements of H isotope signatures of minerals, glasses, and magmatic melt inclusions provide valuable clues to the source of water in Martian meteorites and possibly on the initial D/H ratio of their parent magmas. To test this, we determined the H isotope compositions and water abundances of phases in seven shergottites, two nakhlites, Chassigny and ALH 84001 by the ion probe. The phases studied were the nominally anhydrous minerals olivine and clinopyroxene, feldspathic and mafic glasses, and post-stishovite silica. H isotope compositions of magmatic melt inclusions in the two nakhlites, ALHA 77005 and Chassigny were also measured.

*Nominally Anhydrous Minerals*. The nominally anhydrous mineral olivine in the nakhlites shows a low δD (-79 to 195‰ for Governador Valaderes; 8.3 to 35.4 ‰ for Nakhla) and some olivine grains have D/H that are similar to our olivine blank. Clinopyroxene, however, shows a fractionated H isotope signature (δD 103 to 1243‰ for Governador Valaderes, and 572 to 830 ‰ for Nakhla). Some D-enriched clinopyroxene grains have water contents higher than what is expected for nominally anhydrous minerals and likely contain inclusions of preterrestrial aqueous layer lattice silicates.

*Impact Glasses*. Feldspathic and mafic impact glasses in the shergottites and ALH 84001 and post-stishovite silica contain a highly fractionated H component and a wide variation in D/H. Feldspathic glass and post-stishovite silica in Zagami, Shergotty, and SaU005 show a positive correlation between δD and water abundances. Feldspathic and mafic glass in ALH 84001, ALHA 77005, and EETA 79001 show a negative correlation between δD and water abundances.

*Carbonates and Phosphates*. Both carbonates and phosphates in ALH 84001 show extraterrestrial H isotope signatures. The large carbonate globules show large variation in the δD (331 to 1196‰) and in general are more D-enriched relative to the carbonate in the shock produced crushed zones. Whitlockite shows large variation in δD (92 to 406‰), and the variation is occasionally observed within individual grains. A single apatite grain which was mantled by whitlockite was enriched in D relative to all whitlockites measured (δD 751‰).

*Melt Inclusions*. In both Chassigny and ALHA 77005, the residual magmatic glasses in melt inclusions have low δD values (95 to 225‰ for Chassigny and –106 to +304‰ for ALHA 77005.) In Chassigny, a small impact melted glassy inclusion has a high δD of 1754‰. Melt inclusions in Nakhla have low δD (103 to 218‰). The exception is the glass in one inclusion (δD 1408‰), which was in isotopic diseqilibrium with the coexisting pyroxene (δD 218‰). Melt inclusions in Governador Valaderes have low δD (110 to 361‰) and overlap in isotopic composition with some melt inclusions in Nakhla, Chassigny and ALHA 77005.

The minerals and glasses analyzed may contain an initial primary H component, but their isotopic composition was modified to varying degrees by three different processes: interaction with a fractionated exchangeable water reservoir on Mars, hydrogen devolatilization by impact melting, and terrestrial contamination. The highly fractionated H signature observed in the feldspathic and mafic glass can probably be attributed largely to incorporation of fractionated Martian water during impact melting, but may have been enhanced by devolatilization of H during impact. The positive correlation between δD and water abundance in feldspathic glass and post-stishovite silica in Zagami, Shergotty, and SaU005 is indicative of mixing of a high δD component (3000 to 4000‰) and a less abundant low δD component (~0‰). The high D component is primarily derived from the Martian exchangeable reservoir and may have been influenced by isotopic fractionation associated with shock induced H loss. The low D component is either magmatic or a terrestrial contaminant. The negative correlation between δD and water abundances in mafic and feldspathic glasses in ALH 84001, ALHA 77005, and EETA 79001 is consistent with addition of a low δD terrestrial contaminant to a less abundant high D Martian component.

Determination of the H isotope compositions of magmatic glass from melt inclusions in Martian meteorites may help constrain the initial H isotope signature of Mars. The low δD values we report for magmatic glass in most inclusions that have not been altered or shock melted may approximate the magmatic H isotope signature of their Martian parent magmas. If this is the case, this signature is not unlike that of Earth.

# Abstract # 12790 *(Oral Presentation)* - **Ocean Surfaces on Snowball Earth: Implications for Survival of Surface Life**

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The ocean surfaces on a Neoproterozoic Snowball Earth would vary with latitude and evolve through time. The high-latitude and mid-latitude oceans would consist of snow-covered sea-glaciers (self-sustaining ice shelves), with surface albedo 0.8. At low latitudes in regions of net sublimation, the ocean surfaces would consist of: (1) bare sea ice with salt inclusions, (2) an evaporite deposit of hydrohalite, and (3) bubbly glacier ice emerging from equatorward ice-shelf flow. Their albedos would be 0.6-0.75. These high albedos, when used in climate models for the early part of the snowball event, imply surface air temperatures below –30 C at all latitudes in all seasons. Yet, there is evidence that photosynthetic eukaryotic algae survived the snowball events, requiring liquid water at or near the surface.

Possible locations for survival of surface life are: (a) at geothermal hotspots on coastlines, (b) in the ocean under widespread thin tropical sea ice, and (c) in enclosed tropical seas or lakes under thin ice.

Radiative transfer modeling of the penetration of sunlight, estimates of sublimation rates from climate models, and computation of ice velocities from ice-flow models of sea-glaciers, indicate that ice on the tropical ocean would have been several hundred meters thick, ruling out (b). Thin ice might survive on a lake or nearly-landlocked sea with low salt content, beyond reach of the sea-glaciers. However, only a narrow range of conditions would allow a refugium under such ice to persist. The most likely refugium is therefore isolated geothermal hotspots, as originally proposed by Hoffman and Schrag.

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# Abstract # 12795 - **The Space Physics of Life**

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In the context of astrobiology, the field of space physics deals with measurements and models for the space environments around potentially habitable planetary objects and with the effects of these environments on evolution and survival of life at the surfaces, or within the interiors, of such objects. Primordial and continuing chemical evolution of material in comets and dust grains is also coupled to the space environment and contributes resources such as water and hydrocarbons to life on objects impacted by this material. We can expect to know very little about the local environments of extrasolar planets and their moons for the foreseeable future, even if potential habitats are identified through atmospheric composition. However, there is a great abundance of modern data now available from robotic spacecraft on the interplanetary solar wind and magnetic fields, cosmic rays, dust grains, solar UV irradiance, and planetary magnetospheres which can be used to model the space environment effects in our own solar system and to provide some basis for predicting environments of potentially habitable worlds in other systems. Furthermore, there can be strong correlation between space physics and planetary processes, e.g., the modern presence of the geomagnetic field at Earth (but not at Mars or Venus) as a signature of an active interior needed to support tectonic resurfacing and carbon burial. Supplementary observations of auroral radio and UV emissions might in this case confirm an earth-like habitat on a known extrasolar planet with an atmospheric composition indicative of life. As on Earth but not now on Mars, a planetary magnetic field also allows atmospheric retention with respect to solar wind interactions and provides some shielding against harmful effects of cosmic ray ions.

Within the Solar System, we expect to learn much about environmental effects on Mars, Europa, Titan, and comets through continuing analyses of in-situ and remote-sensing measurements from past, ongoing, and future investigations. Cosmic ray production of neutrons at the Mars surface is now facilitating Mars Odyssey's global surveys of water ice within the surface regolith, while solar wind interactions may account for atmospheric losses, and electronic ionization from solar UV and cosmic ray irradiation at the surface partly drives molecular chemistry. Life within Europa's possible ocean may benefit from rapid accumulation of irradiation products on its icy surface from bombardment by solar UV photons and Jovian magnetospheric particles, the best evidence for a modern ocean actually coming from magnetospheric interactions producing induced magnetic fields. Titan's prebiotic atmosphere is periodically in contact with the magnetosphere of Saturn and with the local interplanetary medium. Organic haze material of interest for prebiotic chemistry, and any life, near Titan's surface is produced by solar UV and charged particle irradiation. Water, hydrocarbons, and other prebiotic molecules have been delivered to Europa, Titan, and the terrestrial planets by comets having long histories of interaction with the space environment of the Solar System from primordial times to the present.

# Abstract # 12799 - **Mechanisms for the Delivery of Volatiles to the Terrestrial Planets**

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We present results from simulations of late stage planetary accretion, focusing on the delivery of volatiles to the terrestrial planets. Our simulations include both planetary embryos (Moon to Mars sized proto-planets) and planetesimals, assuming that the embryos formed via oligarchic growth. We investigate volatile delivery as a function of Jupiter's mass and position, the position of the snow line, and the density (in solids) of the solar nebula.

In all simulations, we form 2-4 terrestrial planets, which vary in mass and in quantity of volatile-rich material. We find that a Jupiter at 5.2 AU scatters significantly more volatile-rich material to the terrestrial planets than a Jupiter at 4 AU or 7 AU. We also form a class of larger (2-4 $M_{EARTH}$) terrestrial planet, which is not present in our solar system. These large icy planets are the product of oligarchic growth and accretion in particularly dense regions of the solar nebula, immediately past the snow line.

# Abstract # 12813 *(Oral Presentation)* - **Volcanic Release of Methane and Hydrocarbons in Early Mars**

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Geologic evidence demonstrates that 3.5 Gyr ago Mars was warmer, held liquid water on its surface, had active volcanoes and a denser atmosphere. Methane and hydrocarbons have been proposed as possible greenhouse gases on early Mars. In this work we study the production of these compounds in the volcanic environments of early Mars.

Numerical simulations and observations indicate that explosive volcanism was widely distributed throughout Mars. Explosive volcanism is characterized by the formation of floating plumes composed of ashes and volcanic gases that acquire electric charge during their ejection into the atmosphere, producing lightning discharges. This geological setting was simulated to study the chemical effects of lightning in early Mars. Simulated Martian magmatic gases contained $CH_4$, $H_2$, $H_2O$ and $N_2$, according to the model of Kuramoto (1) and the nitrogen content measured in Chassigny and the nakhlites (2). Lightning was simulated by focusing a high energy infrared laser beam inside of a Pyrex reactor that contained the volcanic gas mixture. The analysis of products was performed using a gas chromatograph coupled to an infrared detector and a quadrupole mass spectrometer. Eleven hydrocarbons were identified among the products, acetylene ($C_2H_2$) being the most abundant. The amount of energy available in volcanic lightning was calculated to be ~ 8 _ $10^{17}$ J $yr^{-1}$ (3), that may produce ~ 6 _ $10^{12}$ g $yr^{-1}$ of acetylene.

A thermochemical model was used to predict which compounds were directly formed by volcanic heat. The model considers the formation of chemical species with one and two atoms of carbon from the same gas mixture used in the experiment, at temperatures between 1000 and 5000 K. In this case, acetylene and ethylene are formed at 1500 K. Considering the model of Schubert *et al.* (4) an average of 5 $km^3$ $yr^{-1}$ of magma may be released on the first billion years, if the amount of gas diluted in magma is about 0.1% *wt* then the production of acetylene and ethylene by volcanic heat on early Mars will be about $5 \times 10^{11}$ g $yr^{-1}$ each.

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From the composition proposed for Martian volcanic gases the amount of methane injected to the atmosphere may be an average of ~ $10^{13}$ g $yr^{-1}$ during the first billion years, which means a mixing ratio of $3 \times 10^{-6}$, for an atmosphere with 1 bar of pressure in hydrostatic equilibrum ($M_{atmosphere} = 3.87$ _ $10^{21}$ g) and a lifetime of methane of $10^3$ years.

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# Abstract # 12822 *(Oral Presentation)* - **Passing Through Giant Molecular Clouds – Effects on Climate. Possible Link to Snowball Glaciations?**

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Throughout its history, the Solar system encountered a number of Giant Molecular Clouds and will inevitably encounter them in the future. It is important to understand whether those events could cause any significant climatic impact, affect the biosphere and leave any imprint in the geological record.

Previous studies of this problem were mainly focused on the terrestrial accretion of the hydrogen from GMCs and the consequences of the heliospheric collapse. However, the observed extinction of starlight suggests that GMCs contain more than 1% (by mass) of carbonaceous and silicate dust particles. Using a 1-D radiative transfer model coupled with an aerosol microphysical model, we calculated the direct radiative force from the accretion of the GMC dust into the Earth atmosphere. We demonstrate that for most encounters of Earth with typical GMCs ($10^2$ – $10^3$ H atoms/cm$^3$), dust would produce a significant climate impact causing "moderate" glaciations. Rare (but possible) collisions with high density GMCs ($3\times10^3$ - $10^4$ H atoms/cm$^3$) could result in more than a 16 W/m$^2$ change of the solar radiation at the Earth surface, which would last for as long as 200,000 years. An event of this magnitude would most likely result in a Snowball glaciation. Possible geologic imprints of such collisions will be discussed.

# Abstract # 12824 - **Astrobiology at Goddard Space Flight Center**

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It has become clear that the modern Earth (and especially the early Earth) was not isolated from its environment. Organic material was delivered by comets, meteorites, and interplanetary dust particles (IDPs). This material influenced, if not dictated, the origin and early evolution of life. However, its heritage is uncertain. Surely, some was synthesized within the meteoritic parent bodies. At the other extreme, some material may have been delivered pristine from the dense interstellar medium. Other material was processed or even destroyed in the protosolar nebula.

We are interested in modeling, simulating, and testing the production, processing, survival, and delivery of organic material from the interstellar medium to the early Earth (or other body). To do this, we will compare modern observations with models of relevant astronomical objects. We will realistically simulate those environments in the laboratory to clarify both synthesis and destruction of interesting organic species.

# Abstract # 12827 - **Atmospheric Accretion on Airless Planets: The Role of Oblique Impact Events**

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Recent findings have shown that large impacts (10 times K/T events and greater) may not erode planetary atmospheres. We consider the energetics of large bolide impacts on atmosphere-free planets in an attempt to determine whether these large impacts will contribute to or erode from the planet's volatile inventory. Our results show, for a wide range of impact speeds and for all but the most highly oblique impact angles, that volatile material will be added to the planet's inventory, especially if the planet's lithosphere has been depleted in volatiles, as we assume Earth to be following the Giant Impact. For Venus, the situation is much the same. Likewise for Mars, though for a much reduced range of impactor speeds. Volatile retention depends primarily on the planet's escape velocity and the bolide's impact speed and angle of entry.

Gravity plays a dominant role in these impacts. Following the Giant Impact, it is possible to acquire enough volatiles through impacts to account for the Earth's present-day inventory, without requiring significant degassing of surface volatiles and mantle outgassing, both of which seem unlikely following the Giant Impact. The importance of gravity can be summarized in a very simple scenario: an impactor strikes a planet at 20 km/s and vaporizes approximately three times its own mass in target (i.e., surface) material (O'Keefe and Ahrens) [1], hence the vapor cloud has four times the mass of the impactor. Excluding *all* other sinks of energy (i.e., the impact is a perfect conversion of kinetic energy from bolide to vapor cloud), the mean speed of the cloud will be reduced to 10 km/s, which is less than the gravitational escape velocity of Earth. If we subsequently add more realistic sinks of energy (i.e., latent and sensible heat, seismic radiation, etc.), the expansion velocity of the cloud will decrease further, and more vapor will be retained. We are therefore calculating a strict lower bound on retained material. More accurate and inclusive representations of energy sinks will only serve to increase the amount of vapor retained.

Bolides from the outer solar system strike with a much greater speed than those from the inner solar system. However, the expansion of the vapor cloud from a fast impact is moderated by the fact that the impact itself excavates a much greater amount of target material, which reduces the mean velocity of expansion. The velocity reduction is even greater in the horizontal direction to conserve lateral momentum. For instance, if an incoming bolide from the outer solar system has a lateral velocity of 8 km/s, and excavates and vaporizes three times its mass, the lateral velocity of the vapor cloud is

reduced to 2 km/s. (Moreover, some momentum may be imparted to the spinning planet, resulting in a further reduction of the lateral horizontal velocity.)

We have created a simple, physical model derived from the self-similar model of vapor cloud density of Zel'dovich and Razier [2] for expansion of gas in a vacuum. The same model has been used previously by Vickery and Melosh [3]. We also make an assumption as to the amount of target material excavated by an oblique impact based on the findings of O'Keefe and Ahrens [1]. By considering both the expansion speed ($v_{exp}$) of the cloud as well as the bulk drift ($v_d$) of the cloud due to lateral motion of the oblique impactor, we can solve for the fraction of the expanding cloud for which $v_{exp} + v_{drift} < v_{esc}$, where $v_{esc}$ is the escape velocity of the planet. A typical example is found in Fig. 1, for an impact at 21km/s, 30$^o$ from vertical.

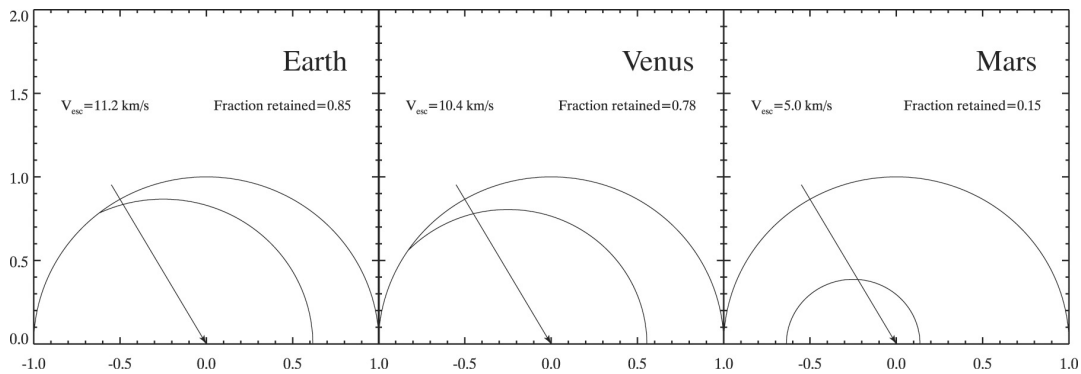


Figure 1*: Schematic illustrating the fraction of vapor cloud retained for a given impact at 21 km/s, 30$^o$ from vertical on Earth, Venus and Mars. Outer curve represents the outer edge of the expanding vapor cloud, while inner curve encloses region of vapor retention. Arrow indicates the direction of impact.*

Further, the amount of volatiles that a planet will retain depends on the ratio of volatiles in the bolide to that in the target planet. For a very 'dry' bolide (e.g., meteorite) impacting a volatile-rich planet, more volatiles will be lost from the escaping vapor than will be contributed by the impactor itself. Conversely, for a very 'wet' bolide (e.g., comet) impacting a volatile-poor planet, more volatiles will be gained from the impactor than will be lost from the planet. In this model, we treat volatiles in a generic sense, and do not attempt to assess the relative importance of extraplanetary sources of volatiles to internal sources in establishing the net volatile reservoir of the planet. However, these results show that extraplanetary sources may be more significant than once thought.

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# Abstract # 12829 - **Heat Flow and Helium and Argon Degassing in Whole Mantle Convection**

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A longstanding problem in Earth science is an apparent paradox between the high heat flow currently measured and the low abundance of radiogenic elements inferred from meterorites, the amount of radiogenic $^{40}Ar$ in the atmosphere, and the current flux of $^{4}He$ from the mantle. One solution has the mantle convecting in layers. The layering impedes both heat flow and degassing, so that the heat is old and the waste products hidden. But seismic imaging does not reveal layering today. Here we ask what is required of Earth if its mantle convects as a whole. We find that self-consistent solutions for argon, helium, $CO_2$, and the temperature of the Archean upper mantle can be obtained in whole mantle convection provided that: (i) inert gases are ~5-fold more compatible with the mantle than is typical of incompatibles such as $CO_2$; and (ii) heat flow has been constant or even slightly increasing over geologic history. The sense of paradox stems from: (i) the presumption that an inert element should behave like an incompatible element; and (ii) the expectation, based on parameterized convection, that heat flow should decrease as the mantle cools.

# Abstract # 12846 - **Investigation of Weathering Products of Martian Meteorite Analog Materials on Earth and Applications to Martian Dust Analysis**

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**Introduction:** In this study, the mineralogy and chemistry of the fine dust produced from weathering of a Martian meteorite analog sample from Antarctica will be characterized in order to try to address the following questions: (1) What kinds of weathering processes might take place on the surface of Mars? and (2) Could Martian dust returned by the proposed 2007 Sample Collection for the Investigation of Mars (SCIM) mission be used to unambiguously tie the Martian meteorites to Mars? The mineralogy of fines can be used to learn about the weathering environment in which they were produced. However, no samples of fines have been returned from Mars and the mineralogical properties of Martian fines have never been directly measured by remote methods. As a result, the extent Martian surface weathering and the nature of Martian weathering environments (e.g., chemical vs. physical weathering, low vs. high water/rock ratios) is unconstrained. The mineralogy of analog materials can be used to investigate possible Martian weathering processes. Fines produced from a Martian meteorite analog in Antarctica, a Mars analog weathering environment, may be a good analog to Martian dust but very limited studies have been done on these fines. These fines are produced in a different environment than the commonly used terrestrial analog, JSC Mars-1, a palagonitic tephra.

Martian (SNC) meteorites possess several unique chemical characteristics that clearly discriminate them from terrestrial basalts. Previous work has shown that the element ratios K/La, Mn/Fe and Na/Al vs. Fe/Mn best differentiate Martian meteorites from terrestrial rocks, and other meteorites [1-3]. Several of these characteristic ratios are consistent with Viking and Pathfinder in-situ analyses of Martian surface materials and remote sensing data, however, the relatively low precision of these remote analyses limits the ability to uniquely tie the Martian meteorites to Mars [1,4]. A sample of Martian dust returned by the SCIM mission would allow the necessary high precision analyzes to be carried out and would thus provide an avenue for directly addressing the question of a Martian origin for the Martian (SNC) meteorites.

**Methods, Results and Discussion:** We have examined the <63 $\mu$m size fraction of a soil collected from a bedrock plateau of the Ferrar Dolerite in the Transantarctic Mountains of Antarctica. The Ferrar consists of two pyroxenes, two feldspars, and iron and titanium oxides and shows mineralogical similarities to the Martian meteorites [5]. Outcrops and hand specimens of the Ferrar are exposed to some of the driest and coldest weathering environments on Earth and show characteristic desert weathering features observed in images of Mars, such as ventifacts, desert varnish, and cavernous weathering [5,6]. For comparison, the <63 $\mu$m size fraction of JSC Mars-1, a palagonitic tephra from the Pu'u Nene cinder cone in Hawaii, was also examined [7]. These initial studies have involved using SEM and laboratory infrared (IR) spectroscopy (spectral range: 5-~45 $\mu$m) to investigate the mineralogical and spectral properties of the Antarctic and JSC Mars-1 dust. The Antarctic dust mineral abundances estimated from preliminary SEM studies were: 23% plagioclase, 3% potassium feldspar, 13% pyroxene, 20% micas, 7% quartz, 15% amphibole, 4% clay minerals and 15% aggregates (various). The estimated JSC Mars-1 dust mineral abundances were: 79% aggregates of Ti-magnetite and aluminosilicate matrix, 13.5% plagioclase, 2.5% olivine, 2.5% spinel/Ti-magnetite, 2% clay minerals, and 1% pyroxene. Overall, the Antarctic dust appears enriched in primary minerals (~77%) compared to JSC Mars-1 dust (~19%), supporting the idea that unweathered minerals may be present in the Martian dust [8]. The IR spectra of the <63 $\mu$m size fraction of the Antarctic and JSC Mars-1 dust show qualitative differences, with the Antarctic dust showing more spectral contrast. Also, the Antarctic dust spectra show qualitative similarities with Martian dust spectra recovered from Mars Global Surveyor Thermal Emission Spectrometer (TES) spectra, while the JSC Mars-1 dust spectra do not. Further spectral studies of a smaller size fraction are needed to make more conclusive comparisons with TES data, however. In addition, mineral types obtained by de-convolution of Antarctic dust spectra are similar to those estimated from SEM studies [9].

**Future Work:** Future work will fully characterize the mineralogy and spectral properties of a smaller, <20 $\mu$m size fraction of the Antarctic and JSC Mars-1 dust. Initial studies of dust mineralogy will be carried out with SEM/EDS, EMP, XRD and IR spectroscopy. More detailed study of the dust mineralogy will be performed with TEM. The results should indicate the nature of the Antarctic weathering processes that produced the dust and allow inferences to be drawn about Martian surface weathering. Future studies will also determine values of the selected element ratios in the Antarctic dust and in a crushed shergottite. If successful, this will show that the ratios can be measured accurately enough in Martian dust analog particles to distinguish Martian and terrestrial materials and set the stage for analysis of similar ratios in Martian dust returned to Earth by SCIM.

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# Abstract # 12847 - **Planetesimal Accretion at 1km Scales**

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Planetesimals (the building blocks of planets) grow by mutual accretion of solid particles inside a disk of gas and dust. At small sizes, particle motions are dominated by gas motions. Once particles grow to roughly 1 km in size, they decouple from the gas disk, and their subsequent evolution is dominated by gravitational interactions. This implies N-body calculations can model planetary accretion in this epoch. We present simulations which explore this phenomenon in isolated patches within a plausible protoplanetary disk. We focus on the terrestrial zone in our Solar System. These patches contain of order $10^5$ planetesimals. The results of these simulations will form the basis of future simulations which will follow the evolution of planetesimals to their final incorporation into planets.

# Abstract # 12848 *(Oral Presentation)* - **Laboratory Investigations into the Production of Organic Haze Aerosols: Focus on the Early Earth**

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In efforts to resolve the "Faint Young Sun" paradox, it has been suggested that early Earth may have had a reduced atmosphere similar to that present on the Saturn moon, Titan. The $N_2/CH_4$ atmosphere of Titan is known to produce organic haze particles in the upper atmosphere. If similar aerosols were present on early Earth, they may have provided a UV-shield to allow greenhouse gases to accumulate. Models have predicted, however, that the presence of moderate amounts of $CO_2$ in Earth's ancient atmosphere may have hindered the production of such haze particles.

We have designed a flow system for producing organic haze aerosols using various mixtures of gases that may have been present in the early Earth's atmosphere, with an emphasis on studying the effects of the $CH_4/CO_2$ ratio (namely C/O) on the particle characteristics. We have incorporated a variety of techniques to analyze the properties of the synthesized particles, specifically the use of an Aerosol Mass Spectrometer (AMS), which provides a novel analysis technique for the rapid characterization of the haze aerosols. Other methods of analysis include complementary mass spectrometric techniques and a scanning particle sizer.

# Abstract # 12855 *(Oral Presentation)* - **The Oldest Known Sediments on Earth and What They Mean**

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What do we look for, and how do we interpret data bearing on the appearance of the first life on Earth? What are the pitfalls that we might face in interpreting complex, ancient (and eventually, non-terrestrial) rock units? As a case in point, isotopically light carbon found in >3.8 Ga metasediments (originally cherts, pelites and banded iron-formations) from Akilia and Isua, West Greenland is suggestive of biological activity in a marine environment, but it implies that metabolically sophisticated life had arisen prior to the end of a period of intense meteoritic bombardment of the inner solar system. This inference has been challenged on the basis that: (a) the interpretation of zircon geochronology from a crosscutting granitoid sheet, which establishes the minimum age of a metasedimentary enclave on Akilia (island), southern West Greenland as >3.8 Ga, is incorrect; and (b) a recent re-interpretation of the Akilia Fe-rich quartzite enclave that hosts the earliest chemical fossils of life claims that it is instead a "metamorphosed (ultramafic) igneous differentiate" rather than an originally aqueous sediment. These two arguments would mitigate against the presence of any biosignatures from the earliest rock record on Earth. The geochemical compositions of the rocks in question from West Greenland have been studied using a U-Pb age depth-profile in a zircon from the same rock and permits direct assessment of the age of these rocks [1]. Results reveal evidence for three phases of concentric zircon growth at 3.83 Ga, ~3.6 Ga and 2.7 – 2.5 Ga. Zircon growth at both ~3.6 Ga and 2.7 – 2.5 Ga is consistent with precipitation from a metamorphic fluid, whereas the chemistry of the zircon mineral core is wholly igneous in character. As only the zircon core could have crystallized from the host rock, the magmatic age of this rock is 3.83 ± 0.01 Ga, therefore establishing a minimum age of the surface hydrosphere and life by that time. Invasive, secondary pyroxenite veinings that overprint the Akilia sediments have been misinterpreted by some workers as suggesting a "metasomatic (ultramafic) igneous origin" for the Akilia rocks containing chemical indicators of life [2]. However, all of the geochemical data reported thus far for these quartz-saturated units strongly support a primary *sedimentary* origin for the Akilia rocks containing evidence for early life [3]. The approaches taken here provide the geological baseline for testing hypotheses to be used in the search for life elsewhere when samples of an ancient martian surface are returned to Earth for study in the coming decade.

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# Abstract # 12887 - **MIF in Archean Rocks: Evidence of $S_8$ Aerosols in the Archean Atmosphere?**

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Mass-independent fractionation (MIF) of sulfur isotopes has been reported in sediments of Archean and Early Proterozoic Age (> 2.3 Ga) but not in younger rocks (Farquhar et al. 2000; Mojzsis et al., 2002). Furthermore, Farquhar et al. (2001) showed that sulfur MIF can be generated in atmospheric photochemical reactions ($SO_2$ and SO photolysis). In our previous work (Pavlov and Kasting, 2002), we demonstrated that in atmospheres with $O_2$ concentrations ≥ $10^{-5}$ PAL, all sulfur-bearing species would have passed through the sulfate reservoir before being incorporated into sediments, so any signature of MIF would have been lost. Therefore, the Archean atmosphere should have been essentially anoxic. However, insufficient experimental data on the details of sulfur MIF in the photochemical reactions did not allow us to constrain the Archean sulfur cycle quantitatively.

Recently, Ono et al. (2002) reported large positive mass-independent anomalies ($\Delta^{33}S$ up to +6.9 ‰) in the core samples from two carbonaceous shale units (2.5 - 2.7 Ga). Here we show that the anoxic Archean atmosphere is a necessary but not sufficient condition to explain this new geologic data.

Even if the Archean atmosphere were anoxic, the exchange between the reduced ($H_2S$, HS etc.) and oxidized ($SO_2$, $H_2SO_4$) sulfur species would have been fast. In our simulation, we have used a one-dimensional photochemical isotopic model (Pavlov and Kasting, 2002) to simulate this exchange. We show that the initially large $\Delta^{33}S$ signature, acquired during $SO_2$ and/or SO photolysis (at ~ 9-10 km) would have been significantly decreased (to less than +2 ‰) in the gaseous sulfur species, as they would reach the

ground level. Hence, it is highly unlikely that gaseous sulfur bearing species could deliver large positive MIF into Archean rocks.

We propose that the large $\Delta^{33}S$ signature can be explained consistently if the reduced sulfur aerosols ($S_8$) were present in the anoxic Archean environment. Our model predicts $S_8$ formation at about 5 - 6 km. Once formed, the $S_8$ aerosols would not exchange isotopes with the rest of the atmosphere and could deliver large $\Delta^{33}S$ to the ground essentially intact.

We find that the magnitude of $\Delta^{33}S$ in $S_8$ aerosols should have been a strong function of $S_8$ atmospheric abundance, what in turns allows us to constrain the redox state of the Archean atmosphere and the $SO_2$ outgassing rate. Important climatic and biological aspects of the $S_8$ aerosols will be discussed.

# Abstract # 12897 - **Inclusion Chemistry of Hadean (>4 Ga) Zircons from Jack Hills, Western Australia**

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In order to unravel the origin and nature of the surface environment during the emergence of the biosphere, it is vital to understand the first 500 million years of Earth history (the Hadean Eon). Yet, there appears to be no preserved crust older than ca. 4.03 Ga on Earth from which direct inferences might be obtained (Bowring and Williams, 1999). What we *do* know about the nature of the earliest crust comes from two sources: models based on studies of the Moon and meteorites, and the oldest known terrestrial solids, rare zircons from the Narryer Gneiss Complex in Western Australia that are older than 4 billion years (*e.g*. Pidgeon and Wilde, 1998). The existence of such ancient zircons has been used to argue for abundant granitoids and perhaps continental crust in the Hadean (Froude et al., 1983; Compston and Pidgeon, 1986; Maas *et al*., 1992). This conflicts with the conventional view of a globally mafic primordial crust modified or destroyed by massive meteorite impacts, with only very minor continental components, present until the terrestrial surface stabilized in the Early Archean (Galer and Goldstein, 1991). Recent results have shown that the oldest zircons may be viewed as evidence of the first buoyant lithosphere and perhaps a hydrosphere as early as 4.38 Ga (Mojzsis *et al*., 2001; Wilde et al., 2001).

Melt inclusions hosted by igneous zircons can be used as a means for investigating the magmatic environment of their formation (e.g. Chupin *et al*., 1998). Previous studies have shown that inclusions present in >4.0 Ga zircons from the Jack Hills (and nearby Mt. Narryer region; Froude *et al*., 1983) comprise quartz, K-feldspar, chloritized biotite, chlorite, amphibole, and muscovite as well as complex polymineralic associations (Maas *et al*., 1992). Such mineral assemblages in the oldest zircons are suggestive of derivation from peraluminous melts (Mojzsis *et al*., 2001) in turn derived from the melting of metasedimentary protoliths (White and Chappell, 1977). Evidence for recycled sediments would imply that a mature rock cycle was already established on Earth before 4.3 Ga.

Preliminary work has already revealed interesting targets for study. A 4.28 Ga zircon (sample JH992_95; for sample descriptions see Mojzsis *et al*. 2001) contains numerous small inclusions of quartz located near the center of the grain away from any obvious

cracks. Other work in progress includes investigation of a muscovite inclusion in a zircon of as yet undetermined age (sample JH992_65) and a Ni-rich pyrite inclusion in a 4.1 Ga zircon (sample JH992_88). The inclusions (typically 1-10 μm in diameter) may represent samples of the formational environment of the zircons and of the crust in which they formed during the Hadean. This primordial crust was the substrate upon which the biosphere emerged on Earth.

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# Abstract # 12903 *(Oral Presentation)* - **What are the Astrobiological Constraints From What is Known About the Late Heavy Bombardment?**

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One of the prime constraints on the development of life on the Earth is the early history of bombardment on our planet. In particular, enormous impacts like those that produced the largest lunar basins would have had potentially devastating consequences for the habitability of the Earth, and it is expected that bombardment of the Earth must have accompanied bombardment of the Moon. Depending on the scenarios for bombardments (nature of projectiles and dynamical processes affecting them), Earth-Moon system bombardments may have affected the other terrestrial planets and even outer-planet satellites, as well. Thus nascent life on other solar system (and extra-solar) bodies might also have been frustrated (or even assisted) by processes analogous to, or even associated with, the lunar Late Heavy Bombardment (LHB) and other, earlier bombardments.

The concept of a ìterminal lunar cataclysmî was advanced early in the post-Apollo years in order to explain certain features of the returned lunar samples. Much work on the LHB in subsequent years has adopted a particular version of the LHB (even as some specialists have continued to debate its very existence) and sought an explanation for a rain of projectiles in the inner solar system some 0.5 Gyr after the origin of the solar system.

The commonly accepted paradigm for the LHB is that it was an inner solar system phenomenon (possibly extending to the outer solar system) in which some reservoir of bodies was quite suddenly perturbed, causing a sudden peak in bombardment rate of projectiles capable of forming multi-hundred km sized basins (and perhaps smaller craters as well) within just ~100 Myr or so, ending about 3.85 Ga.

In order to evaluate astrobiological implications, it is important to understand several features of the LHB and of potential earlier bombardments. In particular, knowing what projectile reservoir/s and dynamical process/es caused the bombardments could tell us which planets and other solar system bodies might have been affected, how much, and for how long. Scenarios recently advanced include the sudden ejection of an additional planet from the inner solar system and bombardment triggered by sudden changes in the configuration of major outer solar system planets, which could cause inner solar system bombardments due to perturbations both of outer solar system planetesimals (which would dramatically affect outer solar system satellites) and of asteroids (which would be less likely to affect outer solar system satellites).

Another attribute of the LHB that could strongly affect the consequences for habitability

of nascent life is the size distribution of the projectiles. The available evidence for the LHB relies almost totally relies on the giant basin-forming impacts. Yet if those bodies were accompanied by a rain of small bodies (like the 10-20 km diameter body inferred to have caused the K-T boundary mass extinction), the environmental disruptions would have been practically continual, in between the basin-forming impacts that would have struck the Earth more often than every million years.

It is important for astrobiologists to realize, however, that the nature and very existence of the LHB (let alone the possibility of earlier bombardments) is based on a set of post-Apollo inferences that can be seriously questioned. The record of lunar impact melts, which has been regarded as robust evidence for the LHB, presents serious questions, especially when viewed in the light of histograms of rock-resetting ages on both the Moon and meteorite parent bodies. One must consider not only the biases potentially introduced by the procedures by which lunar samples were collected (and lunar meteorites ejected), but also by the processes of megaregolith emplacement and surficial regolith evolution, which might strongly affect which rocks are subsequently processed and ultimately made available for study in the upper meter of the lunar regolith. It is possible that the record of lunar impact melts is seriously biased.

Also worthy of re-examination is the entire chronology ascribed to the LHB. The associations inferred between collected samples and distant basins may be the best guesses possible (some remain disputed) but the logic is necessarily weak. Certainly the collection of samples from accessible places on the lunar frontside, near the enormous and relatively late Imbrium basin, raises questions about the certainty of the ~50 Myr decline in bombardment between the Nectaris and Imbrium events. The proposed mission to return samples from the lunar backside, in an area affected by the largest known (and probably very old) basin, named South Pole Aitken Basin, has the potential for addressing these issues from a fresh perspective.

# Abstract # 12910 - **Possible Surface Water/Ice Flow Histories of the Uplands Region Surrounding Gusev Crater**

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Gusev crater may be an ideal landing site for the upcoming MER 2003 mission because of the extensive uplands region with substantial quantities of water/ice and sediments through the paleolake. The total size of the uplands area draining into Gusev Crater is 7M $km^2$ – as big as the largest terrestrial drainage basins on Earth – the Amazon and Nile Basins. Possible sources of water for surface water/ice flow in the uplands include glacial/ice sheet, subsurface aquifers, hydrothermal activity, and precipitation. Yet the duration of time for any surface water/ice activity remains unclear.

Currently we are evaluating four possible surface water and ice flow scenarios across the uplands region of Gusev. In two of these scenarios, potential water bodies that range in size from a Mediterranean sea-sized water body to 1.5 M $km^2$ may be prevalent. In another scenario, smaller 58,000 $km^2$ (Great Lakes-sized water bodies in Michigan, USA) water bodies in closed drainage basins may have persisted with ice/glacial activity highly implicated in their formation. Such closed basins may have provided a source of ground water and recharge of Gusev. A fourth alternative scenario, that ground water/subsurface water dynamics have dominated history of the uplands, is considered as well. The presence of periglacial features (polygonal ground, collapse features, and pingos) in the deepest portions of the several large depressions in the uplands implicates ice in the history of surface water flows in the uplands. The many incised stream features in uplands draining into these depressions also suggest surface water flow.

# Abstract # 12914 - **Assessing the Effect of Impact Shock on Water in Amphibole From a Terrestrial Impact Crater**

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Impact cratering dominated geological processes in the early history of planetary formation and, for many planetary bodies, it remained an important process throughout geologic time. Laboratory studies have demonstrated that the impact process can devolatilize geologic materials (e.g., water loss from serpentine; Tyburczy et al., 1990) and fractionate stable isotopes during devolatilization (e.g., preferential loss of H relative to D from Murchison meteorite material; Tyburczy et al., 1995). Evidence for devolatilization and isotopic fractionation has not yet been pursued in natural samples, although the longer duration of shock waves and the slower post-impact thermal relaxation of natural impacts relative to laboratory impacts may facilitate devolatilization and isotope fractionation (Schärer and Deutsch, 1990). If impact shock were demonstrated to affect water and H isotopes in amphibole, the results could be applied to the Martian meteorites. A subset of the Martian meteorites contains amphiboles with low water contents (0.1-0.5 wt.% $H_2O$ versus 1-2 wt.% $H_2O$ expected in fully hydrous amphibole) and highly enriched and variable H isotopic compositions. Martian meteorite amphibole H isotopic compositions fall between $\delta D \approx +800‰$ to +4300‰, where δD is a measure of D and H content relative to a terrestrial standard (higher δD's represent more D-rich compositions). Variations in Martian amphibole H isotopic compositions range from 900‰ between different amphibole grains to 1000‰ within single large amphibole grains. The H isotopic character of the Martian amphiboles was interpreted by Watson et al. (1994) to represent partial isotopic exchange of magmatic water in the amphiboles with water that equilibrated with the Martian atmosphere (currently with $\delta D \approx +4200‰$). The degree of equilibration indicated by the amphiboles implies extensive water-rock interaction on Mars, and a groundwater reservoir perhaps 2–3 times larger than previously thought (Leshin, 2000). Evidence of a significant groundwater system on Mars has important implications for the development and sustenance of life on Mars. Thus, if the H isotopic compositions of the Martian amphiboles result from impact devolatilization and fractionation and not from exchange, the implications of Leshin (2000) for Martian groundwater must be revisited.

To assess the effect of impact shock on amphibole water contents and H isotopic compositions, we have obtained shocked, amphibole-bearing rocks from Haughton Crater on Devon Island, Canada. The impact breccia of Haughton Crater contains multiple amphibole-bearing lithologies, all of which experienced the same degree of shock as the amphibole-bearing Martian meteorites (20-40 GPa; Redeker and Stöffler, 1988). Samples of four amphibole-bearing lithologies were prepared for water content and H isotopic analysis in the Cameca IMS 6f ion microprobe at Arizona State University. Data collected thus far demonstrate that the water contents and H isotopic compositions of shocked amphiboles from one Haughton sample fall within the range of water contents and H isotopic compositions of typical unshocked terrestrial amphiboles (Figure 1).

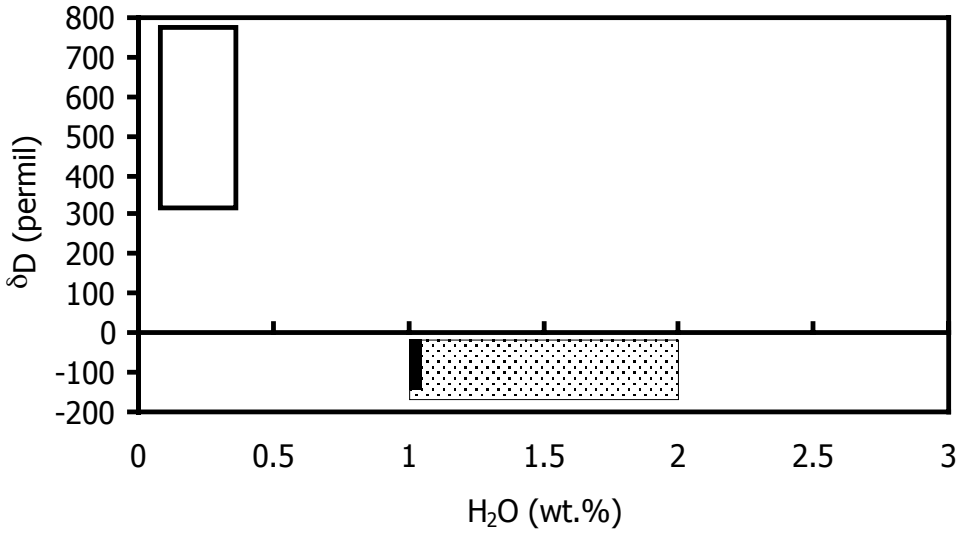


**Figure 1:** Preliminary data for naturally shocked amphibole. Stippled rectangle represents range of unshocked terrestrial amphibole water contents and H isotopic compositions. Filled rectangle represents water contents and H isotopic compositions measured in shocked amphiboles from one Haughton Crater sample. Open rectangle represents water contents and H isotopic compositions expected in shocked Haughton Crater amphibole if low water contents and high, variable H isotopic compositions in Martian amphiboles are entirely caused by impact shock.

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If impact shock produced the low water contents and H isotopic variability in Martian amphiboles, and the same degree of shock alteration occurred in a terrestrial amphibole, the expected shocked terrestrial amphibole compositions would fall in the open box of Figure 1. The fact that the actual shocked Haughton amphibole compositions (filled box) overlap unshocked amphibole compositions (stippled box) and do not approach the compositions of shocked amphiboles expected on the basis of the Martian amphibole data suggest that the effect of impact shock is minimal. In turn, this preliminary result supports the conclusions of Leshin (2000) because H isotopic variability in Martian minerals would be due to rock interacting with a significant Martian groundwater reservoir. Further analyses of shocked Haughton samples will be used to confirm or refute these preliminary results.

# Abstract # 12927 - **Rogue Earth-Moon Systems: Safe Havens for Life?**

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The process of planetary system evolution is naturally chaotic and thus impacts the probability of life on other planets. Some systems will inevitably suffer ejections of terrestrial planets, leading to a population of "rogue" terrestrial planets. Prospects for life on these planets are not great without a significant source of energy, limiting the chances for life to arise. One potential source of energy for a rogue terrestrial planet would be from tidal heating due to a companion satellite. If an Earth-Moon analogue system were to survive ejection, the resulting tidal heating could perhaps be enough to sustain life on the planet. In order to investigate the plausibility of this scenario, we have performed several numerical simulations of Earth-Moon systems in unstable orbits around a Jupiter analogue. We present the resulting probability of Earth-Moon systems being ejected together in a bound state and report on the potential for such systems to harbor life.

# Abstract # 12941 - **Iron-Silica Complexation in Aqueous Solutions: A Key to Understanding the Origin of Banded Iron Formations**

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The environment and formational mechanism of banded iron formations (BIFs) have been debated for decades. Most current researchers agree that both iron and silica in BIFs were transported to the depositional sites by hydrothermal fluids: iron as $Fe^{2+}$ ion and silica as $H_4SiO_4$. However, the mechanism for precipitation of $Fe^{2+}$ as ferric (hydr)oxide minerals (goethite and hematite) and $H_4SiO_4$ as amorphous silica, and the formation of alternating iron-rich and silica-rich bands are not well understood. To understand these processes, a series of experiments on co-precipitation of ferric hydroxides and amorphous silica from ferric- and silicic acid mixed solutions in the wide range of pH (3-10) and silica content (0 – 500 ppm) were conducted.

The experiments were carried out in the beakers contained 5 ppm of $Fe^{3+}$ as $FeCl_3$ and the initial silica concentrations of 0, 10, 100, 150, 300, 400, and 500 ppm. The pH of the solutions were subsequently adjusted to 3, 4, 5, 6, 7, 8, 9, and 10 by adding appropriate amounts of HCl. The precipitates were filtered using 0.45 $\mu$m filter paper after specific time (1 day, 1 week, 1 month), and the concentrations of iron and silica in the filtered solutions and Fe/Si ratios of the precipitates were analyzed.

The experimental results indicate that precipitation of ferric hydroxides and silica under oxygenated conditions is strongly influenced by the pH and silica content of solution. When silica content is below the solubility value of amorphous silica (~120 ppm at pH < 9; 25ºC), silica in solution predominantly occurs as monosilicic acid. Ferric hydroxide precipitates at any pH above ~3; some silica also co-precipitate with ferric hydroxide even when solution is undersaturated with respect to amorphous silica. Silica precipitation probably occurs through the adsorption on ferric hydroxide particles.

When silica content of solution is above the solubility of amorphous silica, it occurs in solution both as monosilicic and polysilicic acids. Precipitation of ferric hydroxide from such solution becomes increasingly more difficult with increasing pH and silica content, and iron remains in the solution. This result suggests the formation of aqueous complexes of ferric iron and silicic acid.

Based on the analyses of the Si/Fe ratios and UV absorption spectra of the colloids, two types of ferric iron – silicic acid complexes were recognized. The first colloid form (termed ISAC-I) is composed of ferric hydroxide particles with silica adsorbed on their surfaces. The second colloid form (termed ISAC-II) consists of silicic acid particles with adsorbed ferric hydroxides. The apparent formation constant of ISAC-II calculated from the experimental data is about $10^7$ at the ambient temperature, indicating that this complex is very stable.

The experimental results suggest that Si/Fe ratios of the precipitates from hydrothermal solutions depend not only on the iron and silica content, but also on the pH of these solutions and the degree of saturation with respect to amorphous silica. Even when hydrothermal solutions with high concentrations of $Fe^{2+}$ react with oxygenated water, ferric hydroxide may not precipitate if the solutions were supersaturated with respect to silica. This fact may explain some observations of iron behavior in submarine hydrothermal systems.

# Abstract # 12981 - **Facies-Dependent Sulfur Isotopic Fractionation in a mid-Proterozoic Marine Basin**

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Sulfur isotopic values of penecontemporaneous pyrite in the early Mesoproterozoic Roper Group, Australia, range over 70‰, but observed variation is partitioned among sedimentologically defined paleoenvironments within the basin. Deep waters were euxinic, as evidenced by Black Sea-type iron enrichment. $\delta^{34}S_{pyrite}$ values from basinal facies range from –20.7‰ to +25.5‰, reflecting non-limiting sulfate conditions for bacterial sulfate reduction. In contrast, shelf facies display $\delta^{34}S_{pyrite}$ values of +10.2‰ to +27.6‰, and pyrites in coastal sediments are still further $^{34}S$ enriched; maxima as high as +49.7‰ reflect Rayleigh distillation effects. Roper sediments, thus, directly support hypotheses of a mid-Proterozoic ocean characterized by low sulfate and anoxia at moderate depth. The Roper results also demonstrate the importance of sequence stratigraphy in the interpretation of Proterozoic biogeochemical data.

# Abstract # 12989 - Ce Anomalies in the 2.6 – 2.4 Ga Kalkkloof Paleosol in South Africa: Evidence for the Early Development of an Oxygenated Atmosphere

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The behaviors of rare earth elements (REEs) during soil formation are influenced by Eh, pH, and the concentrations of carbonate and organic ligands in soil water; the concentration of organic ligands in soil water, in turn, depends on the activity of microbes on and in soils. Under normal Eh-pH conditions, all REEs in aqueous solutions occur dominantly as trivalent complexes. However, in oxic conditions, Ce may form insoluble Ce(4+) oxide and coprecipitate with (or be adsorbed by) ferric hydroxide. This is the reason why the upper part of many modern soils, especially laterites, is enriched in Ce relative to other REEs (i.e., positive Ce anomaly). The REEs leached from the upper soil zone may reprecipitate in the lower soil zone (saproplorite zone), thereby exhibiting a REE distribution pattern that is characterized by depleted Ce (i.e., negative Ce anomaly). Therefore, the REE distribution pattern of a paleosol section can be used as an excellent indicator for the redox state of soil water and the paleoatmosphere.

The paleosols that developed on Archean basement complexes are preserved in many areas of the Eastern Transvaal district, South Africa. The paleosols in the Kalkkloof area developed on a >2.7-Ga ultramafic intrusive rock (dunite) and are overlain by different sedimentary rock units that range from 2.54 to 2.35 Ga in age. The particular paleosol section we have investigated in detail is about 30 m thick. From the stratigraphic relationships, we have estimated this paleosol section formed during a ~200 million year period between ~2.6 Ga and ~2.4 Ga. This paleosol profile is characterized by very high enrichments of silica, especially in the upper ~20 m section where the $SiO_2$ contents typically range from ~70 to ~90 wt.%, compared to the value of ~38 wt% in the parental rock (dunite). The contents of relatively immobile elements, such as Al and Ti, are also significantly increased in the silica-rich zone, but the Al/Ti ratio remains essentially constant, the same as that of dunite, throughout the soil profile. The $Fe_2O_3/TiO_2$ ratio decreases from ~200 in the parental rock to ~15 in the present top of the paleosol profile.

Samples from the lowest part of the soil profile have the lowest concentrations (1-2 ppm) of total REEs. Their REE patterns, as well as total REE concentrations, are essentially

identical to those of the parental rock. However, the samples from the overlying paleosol section are strongly enriched in total REEs with distinct negative Ce anomalies. Towards the present top of the paleosol profile, the total REE concentration and La/Lu ratio generally increase, but the magnitude of negative Ce anomaly decreases (i.e., the Ce/Ce* values increase from ~0.15 in the lower part to ~0.9 in the uppermost part).

The observed behaviors of $SiO_2$, $Al_2O_3$, $TiO_2$, $Fe_2O_3$, and REEs in the Kalkkloof paleosol profile suggest the paleosol section developed primarily by downward moving soil water (rain water) under an oxygenated atmosphere. The silica, Fe, and REEs (and many other soluble elements) were continuously leached from the upper zone, and they were transported to the lower zone where some of the elements reprecipiated, primarily by the evaporation of soil water. Mass-balance calculations based on silica and REE suggest that an approximately 200m thick section of dunite existed above the present top surface of the paleosol. Rocks in this missing section were probably continuously converted to soils with positive Ce anomalies by reactions with oxygenated rain water, and provided silica, Ce-depleted REEs, and other mobile elements to the lower soil section. Concurrent to these chemical processes, the residual soils must have been removed from the soil surface by aerial and fluvial processes at an average rate of ~1m/Ma. Continuation of such chemical and mechanical processes would have resulted in the continuous downward migration of the soil zone that became increasingly enriched in silica and REEs with increasingly more negative Ce anomalies.

The results from our study, therefore, suggest the atmosphere was already oxygenated ~2.6 Ga ago. This suggestion is consistent with our geochemical study on a 2.6 Ga paleosol section at Schagen area in the East Transvaal district (Watanabe et al., 2000).

# Abstract # 13007 - **Uranium Budget of the Archean Oceans: Implications for the Redox Evolution of the Atmosphere**

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Uranium contents of shales and the correlation of U and $C_{org}$ (organic carbon) contents of shales have been used as a proxy for the paleoredox environments. This is based on the assumptions that the chemical weathering flux of the U-bearing minerals on the continent (and thus the U contents in the oceans) should be higher in an oxic world than in an anoxic world, because of the increased solubility of $UO_2$ as $U^{6+}$-complexes with increasing $pO_2$. A positive correlation is expected between U and $C_{org}$ contents of shales deposited under an oxic atmosphere, because organic matter fixes dissolved $U^{6+}$-complexes. Uranium in the shales accumulated in an anoxic world would be dominated by a component of detrital minerals. Therefore, a correlation is not expected between the U and $C_{org}$ contents.

However, the data from numerous studies on the U-$C_{org}$ relationships in modern marine sediments and Phanerozoic shales do not fit into such a simple prediction. Questions remain concerning whether the trend of the U enrichment in marine shales is really a function of the redox state of the atmosphere, and, if not, which factors control U enrichments in shales. Moreover, additional factors need to be considered: (1) the chemical composition and volume of the continental crusts (e.g., Taylor and McLennan, 1985); (2) enhanced weathering intensity due to higher $pCO_2$ (e.g., Kasting, 1993); and (3) enhanced hydrothermal activity due to higher heat flux from the Earth's interior (e.g., Sclater *et al*., 1980) in the early Precambrian. For (1), U is typically more enriched in felsic rocks than in mafic rocks. A prevalent model of the chemical and volumetric evolution of continental crusts postulates a transition from more mafic to more felsic, associated with a great increase in crustal volume, at around the Archean-Proterozoic boundary. For (2), weathering flux of U into the oceans from the continents might have been higher in early Precambrian than present. For (3), U is fixed in hydrothermally altered mid-oceanic ridges (MOR) and thus reduces its oceanic concentration.

We have constructed a model of geochemical budget of U in the Archean oceans in which the above-mentioned aspects are incorporated, and estimated oceanic

concentration of U in the Archean. A major, but reasonable, assumption is that the extent of U fixation into MOR is proportional to a heat flux.

The continental weathering flux of U in the Archean would have been probably the same as today, in spite of the possibility that the chemical composition of the upper continental crust was less felsic and lower in U content than that of today. This is because the weathering rate of U-bearing silicate minerals would have been enhanced under high $pCO_2$ atmosphere. Feldspars are quantitatively important U-bearing minerals in the upper crust, and uraninite ($UO_2$), contrary to popular view, is considered to be minor for the total continental weathering flux of U. Previous researchers have not recognized the importance of feldspars weathering over uraninite weathering as a source of U into the Archean oceans.

Based on the estimates by previous researchers that the heat flux in the Archean was 2~3 times higher than that of today, we estimated that the sink flux of U into sediments in the Archean would have been less than one-third of that of today. Previous researchers have not recognized the importance of U fixation by MOR in the warmer Archean oceans. We also estimated that the concentration of U in the Archean oceans would have been ~2 ppb (parts per billion), which is only ~60 % of the present-day oceanic concentration of U (3.2 ppb).

Generally low U contents of Archean-Paleoproterozoic shales (< 10 ppm; based on the geochemical analyses of >110 samples from S. Africa and Australia: Yamaguchi, 2002) with the continental weathering flux of U similar to today are probably explained by the following: more extensive submarine hydrothermal activity at MOR as a major sink for oceanic U and the lack of significant enrichment of organic matter in the shales (< 3 wt. %). Shales and sediments of low U and low $C_{org}$ contents are typically found in Phanerozoic and modern geological records.

Although our estimates are first-order approximation, we suggest that the geochemical budget of U in the warm Archean oceans was quite different from that of today, and the U content of shales is not necessarily a good paleoredox proxy for the Archean environments. Contrary to the previous suggestion by Holland (1994), the low U Archean shales may not be used as evidence for a globally anoxic environment.

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# Abstract # 13026 - **Molybdenum Isotopes and the Oxygenation of the Mid-Proterozoic Ocean**

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Recently debate has arisen over the redox state of the mid-Proterozoic oceans. The occurrence of banded iron formations (BIF) in the Archean and Paleoproterozoic strongly suggests oceans with little dissolved $O_2$ or $H_2S$ until ca. 1.8 Ga. The disappearance of BIF after this time is commonly taken to indicate ocean oxygenation. Alternatively, the extent of sulfidic conditions in the oceans may have increased after 1.8 Ga (Canfield, 1998). According to this view, ocean oxygenation did not occur until $P_{O2}$ approached modern levels after ~1 Ga. These different scenarios have important evolutionary implications (Anbar and Knoll, 2002). The molybdenum (Mo) stable isotope system may provide insight to this debate

We previously observed systematic Mo isotope fractionation ($\delta^{97/95}$Mo) between recent oxic and sulfidic sediments (Barling et al., 2001; Arnold et al., 2001). $\delta^{97/95}$Mo of seawater and sulfidic sediments are essentially the same, suggesting that the Mo isotope composition of the oceans is largely controlled by fractionation during removal to oxic sediments. The extent of fractionation between adsorbed and dissolved Mo in laboratory experiments is comparable to the extent of fractionation observed between Mn oxides and seawater (~1.7 ‰), supporting this suggestion (Barling and Anbar, 2002; Siebert et al., 2001). The laboratory experiments indicate that adsorption of Mo onto Mn oxide particles is an equilibrium process with a characteristic $\alpha_{solution\text{-}MnO}$ of 1.0017. Therefore, $\delta^{97/95}Mo_{seawater}$ may reflect the global balance between Mo removal to oxic and sulfidic sediments and changes in this balance could be recorded as changes in $\delta^{97/95}$Mo in ancient black shales deposited under sulfidic condtions. If the proportion of seafloor under oxic waters were smaller in the past, $\delta^{97/95}$Mo in black shales should shift toward lighter values.

An investigation of Mo-rich black shales from the Wollogorang Fm. (~1.73 Ga) and Velkerri Fm. (~1.4 Ga) from the McArthur Basin, Australia reveals $\delta^{97/95}$Mo lighter than in recent sulfidic sediments (0.22 to 0.79 ‰ vs. 1.0 to 1.5 ‰). Mo in these sediments is primarily authigenic. Therefore, these data are consistent with less extensive oxic deposition in mid-Proterozoic oceans.

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# Abstract # 13063 - **Scientific Drilling of Archean Stratigraphic Successions in Western Australia: A Mission to Early Earth**

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The Mission to Early Earth (MtEE) Focus Group of the NASA Astrobiology Institute advocates the acquisition, curation and distribution of geological samples from critical stratigraphic intervals to facilitate investigation of the biogeochemical evolution of the Precambrian Earth. The goals of the MtEE Focus Group, and plans for a pilot drilling project, were presented at the 2001 GSA and Fall AGU meetings.

As part of this effort, a drill-hole is planned in late Archean rocks of the Hamersley Basin, Western Australia. The goal of this project is to obtain clean core for biosignature and geochemical analysis to better understand the early evolution of life and its habitat during this critical time. In addition, this project will test the feasibility of a broader stratigraphic drilling program in Precambrian basins globally. A secondary drilling project is planned in the early Archean, sampling across the oldest land surface (the Warawoona-Coonterunah unconformity, ~ 3.5 Ga). Initial funding for the Hamersley core has been committed by the NAI as part of the Astrobiology Drilling Program.

The planned hole will be collared in the lower Dales Gorge Member of the Brockman Iron Formation, lower Hamersley Group. The site selected will be in the lowest metamorphic grade and least deformed part of the basin, along the front of the Hamersley Range. The hole, obtained using hydrocarbon-free diamond drilling techniques, will be about 1000 meters deep, drilling down to the uppermost flood-basalt of the Maddina Formation in the upper Fortescue Group. Hence, it will sample ~ 200 million years of late Archean geological history. It will pass through rocks providing the following types of data:

- Kerogenous black shales of the Mt. McRae, Mt. Sylvia, and Jeerinah Formations, and the Bee Gorge, West Angelas and MacLeod Members of other formations. This will provide material for analyses of $\delta^{13}C_{organic}$, $\delta^{34}S_{sulfide}$, redox-sensitive metal abundances and isotopic compositions, and hydrocarbon biomarkers;

- Banded iron formations of the Brockman and Marra Mamba Formations, shedding light on what controls the inception and cessation of BIF deposition;

- Carbonates of the Wittenoom Dolomite, providing material for $\delta^{13}C_{carbonate}$, $\delta^{34}S_{sulfate}$ and other isotopic tracers;

- Meteorite impact horizons in the Dales Gorge, Bee Gorge and Roy Hill Members, providing fresh samples for determining target geology and impactor composition.

Core materials will be analyzed for these and other tracers, and ultimately made available to the research community.

Such research on some of the least-altered sediments of the late Archean will provide unique insight into: (1) the rise of atmospheric oxygen and the oxygenation of ancient oceans; the chemical composition of ancient oceans; (2) long-term global temperature regulation; (3) the impact history of the early Earth and its effect on evolution; and (4) the radiation of life, as recorded in molecular hydrocarbon biomarkers in carbonaceous sediments and stable isotope records.

# Abstract # 13064 - **Astrobiology Drilling Program**

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Despite intense interest, research into the emergence and early evolution of life, particularly in relation to environmental conditions, is limited by availability of suitable samples. Most Archean and Paleoproterozoic rocks have been altered by metamorphism, hydrothermal mineralization or modern weathering. Where classic Precambrian stratigraphy has survived such alteration, suitable exposures are often scarce due to the occurrence of flat-lying strata or sedimentary cover.

Stratigraphic drilling using clean diamond drilling techniques, targeted in accord with scientific priorities, could provide samples of unmatched quality across the most interesting stratigraphic intervals. The NAI's Astrobiology Drilling Program (ADP) aims to promote such sampling activities, beginning with a coordinated investigation of critical Archean successions in Western Australia.

Samples acquired under the auspices of the ADP will be made available to the research community after a period of priority access to the lead investigators on each project. In Western Australia, sampling activities are expected to commence in Summer, 2003 and beyond. Opportunities are expected in the future for teams of investigators to propose new projects. Plans for community sample access and for future opportunities are being formulated. They will be discussed at the NAI Annual Meeting.

# Origin(s) of Living Systems Abstracts

# Abstract # 12543 - **Atmospheric Aerosols as Prebiotic Chemical Reactors**

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The high organic content of individual upper tropospheric aerosol particles measured from the WB57F high altitude aircraft leads to an inverted micelle structure, with the polar aqueous core contained within a film of amphiphilic molecules with their polar heads bound to the surface of the core and their hydrophobic tails exposed to the air. Recent field studies have shown that some marine aerosols have an inverted micelle structure and composition. This model aerosol is explored (Dobson et al. 2000) as a reaction medium in prebiotic chemistry. We suggest that their versatility eventually led to unicellular life. The emergence of several key properties of unicellular life is shown to be addressable in principle, including size, structure, composition, and replication of chemical populations.

We examine the prebiotic applicability of our recent analysis of the fission of an atmospheric aerosol particle coated with an organic film. The size of the parent particle is determined by the balance between aerodynamics and gravity, while the ratio of the radii of the daughters is determined by the compression characteristics of the amphiphilic molecules comprising the parent film. For an Earth atmosphere of one bar surface pressure, the larger and smaller daughters have the sizes of a single-celled bacterium and of a virus, respectively (Donaldson et al. 2002).

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# Abstract # 12625 - **Early Photosynthetic Events from Phylogenetic Tree Reconstructions: An Assessment**

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Recent work on *Heliobacillus* has completed the gene set for the chlorophyll biosynthesis genes (Xiong et al., PNAS 1999) for the non-oxygenic and oxygenic photosynthetic bacteria. At the same time, the structure of both PSI and PSII of oxygenic photosynthetic bacteria (Cyanobacteria) has shown that all the photosynthetic reaction centres (RCs) are probably homologous. These advances improve our predictive capabilities over the evolution of photosynthesis in terms of timing and sequence. However, there are still many uncertainties.

The question of whether chlorophyll or bacteriochlorophyll came first has the weight of evidence on the side of bacteriochlorophyll, but it is still possible that the early enzymic process produced a mixture of both and that only later did the separation and distinction occur between chlorophyll in oxygenic photosynthesis and bacteriochlorophyll in anoyxgenic photosynthesis.

Clearly anoxygenic photosynthetic bacteria preceded the oxygenic forms. The question of which anoxygenic bacteria evolved first is still a matter of debate although the evidence suggests that it was in the S purple bacteria (*Rhodobacter*) line.

Since the assemblage of extant RCs is small and therefore fragmentary, it is also still an open question as to how Photosystem I and Photosystem II evolved in Cyanobacteria. A fusion model involving fusion (by lateral transfer?) of a quinone type RC and an Fe-center type RC is favoured. However, there is debate over what the original RC, involved in this fusion, was like. Was it a 5 membrane spanning helix (MSH) polypeptide or a 12 MSH polypeptide? The recent discovery of a ring of a light-

harvesting 7 MSH polypeptide around PSI of Cyanobacteria (mainly under iron stress conditions) favours a 5MSH model. This would open up the possibility for the evolution of a light-harvesting 6 MSH polypeptide. However, the puzzle then is why this has not been developed at all within the anoxygenic bacteria.

A further question concerns the relationship of the extant Cyanobacteria to the plastids, which it is generally agreed arose by endosymbiosis from ancestral cyanobacteria. New evidence suggests that the plastids arose from an early assemblage of Cyanobacteria (= Chloroxybacteria), which differed significantly from the assemblage of extant Cyanobacteria.

Keywords: photosynthesis, evolution, phylogenetic trees, anoxygenic bacteria, cyanobacteria, plastids

# Abstract # 12638 *(Oral Presentation)* - **Does Abiotic Synthesis of Organic Compounds in Hydrothermal Environments Require a Vapor Phase?**

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One of the reasons that marine hydrothermal systems are considered as one of the primary candidates for the site of the origin of life on Earth is that conditions within these systems appear to be very favorable for abiotic synthesis of prebiotic organic compounds. Indeed, the notion that organic compounds are readily synthesized under hydrothermal conditions has become widespread in astrobiology. Nevertheless, there remain no identified examples of unambiguously abiotic organic compounds from extant or fossil hydrothermal systems and, while there have been numerous experiments that have demonstrated organic synthesis in the laboratory, very few of these have been performed under conditions which clearly correspond to those in natural systems.

For instance, one frequently invoked mechanism for the abiotic synthesis of organic compounds in hydrothermal systems involves the reduction of dissolved $CO_2$ or CO, with $H_2$ produced from fluid-rock interactions serving as the reductant. At the present time, however, there is little experimental evidence demonstrating that reduction of aqueous $CO_2$ or CO can proceed under such conditions. While many studies cite the well-known, surface-catalyzed Fischer-Tropsch process as the mechanism for organic synthesis of hydrocarbons and other organic compounds in hydrothermal environments, this process has only been shown to occur in gaseous mixtures of $CO_2$/CO with $H_2$ and has never been demonstrated to proceed with dissolved, aqueous reactants. In addition, although many experimental studies have reported synthesis of organic compounds under hydrothermal conditions, essentially all of these studies have been conducted with both vapor and aqueous phases present, leaving it uncertain whether the observed reactions took place in the vapor or aqueous phase.

To date, the only organic compounds that have been unambiguously documented in laboratory experiments to form by reduction of dissolved $CO_2$ in the absence of a vapor phase are simple, one-carbon compounds (methane, methanol, formate) [e.g., 1,2]. One experimental study had previously reported reduction of dissolved $CO_2$ to methane, ethane, and propane during serpentinization of olivine [2], but attempts to replicate these results with $^{13}C$-labeled $CO_2$ have shown that, except for a small fraction of the methane, the organic products were derived from reduced carbon already present in the minerals at the start of the experiment rather than reduction of dissolved $CO_2$ [3].

In order to explore the potential for organic synthesis from dissolved $CO_2$, I have made a number of experimental attempts to reduce dissolved $CO_2$ over the last several years,

including experiments conducted in the presence of various potential mineral catalysts such as serpentinized olivine, magnetite, hematite, and NiFe alloy. Thus far, the only organic products of $CO_2$ reduction I have observed are methane, formate, methanol, methylformate, and dimethylether. None of these experiments have generated any organic compounds containing a carbon-carbon bond. My results, combined with the lack of previous reports demonstrating reduction of dissolved $CO_2$ to other compounds, suggest the possibility that surface-catalyzed formation of carbon-carbon bonds may be inhibited under purely aqueous conditions, and formation of organic compounds more complex than methane in hydrothermal environments may require the presence of a vapor phase.

The presence of a vapor phase can significantly increase the potential for organic synthesis. For instance, heating a 250 *m*molal solution of formic acid at 260°C in the presence of magnetite and a NiFe alloy (2-9 mole% Fe) at pressures that precluded the formation of a vapor phase (350 bar) resulted in essentially complete decomposition of the acid to $CO_2$ and $H_2$ within 48 hours, but the only organic compound generated in over 2500 hours of continued heating was a small amount of methane. When a similar solution of formic acid was heated for 72 hours at 175°C at lower pressure with a vapor phase present, a diverse array of organic compounds were generated, including homologous series of normal alkanes, alkenes, alkanoic acids, and 1-alkanols ranging from $C_1$ to $>C_{20}$ in length [4]. The products resemble those typically generated by Fischer-Tropsch-type reactions, suggesting the organic compounds formed by decomposition of formic acid to $CO_2$, CO, and $H_2$, followed by catalyzed synthesis in the gas phase. Similar vapor phase reactions may be required to explain many occurrences of abiotic hydrocarbons observed in natural systems, particularly those where methane is accompanied by more complex compounds.

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# Abstract # 12658 - **Abiotic Nitrogen Reduction in Submarine Hydrothermal Systems: A Modeling Study**

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Environments containing reduced nitrogen compounds (e.g., ammonia, ammonium ion, hydrogen cyanide) are thought to be far more effective in abiotic organic synthesis than ones dominated by dinitrogen. The sustained chemical disequilibrium present in submarine hydrothermal environments may have provided a driving force for prebiotic synthesis on a Hadean Earth. However, to synthesize nitrogen-containing compounds, such as amino acids, it is necessary to either advect reduced nitrogen compounds or from them *in situ*. The two major sources of nitrogen in vent solutions on a prebiotic Earth are atmospheric N-gases and nitrogen degassing from the mantle. In a moderately reducing atmosphere, nitrogen in the atmosphere will predominantly be present as dinitrogen. Mantle-derived nitrogen is also present as dinitrogen, unless the oxidation state of the mantle is much lower than today. In this modeling study, we evaluated under what conditions dinitrogen is reduced as it circulates through the oceanic crust around a spreading center or hot spot.

The circulation of seawater at mid-ocean ridges was modeled using the Geochemist's Workbench™ software. We used seawater of present-day composition with a total nitrogen concentration of 1.18 mmol/kg, but devoid of molecular oxygen. Because the concentration of sulfate in the Hadean ocean is poorly constrained, we evaluated the seawater with 0%, 25%, 50%, 75%, and 100% of present day sulfate concentration (2.89 mmol/kg). Various scenarios were modeled for seawaters with nitrogen initially present as dinitrogen, nitrite, and nitrate. Nitrate and nitrite may be present in seawater in small concentrations as a result of formation in the atmosphere during lightning strikes. In a flow-through model, the seawater equilibrates with various mineral redox buffers (Iron-Wustite IW, Quartz-Fayalite-Magnetite QFM, Hematite-Magnetite HM, Pyrite-Pyrrhotite-Magnetite PPM) at temperatures between 25 and 300 °C.

All tested redox buffers were found to be effective in reducing dinitrogen. In the temperature range of 25-300 °C, solutions in equilibrium with IW, QFM, and PPM buffers are dominated by ammonium ion with virtually no dinitrogen present. Except for the simulations with HM as buffer, the sulfate concentration has no effect on the nitrogen reduction. However, the sulfate concentration does affect the ammonium ion/ammonia

ratio (i.e., there is a pH dependence) regardless of the redox buffer present. The extent of nitrogen reduction in solutions buffered by the HM assemblage is affected by the sulfate concentration. The HM assemblage fixes $fH_2$ at lower values than QFM, IW, or PPM buffers. The nitrogen speciation in a solution with present day sulfate concentration is dominated by the ammonium ion at temperatures below ~ 290 °C, whereas at higher temperatures dinitrogen dominates the solution. The point at which dinitrogen starts to be the dominant nitrogen species in the solution shifts towards higher temperatures as the sulfate concentration decreases.

Nitrate and nitrite are completely reduced upon equilibration with all mineral buffers considered here. The nitrogen speciation is following the same pattern as described for the dinitrogen reduction.

Organic species (urea, methanamine) were formed in the presence of all mineral buffers and their concentrations never exceed $10^{-9}$ log molal. The presence of urea and methanamine as the most abundant organic species is in good agreement with the results of Shock (1992), however our calculations predict concentrations for these species that are approximately three orders of magnitude lower than predicted in the earlier work by Shock (1992).

Our geochemical model suggests, that regardless of the original nitrogen speciation in the recharging seawater, virtually all nitrogen is reduced to ammonium ion upon contact with HM, PPM, QFM, or IW mineral buffers. It should be stressed that it is assumed in these calculations that the system equilibrates. In reality, there could be significant kinetic barriers, preventing equilibration (e.g., Schoonen and Xu, 2001). In the next phase of this project, we will conduct experiments to assess whether interaction of N-containing seawater with redox buffers could have would provided sufficient amounts of ammonium to sustain prebiotic synthesis in hydrothermal vent systems.

*References*

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# Abstract # 12685 - **A Test for Polyaminomalononitrile as an Intermediate in HCN Polymerization**

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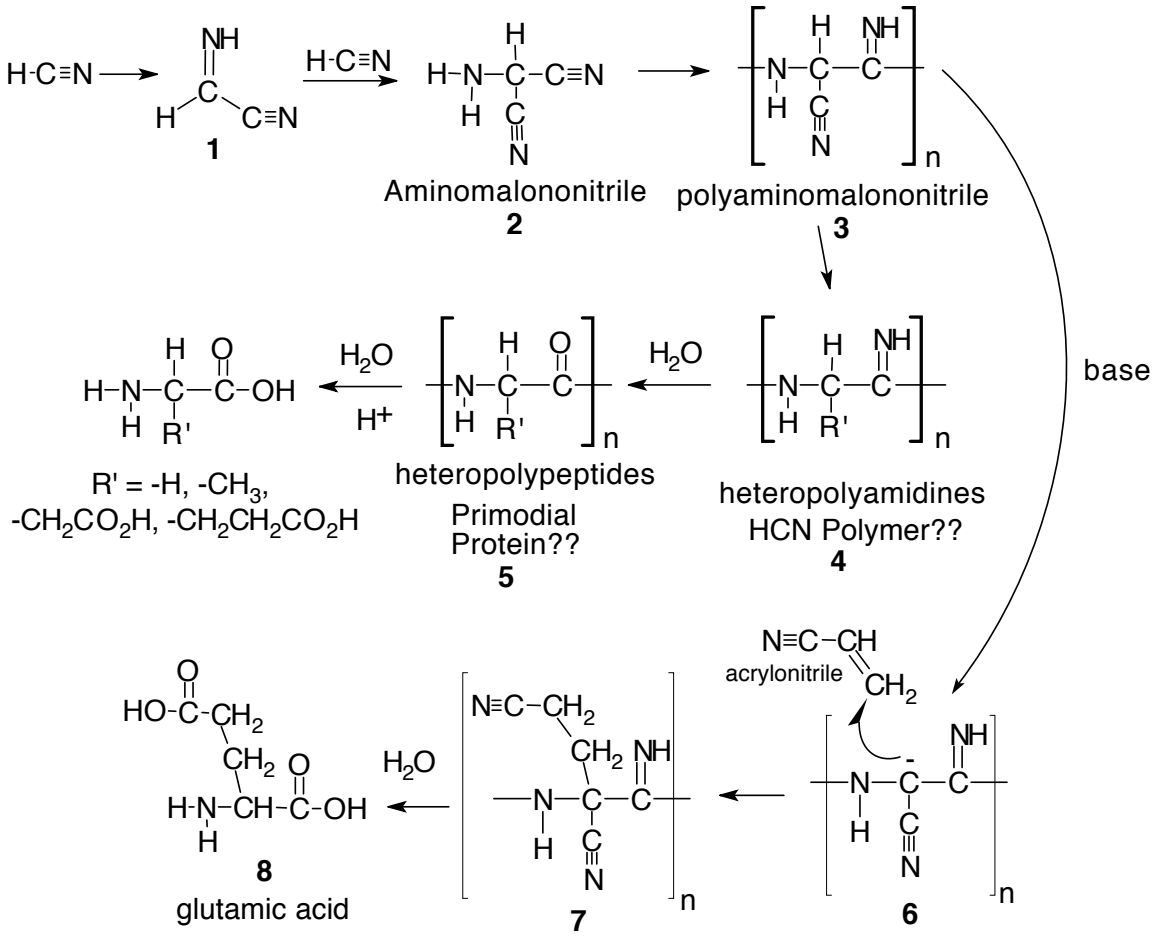
HCN polymerizes rapidly at room temperature when small amounts of base catalysts are present. In 1966, C.N. Matthews proposed that this chemistry could lead to the direct formation of "primordial" proteins from HCN and $H_2O$ according to the scheme shown below. As suggested by Albert Eschenmoser at the ISSOL 2002 conference in Oaxaca Mexico last summer, one possible proof for the validity of the Matthews pathway would be to test for the intermediacy of the polyaminomalononitrile, **3**, by looking for its Michael addition product with acrylonitrile that has been added to the HCN polymerization reaction. This reaction would result in the formation of increased amounts of glutamic acid, **8**, in the final hydrolysis products of HCN polymer. After hydrolysis (6M HCl, 110°C, 24 hr), the amount of glutamic acid is measured as its TBDMS derivative using GC-MS. Initial studies show a significantly increased yield of glutamic acid, supporting the hypothesis of polyaminomalononitrile, **3**, as one possible intermediate in HCN polymerization.

Scheme I:


H-C≡N
1
H-C≡N
Aminomalononitrile
2
polyaminomalononitrile
3
base
heteropolyamidines
HCN Polymer??
4
H2O
H+
heteropolypeptides
Primodial
Protein??
5
R' = -H, -CH3,
-CH2CO2H, -CH2CH2CO2H
acrylonitrile
6
7
8
glutamic acid

# Abstract # 12732 - **Fate of RNA, Adenine and Glycine in the Presence of Minerals**

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Whether life arose from a surface, oceanic, or subsurface environment, the preceding prebiotic organic compounds co-existed with a suite of minerals. The resultant reactions derived from this co-existence could have greatly affected the Earth's prebiotic organic composition. The objective of this study is to understand the fate of selected biomolecules and amino acids on a molecular scale. The fate of organics in the presence of minerals could range from no interaction, simple adsorption and protection from hydrolysis, complete destruction to partial decomposition and possible formation of intermediate species. The focus of our work has been to understand the fate of RNA, adenine, and glycine in the presence of selected minerals.

The fate of RNA dissolved in an aqueous pyrite slurry has been studied in some detail. Experiments were performed using crushed and acid cleaned pyrite stirred in an anoxic RNA solution. A rapid decrease in solution RNA concentration is experimentally observed (Fig. 1). After RNA reached zero in the reaction vial, the pyrite was transferred to another vial with de-oxygenated de-ionized water and stirred. No solution RNA was detected, suggesting either irreversible adsorption or RNA destruction. FTIR analysis of the pyrite revealed an absence of major RNA peaks, suggesting no surface-bound RNA (Fig. 2). We speculate that a loss of structurally intact RNA could have resulted from pyrite-induced hydrogen peroxide formation and subsequent reactivity (2). 35 microMolar $H_2O_2$ was measured mid-experiment.

Adenine has been shown to interact with several minerals. Its surface concentration was about 15, 5, 3.75, and 1.25 times that in solution for pyrite, quartz, pyrrhotite, and magnetite, respectively when the solution concentration was 20 microMolar (1). Increasing the proximity of organics to mineral surfaces could greatly facilitate reactions.

We plan on reporting results from macro (overall vial concentrations e.g., Fig. 1) and surface (FT-IR-ATR) analyses of organics such as RNA, adenine, and glycine interacting with different minerals.

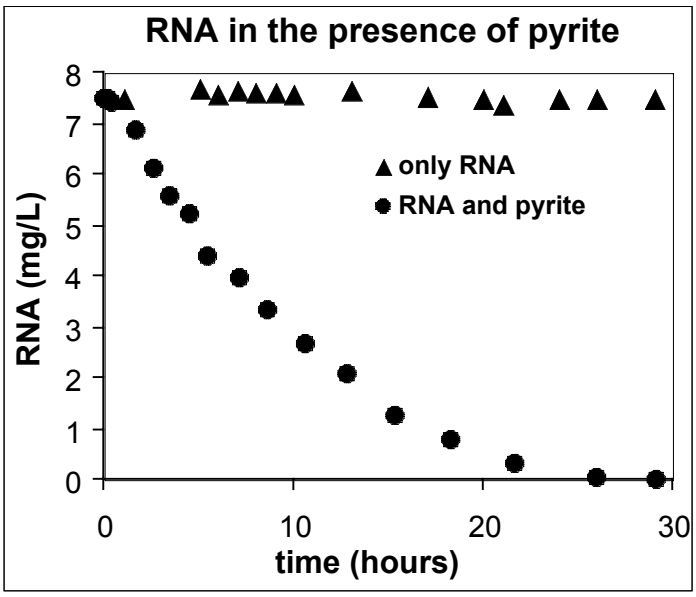


Fig. 1.
Two septum vials prepared under $N_2$ atmosphere. Both with 7.5mg/L RNA, one vial loaded with 75mg/L pyrite (125 – 425 microns). RNA measured by fluorescence using RiboGreen dye (Molecular Probes).

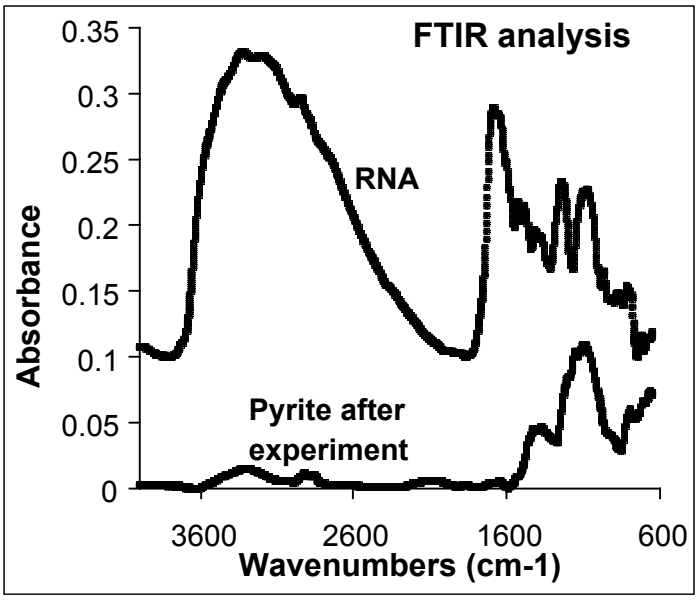


Fig. 2.
FTIR-DRIFT analysis in KBr shows an absence of major absorption peaks from RNA on the dried pyrite surface. The RNA baseline is shifted up for clarity. In other analyses, the pyrite spectrum was compared to that of a cleaned pyrite surface showing little difference.

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# Abstract # 12738 - **Common Ancestry of Some Metabolic Enzymes in Selected Bacteria**

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We have examined some groups of sequence-related metabolic enzymes in E.coli in order to learn more about the different modes of protein evolution. Our results have shown how divergence in evolution of enzymes used common features of reaction chemistry and/or ligand specificity to create catalysts for different kinds of biochemical reactions.

Gcl, IlvI, and PoxB are sequence-related enzymes in different metabolic pathways that illustrate the process of functional divergence from common ancestors. Inspection of the reactions showed that they share bound cofactor (ThDP), often the redox prosthetic group (FAD), and basically use the same reaction chemistry for decarboxylation.

We compared the structures of these proteins by comparative modeling and found considerable similarities, thereby indicating that they may have a common ancestry. Bacillus subtilis contains members of the same family. When trees of the families in the two bacteria were compared, both the commonalties and differences in the paths of divergence are seen. Another family of proteins, class III transaminases in both E.Coli and Bacillus subtilis, was also analyzed.

Understanding the mechanisms of protein evolution helps us to delineate early ancestors and provide important information on the earliest proteins involved in the origin of life on Earth.

# Abstract # 12741 *(Oral Presentation)* - **Replicating Vesicles**

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We are attempting to study the origin of life through the synthesis of molecular assemblies capable of autonomous replication and Darwinian evolution . Cellular life requires both a genetic polymer to encode heritable information, and compartment boundaries to enable Darwinian evolution by preventing the random mixing of genetic molecules. Because of the absence of complex biochemical machinery, both the earliest genetic molecules and the earliest cell membranes must have been able to replicate purely under the influence of chemical and physical forces. We have therefore focused our attention on the *in vitro* evolution of replicating nucleic acids and the design of replicating membrane vesicles. Building on the pioneering studies of Deamer and Luisi, we have begun to study vesicles composed of simple fatty acids, with the goal of identifying conditions under which such vesicles could grow and divide spontaneously.

We have confirmed the observations of Luisi that fatty acid vesicles can grow through the incorporation of additional fatty acids, supplied in the form of micelles. We were initially able to monitor the growth process by dynamic light scattering, and by physical separation methods such as flow-field fractionation. Recently we have a developed a more quantitative fluorescence resonance energy transfer (FRET) assay based on donor and acceptor dyes localized to the membrane of pre-formed vesicles. As material from the incoming micelles is incorporated into the membrane, the donor and acceptor dyes become farther apart on average, resulting in a decrease in FRET efficiency. This assay has proven useful both for measurements of the efficiency of fatty acid incorporation under different conditions, and for kinetic studies of the mechanism of membrane growth.

Once vesicles have grown to twice their initial surface area, they can be forced to divide by extrusion through small pores. A remarkable aspect of division by extrusion is that the concentration of encapsulated material remains constant before and after extrusion; this is most consistent with division by a pinching-off process which does not allow equilibration of the contents with the surroundings. We have been able to take populations of vesicles through five cycles of growth and division with continuous monitoring of size changes by DLS, and contents by fluorescence detection. This system provides useful model for the study of primitive growth and division processes under purely physico-chemical control. We hope that this approach will eventually lead to the synthesis of replicating vesicles that are suitable for the incorporation of replicating nucleic acids.

In order for Darwinian evolution to take place at the organismal level (i.e., at the level of the whole cell, not just the encapsulated nucleic acid), the nucleic acid genome must influence the cell as a whole. Although this could occur through the emergence of a second RNA function (such as a structural RNA or a ribozyme that generates additional lipid), a more direct link between genome and cell would provide a simpler path for the emergence of cellular evolution. We hypothesized that faster RNA replication inside a membrane compartment might lead to osmotic swelling of the vesicle and hence faster growth of the membrane. We have tested this idea in a model system in which fatty acid vesicles were osmotically swollen with sucrose. Such swollen vesicles are stable by themselves, but when mixed with relaxed (isotonic) vesicles, the swollen vesicles grow in size at the expense of the relaxed vesicles, which shrink. Thus, vesicles can directly compete for limiting resources such as membrane components on the basis of their internal osmotic pressure. Current efforts are directed towards demonstrating vesicle competition in response to the concentration of encapsulated nucleic acid.

If living systems actually emerged from the combination of replicating nucleic acids and replicating vesicles, then we must also consider the ways in which nucleic acids might become internalized by vesicles. Although random encapsulation as a new vesicle forms *de novo* can certainly occur, this process is inefficient. However, in the course of studying vesicle replication, we have observed a remarkable effect of the clay mineral montmorillonite on spontaneous vesicle assembly. Normally, when fatty acid micelles (at high pH) are added to a buffered solution at lower pH, the micelles begin to aggregate and eventually assemble into new vesicles. This process has a long lag phase, which can be essentially eliminated by the presence of small amounts of clay particles. Microscopic observations show that clay particles often end up encapsulated inside the vesicles that they have helped to assemble. These observations suggest that nucleic acids might be synthesized on the surface of clay particles that are already inside vesicles, or they might be subsequently encapsulated while still bound to the clay surface. We suggest that this coupled pathway for nucleic acid synthesis and vesicle encapsulation provides a significant simplification of this step in the origin of life.

# Abstract # 12786 - **Promiscuous Nature of FadB Protein of *E. coli***

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We can learn about some of the mechanisms of molecular evolution by close study of individual modern proteins. One example is the FadB protein of *E.coli*. Fatty acid biosynthesis is an important pathway for every organism. It is a multi-step process, and one of the key enzymes in the biosynthesis of lipids is FadB. In this case, we examined the FadB protein from *E.coli*. The uniqueness of this protein lies in its functionality. FadB protein has four known functions in the same protein. By sequence similarity, the C terminal part of the protein has dehydrogenase activity, whereas the N terminal part of the protein has the other three known activities, namely epimerase, isomerase, and hydratase.

We focussed our observation on the N terminal part of the protein to identify the regions responsible for the variety of reactions. The N terminal sequence mapped onto known structures of enzymes that catalyse reactions as diverse as epimerase, isomerase, hydratase, and protease. Known active residues in three biochemically characterized proteins were found to have counterparts in the single catalytic site of the FadB N terminal region.

Using multiple sequence analysis and protein modeling, we could identify a common reaction pocket for all the activities but different sets of amino acids for each function. FadB is an example of efficient evolution, using a single enzyme active site to perform three reactions.

# Abstract # 12789 - **Molecular Structure of Titan Organic Haze: Studies of Laboratory Analogs**

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Titan's atmosphere supports a rich organic chemistry that may have implications for prebiotic chemistry on Earth and elsewhere in the universe. Voyager detected a complex organic chemistry in the upper atmosphere of Titan, driven by a combination of ultraviolet and particle radiation (Lunine et al. 1989, in *Origin and Evolution of Planetary and Satellite Atmospheres,* S. K. Atreya et al., eds., Univ. Arizona Press, p. 605). Laboratory simulations of Titan's atmosphere involving cold plasma discharge excitation of a 10% methane, 90% nitrogen gas mixture produce complex heteropolymeric organic solids, known as tholins, that serve as laboratory analogs of Titan organic haze (e.g. Thompson et al. 1991, *Icarus* **90**, 57). Voyager broadband visible spectra of the aerosol haze layer fit reasonably well the optical constants of Titan tholin (Khare et al. 1984, *Icarus* **60**, 127). Ultraviolet and infrared spectra of bulk tholin and its water-soluble components, as well as analysis by high-pressure liquid chromatography, indicate a complex mixture of hetero-polymeric molecules (McDonald et al. 1994, *Icarus* **108**, 137). Acid hydrolysis of Titan tholin yields several amino acids at approximately 10 mg per gram tholin (Khare et al. 1986, *Icarus* **68**, 176; McDonald et al. 1994). Pyrolysis GCMS of Titan tholin yields numerous pyrolysis products (Khare et al. 1984, Ehrenfreund et al. 1995, *Adv. Space Res.* **15(3)**, 335) including alkanes and alkenes, linear and branched aliphatic nitriles, as well as five- and six-membered ring compounds including the heterocyclic molecules pyridine and pyrrole.

In an effort to more fully understand the potential structural complexity of Titan organic haze, we have subjected Titan tholin to analysis by nuclear magnetic resonance (NMR). Techniques employed include $^{1}H$, $^{13}C$ and $^{15}N$ NMR with variable amplitude cross polarization and interrupted decoupling experiments (Cody et al. 2002, *GCA* **66**, 1851).

The $^{13}C$ NMR data reveal minimal nitrile groups, and a trace of carbonyl (possibly aldehyde or ketone) indicating at least some oxygen incorporation either during the laboratory synthesis or during subsequent handling in air. The predominant features are a asymmetric resonance from 160-175 ppm, potentially from amidines and/or urea, and a broad resonance from ~ 5-70 ppm consistent with aliphatic carbon and aliphatic amines (note that interrupted decoupling experiments indicate a substantial amount of methyl functionality, but no N-methyls). There is a broad peak centered at ~ 137 ppm that is

consistent with aromatic carbon in N-heterocycles. Overall, the aromaticity of Titan tholin is very low (7.1 %).

**$^{13}$C CPMAS NMR**

| Peak Position (ppm) | % Total Intensity | **Possible Assignments** |
|---|---|---|
| 206-190 (broad) | 3.8 | Carbonyl (aldehyde or ketone) |
| 160-175 (broad) | 42.3 | Amidine, urea, carboxamide, carboxyl |
| 137 (broad) | 7.1 | Aromatic heterocyclic, pyridine |
| 120 (sharp) | 1.3 | Nitrile |
| 50-70 (broad) | 15.0 | $CH_xN$ |
| 35 (broad) | 17.5 | $CH_x$, $CH_xN$ |
| 15 (broad) | 12.8 | $CH_3$ |

**$^{15}$N CPMAS NMR**

| Peak Position (ppm) | % Total Intensity | **Possible Assignments** |
|---|---|---|
| -200 | 7.2 | Isonitrile, imidazoles, nucleosides |
| -245 | 10.7 | Indoles, amides, lactam |
| -272 | 32.7 | Amides, carbodiimides, enamine ketone, carbamate |
| -301 | 40.0 | Urea, nucleoside amines, amidines, carbodiimides |
| -334 | 9.4 | Amines, alicyclic enamines, anilines, hydrazines, aziridines |

relative to $CH_3NO_2$

The $^{15}$N NMR data are consistent with isonitrile, imidazoles, nucleosides, indoles, certain amides, and/or lactones, and possibly some amides and peptides. Carbodiimides also may be present, as well as enamine ketones and carbamates. The peak at –334 ppm is undoubtedly due to amine, indicating that there is relatively little amine functionality.

A linear, branched, acyclic tholin structure, presumably formed by polymerization of simple nitriles, has been proposed (Thompson and Sagan 1989, *Origins Life Evol. Biosph.* **19**, 503; Ehrenfreund et al. 1995). Pyrolytic degradation of linear polynitriles is consistent with most of the major tholin pyrolysis products (Khare et al. 1984, Ehrenfreund et al. 1995), although the data also show measurable amounts of pyrrole, pyridine, and other cyclic structures. We will examine model tholin structures in the light of these new experimental data, as well as the ramifications of tholin structure for organic chemistry, particularly aqueous organic chemistry, on the surface of Titan.

# Abstract # 12806 *(Oral Presentation)* - Protometabolism Under Hydrothermal Conditions: Primitive Carbon and Nitrogen Fixation Strategies of a Young Terrestrial Planet

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The hypothetical path from the initial abiotic world to Earth's first biology has been described (in purely general terms) as passing through several key stages (e.g. de Duve, 1991). In a condensed format, such a path starts with proto-metabolism (with an emphasis on abiotic nucleotide synthesis), leads into RNA replication (the nascent stages of "RNA world"), and eventually achieves encapsulation (the first membrane). The development of RNA dependent peptide synthesis, followed by the final development of translation, yields the "pre"-biotic system poised to intiate biological metabolism and herald in Earth's first life (de Duve, 1991). Although, over the past three decades there has been substantial progress made in research covering many of these path segments, for example in the area of RNA catalysis, there remains considerable uncertainty regarding how organic chemistry intrinsic to a primitive terrestrial planet segued into the initiation of the RNA world.

Recently we have set out to establish, experimentally, whether transition metal catalyzed reactions in the presence of water could provide potentially useful protometabolic chemistry. Our early efforts focused on primitive carbon fixation pathways. We have found that the all but one of the transition metal sulfides studied thus far promote reactions that mimic the key intermediate steps of the critical enzyme complex acetyl-CoA synthase operating at the core of the anabolic metabolism of acetogens and methanogens (Cody et al. *submitted*). We have further shown that metal sulfide catalysis can promote a series of hydrocarboxylation reactions that highlight a potential reaction pathway leading up from propene to hydroaconitic acid; i.e., an abiotic carbon fixation pathway that ends within two electrons and one water molecule away from citric acid. The potential of such a pathway is compelling as it is well known that under hydrothermal reactions citric acid can be a good source for pyruvic acid and possibly oxalacetic acid (although this compound has never been observed due to its extreme thermal instability). Pyruvic acid is a very useful prebiotic product, for example, in the presence of $NH_4^+$ a simple reductive amination reaction provides a ready source of alanine (e.g. Brandes et al. 1999).

Recent experiments investigating the effects of $NH_4^+$ addition to hydrothermal solutions containing citric acid and in the presence of transition metal sulfide (pyrite) have revealed some very interesting results. Based on our previous work (Cody et al. 2001,*GCA* **65**, 3557) it appeared reasonable that one could capture reactive alpha ketoacids formed from the hydrothermal decomposition of citric acid via a reductive amination reaction.

The presence of nitrogen yields a broad range of nitrogen containing compounds derived from the hydrothermal reaction of citric acid at 150 °C. Preliminary analysis reveals the presence of lactams and a variety of amino acids, but interestingly no alanine or aspartate. At higher temperatures (200 °C), the reaction scheme changes substantially. In the presence of ammonia and a reducing agent alone, a significant amount of alanine is formed. Trace amounts of aspartate are also formed. With presence of a transition metal sulfide the yields of these two amino acids increases substantially. The presence of the sulfide likely enhances the reduction of the imine favoring the accumulation of the amino acids. The formation of detectable quantities of aspartate is significant for two reasons. First it establishes the presence of oxalacetic acid derived from citric acid at, albeit, low levels. Second, although early hydrothermal studies of aspartate have focused on their destruction it is clear from the present result that aspartate sources can be sufficient even at 200 °C to sustain, at least low, steady state levels of this critical amino acid.

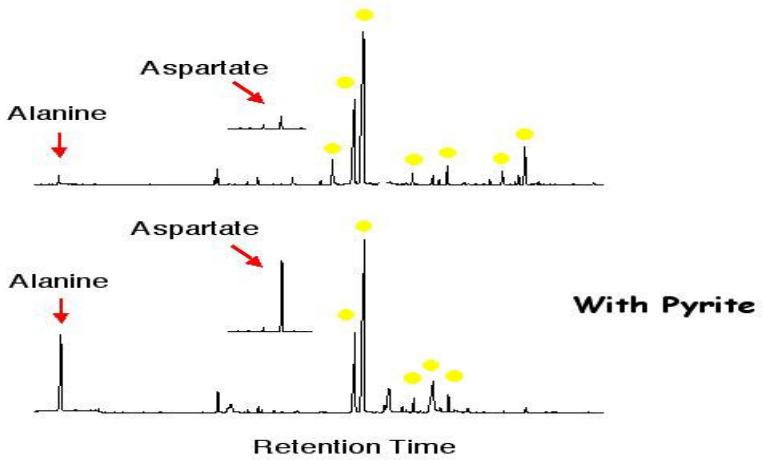


**Figure 1:** Reactions of citric acid in the presence of ammonia and a reducing agent (formate) at 200 °C yields significant quantities of alanine and trace amounts of aspartate. In the presence of a transition metal sulfide (pyrite) the reductive amination reaction is strongly enhanced as is observed in the lower chromatogram.

In this presentation, we will explore the important protometabolic connections derived from the nitrogen fixation chemistry coupled with on going exploration of metal catalyzed carbon fixation reactions. The geochemical route to RNA world may derive from chemistry similar to that described above.

# Abstract # 12814 - **Protein Evolution of Sulfite Reductase**

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Isotopic evidence shows sulfite reductase is an ancient pathway that probably has existed 2700 million years. The key gene for the sulfite reduction is a dissimilatory sulfite reductase (dsr) found in anaerobic sulfur reducing bacteria. In this study we attempt to find the evolution and divergence of assimilatory (*asr*) and dissimilatory types of sulfite reductases. It has been observed that both assimilatory and dissimilatory type of sulfite reduction have similar reaction mechanisms, the substrate (sulfite) and the end products (sulfide). In the case of assimilatory sulfite reduction, the $H_2S$ produced is utilized further for biosynthesis of sulfur-containing amino acids (cysteine and methionine), whereas in dissimilatory sulfite reduction $H_2S$ is excreted.

In this study we used sequences from some of the cultured sulfate reducing bacteria and *dsr* sequences from the Guaymas Basin (Gulf of California, Mexico). Since *dsr* enzyme are heterodimers $\alpha_2\beta_2$ and $\alpha$ and $\beta$ subunits are related by sequence to each other, they fall into distinct groups. The *dsr* polypeptides have both a siroheme prosthetic and a ferredoxin type iron sulfur cluster. Multiple alignment of sequences from the Guaymas and some of the cultured sulfate reducers like e.g. *Desulfovibrio vulgaris*, *Desulfotomaculum sp*, *Archaeoglobus fulgidus* show that the siroheme and iron sulfur cluster domains are well conserved with a few exceptions that could be mutants having lost this function.

Introducing *asr* sequences to the *dsr* tree gives information on the evolutionary relationships between *asr* and *dsr* enzymes. The *asr* have two dissimilar polypeptides chains one is a flavoprotein, while the other is similar to the *dsr* sequences and has a siroheme (but no ferredoxin like site). Comparative study of protein from disparate ecological niches and comparison of related enzyme provide information on the process of molecular evolution. We did the sequence and structural comparison of these sulfite reductases using *E. coli* sulfite reductase structure and found the siroheme binding region has strong consensus, thereby indicating that these sulfite reductases might have a common ancestor.

# Abstract # 12815 - **Amino Acid Production under Irradiation of Interstellar Ice Analogs**

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During a long time, first biological building blocks, as amino acids, were believed to be synthesized in the atmosphere of the early Earth, as successfully simulated by the Urey-Miller experiments.[1] However geochemistry data have progressively questioned a chemical composition of the early atmosphere able to produce organics of biological interest. So far, about 70 organic molecules have been identified in the interstellar medium by radioastronomy, including the chemical precursors of the biological monomers such as $H_2O$, HCN, HCO, $NH_3$, $CH_4$, $CO_2$ or HCHO. Moreover, many organic compounds were discovered in meteorites. The Murchison meteorite, a CM2-type chondrite, contained about 500 organic compounds including nucleic bases, and about 80 amino acids, 8 of them being proteinaceous. More recently, excesses of L-enantiomers, ranging from 2 to 9%, of several C$\alpha$ disubstituted amino acids ($NH_2$-CRR'-COOH) were recently found in the Murchison and Murray meteorites [2]. These amino acids are not biological and cannot, therefore, be the result of terrestrial contamination. On the other hand, the corresponding C$\alpha$-monosubsituted amino acids ($NH_2$-CHR-COOH), which can easily racemize, are present as racemic mixture. These molecules are expected to be produced under interstellar radiation in the icy mantle of interstellar grains. In situ

analysis of the comet Halley showed that organic matter could represent up to 25% of the total composition. Formaldehyde and methane could represent 4% and 5%, respectively, of the cometary organic mass and hydrogen cyanide has been estimated up to 7% [3; 4].

In order to mimic the physico-chemical processes in interstellar ices, we deposited a representative gas mixture containing $H_2O$, $CO_2$, CO, $CH_3OH$, and $NH_3$ onto an aluminium surface at 12 K under high vacuum, $10^{-7}$ mbar. During deposition this mixture was subjected to ultraviolet radiation mainly at Lyman-$\alpha$ band of hydrogen. The product of the reaction was progressively warmed back to room temperature, then hydrolyzed and derivatized prior to GC/MS analysis. Among the rich mixture of produced organic molecules, 16 amino acids as well as furans and pyrroles were identified [5]. The results were confirmed by control experiments using $^{13}C$-labelled ice analogues in order to exclude contamination. The separated and quantified enantiomers of the amino acids showed racemic occurrence. An interstellar origin of amino acids on the primitive Earth may be now considered as a serious alternative to the Urey-Miller mechanism. The advantages of the interstellar model will be introduced.

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# Abstract # 12818 - **Origins of Biomolecular Homochirality: Selective Molecular Adsorption on Crystalline Surfaces**

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Strong chiral preference for amino acids, sugars and other essential biomolecules is a defining characteristic of biological systems. Abiotic processes that select left-handed versus right-handed molecules are thus central to geochemical models of life's origin and evolution. Chiral recognition and separation of molecules, furthermore, is vital to the pharmacological activity of many drugs, the biodegradation of packaging materials, the development of improved polymers, and many other applications in science and industry.

Current research on chiral selection by mineral surfaces progresses on two complementary fronts: phenomenological investigations using natural minerals and fundamental studies using single-crystal samples of manufactured materials. The principal experimental challenge lies in detecting a chiral excess that may be as small as 1% for adsorbed molecular species in concentrations no more than ~1 nanomole/$cm^2$. Researchers have also attempted to understand the theoretical basis of chiral interactions between molecules and surfaces. This task, which merges experimental studies with computational techniques, requires an exact knowledge of crystalline surface structures that are typically deformed in the vicinity of an aqueous medium, as well as molecular and crystal surface charge distributions that are strongly dependent on pH, aqueous ions, and other chemical factors.

Selective adsorption of a chiral molecule on a crystalline surface implies at least three non-colinear points of interaction between the molecule and an acentric solid surface. While the properties of chiral molecules have been studied for more than a century and a half, the subject of chiral crystalline surfaces has received relatively little attention and most previous studies of chiral adsorption have failed to exploit these surfaces effectively. For example, almost all previous experimental studies of chiral adsorption have focused on symmetry-breaking effects of <u>powdered</u> right- versus left-handed quartz ($SiO_2$). Powdering increases surface area but it severely limits the possibility of determining the magnitude, or identifying structural mechanisms, of adsorption on <u>specific</u> surfaces. Different crystallographic planes of quartz possess dramatically different adsorption characteristics; powdering randomizes these different surface structures.

Somewhat counter intuitively, centric crystals can also provide a rich variety of chiral solid surfaces for study because any crystal plane with a surface structure lacking mirror symmetry is intrinsically chiral. Most common rock-forming minerals display crystal growth faces that meet these conditions. Chiral surfaces of acentric calcite ($CaCO_3$), for example, selectively adsorb D- and L-aspartic acid, as well as other amino acids.

Our recent experiments demonstrate a similar molecular selectivity on crystal growth faces of quartz. In particular, adsorption is strongly influenced by the difference between the mineral surface's point of zero charge ($pH_{pzc}$) and the molecule's isoelectric point (pI). We find, for example, that quartz crystal surfaces ($pH_{pzc} \sim 2.9$) strongly adsorb lysine (pI ~ 9.7) compared to other amino acids with lower pI. Mineral surfaces thus have the potential to select and concentrate molecular species in prebiotic environments.

Some authors argue that quartz and other minerals cannot contribute to the origins of biochemical homochirality because left- and right-handed surfaces are present on Earth in equal abundance. This argument is based on the questionable assumption that multiple origin events occurred at different geographical locations on Earth. The preponderance of L-amino acids in biology is thus taken as evidence for a global prebiotic excess of L-amino acids rather than an excess of L-adsorbing environments. We hold a different view: we assume that the nucleation of chiral self-replicating molecular systems is infrequent, while the growth of such systems once nucleated is relatively rapid and efficient. In this scenario a single successful self-replicating chiral synthesis (for example, on one chiral crystal face of one calcite or quartz crystal) purely by chance became the dominant biochemical overprint in spite of initially racemic mixtures both of molecules and surfaces.

# Abstract # 12828 - **Factors that Influence the Emergence of Complexity in Prebiotic Geochemical Systems**

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When energy flows through an intermediate system from a source to a sink, that system tends to become ordered in new and sometimes surprising ways. Natural systems with many interacting components, such as atoms, molecules, cells or stars, often display such complex, "emergent" behavior not associated with their individual components.

A familiar non-biological example is provided by the formation of sand dunes. Gradual deposition of sediments in a lake or deltaic environment may lead to flat-flying sand deposits with poorly sorted grain sizes. Such a sediment system has minimum gravitational potential energy and maximum configurational entropy. If, however, that sediment system dries and is subjected to a steady wind, new structures will emerge. Sand dunes form with a variety of periodic shapes, while sediment grains become highly sorted by size. As wind energy flows across the sediment-atmosphere interface, the sediments spontaneously gain gravitational potential energy, while their configurational entropy decreases.

Observations and experiments on sediment systems suggest that the emergent complexity of a system is a function of at least four factors:

*Density of Interacting Agents:* The emergence of complexity requires a minimum density of interacting agents. In the case of medium-grained sand (average grain size ~0.4mm), for example, a minimum of $10^3$ grains per $cm^2$ is necessary for organized structures to emerge. Similarly, pillar structures built by termites only emerge if the number of termites in the colony exceeds a minimum value.

*Energy Flow Through the System:* Complexity requires an energy flow between minimum and maximum limits. In the case of sand, a minimum energy is required to initiate the saltation of grains that leads to ripple and dune structures. Above a maximum energy, for example in a sandstorm, these structures are destroyed. Similarly, consciousness emerges at energy flows intermediate between that of REM sleep and an epileptic seizure.

*Cycling of Energy Flow:* Experiments on sand ripple formation reveal that cycling of the amplitude or the frequency of water waves leads to added structural complexity (e.g., braided ripples) in the resultant sand structures. Similarly, thermal cycling may play a role in the emerging complexity of prebiotic chemical systems.

*Interconnectivity of Agents:* The degree of complexity is a function of the connectivity and nature of interactions among agents. Sand grains interact only by direct contact with a few adjacent grains and therefore produce relatively simple structures. The greater connectivity and variety of signals of ants, which interact with many other individuals through release of as many as a dozen pheromones, leads to more complex emergent behavior.

These four empirical factors can serve as a guide in the design of experiments that attempt to reproduce the emergence of complexity in prebiotic chemical systems. In particular, these factors underscore the possible roles of mineral surfaces in selecting, concentrating and promoting reactions among prebiotic reactants.

# Abstract # 12844 - **Emergence of Animate Behavior in Peptide-based Ecosystems**

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Living systems are comprised of autonomous self-reproducing 'molecular ecosystems', defined as a collective of self-organized communities of dynamic interacting molecular species. Understanding how such systems have evolved and grown in complexity to transition from inanimate matter to living systems remains a major experimental and theoretical challenge.

Theoretical biologists have described the existence of a self-replicating molecule as a prerequisite, and probably a sufficient demand, for preparing a self reproducing system. Consequently, self-organization of such biopolymers was thought to be the driving force that led to the evolution of the biological world from inanimate matter.[1-2] Although the main conclusions of these theories are generally accepted, there have been very few experimental results to support them.

In the recent years chemists postulated that devising molecular systems to operate in multimode fashion, through the implementation of many template-directed processes, would result in behaviors that far exceed the sum of the individual properties of the molecules.[3] Several minimal molecular networks have been reported to display collective properties such as reciprocal catalysis, autocratic dominancy, and symbiotic replication.[4-7]

We discuss here the design, synthesis and evaluation of a large peptide-based reproducing array, which we termed a molecular "ecosystem". The molecules in the array were designed based on our earlier principles for peptide self-replication and ligation via coiled-coils formation.[8] Peptides were selected to resemble a scenario in which a parent

(self-reproducing) molecule is mutated randomly without significant consequence to the overall structure. The resulting offspring replicate via the same chemistry as the parent molecule, but present substantially altered behaviors such as varying self-replication efficiencies. The structural similarities among mutants allowed for new replication pathways to occur, specifically cross-catalysis. As a result, in a system containing all of the substrate precursors, some of the mutant species replicate by these emergent pathways, and the entire system prevail because the formation of every species is catalyzed. Selective amplifications of product formation in the catalytic network – due to template-assisted processes – triggered the emergence of interesting behaviors such as commensalism, mutualism, and parasitism. Testing the performance of the ecosystem modules in isolated environments allowed for only a limited prediction of these behaviors. Thus, we developed a mathematical algorithm that scored the aggregation stability of the transition state coiled-coils and by that afforded a hierarchy of binary interactions, which was found useful for predicting productive processes.

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# Abstract # 12852 - **Transfer RNA May Have Arisen by RNA Ligation**

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The origin of transfer RNA (tRNA) from smaller historical precursors is difficult to envision because of the apparently complex idiosyncratic interaction between the D-loop and T-loop. Recently, multiple examples of the T-loop structural motif have been identified in ribosomal RNA. These examples show that the long-range interactions between the T-loop and D-loops seen in tRNA are not an essential part of the motif but rather are facilitated by it. Thus, the core T-loop structure could already have existed in a small RNA prior to the emergence of tRNA. A subsequent expansion of an RNA that carried this motif might then produce a full tRNA. With this idea in mind, Di Giulio's earlier hypothesis that tRNA evolved by a simple duplication or ligation of a minihelix RNA was re-examined. It is shown that an essentially modern tRNA structure can in fact be generated by the ligation of two 38-nucleotide RNA minihelices of appropriate sequence. Although rare, such sequences occur with sufficient frequency, that they could be found in a standard *in vitro* RNA selection experiment. The results demonstrate that a series of RNA duplications, as previously proposed, can in principal account for the origin of tRNA. More generally, the results point out that RNA ligation can be a powerful driving force for increased complexity in the RNA World.

# Abstract # 12870 - **Structural Elucidation of the HCN Polymer via Solid-State NMR**

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Hydrogen cyanide polymers form spontaneously from HCN and traces of base catalysts. These materials have been detected in early Earth chemistry experiments and are recognized as ubiquitous substances throughout the cosmos. Despite the profound implications for prebiotic chemistry raised by these materials, full characterization of these intractable heteropolymers has not yet been achieved. As a non-degradative analysis tool, Solid-State NMR (SS-NMR) lends itself well to the structural investigation of such complex materials. For this work, 13C/15N labeled samples of the HCN heteropolymer were prepared and analyzed before and after treatment with H2O. Presented here are results of SS-NMR experiments performed on the singly- and doubly-labeled 13C/15N hydrogen cyanide polymers. Data from both 15N-detect and 13C-detect single pulse experiments are correlated with Cross-Polarization (CP) and Double Cross-Polarization (DCP) spectra in order to elucidate the structure and mechanism of formation of this interesting material. The feasibility of various structural and mechanistic proposals is discussed.

# Abstract # 12916 - **Thermal Stability of Glycine: Decomposition and Oligomerization at 260 °C and 200 Bar in a Static Au-Ti Reactor**

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The kinetics of aqueous glycine decarboxylation to form carbon dioxide and methylamine (decomposition), conversion of glycine into glycylglycine and glycylglycylglycine (oligomerization), cyclization of glycylglycine into diketopiperazine and hydrolysis of the peptide chain have been been determined at 260 °C and 200 bar. Experiments were conducted in a flexible Au-Ti reactor maintained at pH 6.8 with phosphate buffers. Glycine stock solutions were injected into the Au-Ti reactor containing organic-free distilled water pre-equilibrated at the experimental conditions. Reaction products were extracted over a period of 200 hours and analyzed with high pressure liquid chromatography (HPLC) by UV-detection.

At 260 °C and 200 bar we observed a first-order rate loss of glycine ($k_1 = 1.3\times10^{-5}$ $s^{-1}$) corresponding to a half-life of 14.8 hours. Comparison between our rate of glycine decarboxylation and previously reported rates at the same temperature[1,2], indicates that glycine decarboxylation proceeds approximately 10- and 170-fold slower in a reactor made of Au-Ti than in quartz and stainless steel reactors, respectively. In experiments at the same temperature and pressure where hydrogen ($3.0\times10^{-3}$ molar) was added to the Au reactor, the rate of glycine decarboxylation is decelerated to $k_1 = 4.7\times10^{-6}$ $s^{-1}$ ($t_{1/2} = 40.1$ hours), agreeing well with previous redox buffered hydrothermal studies of glycine[3,4]. Formation of glycylglycine from glycine occurred within 10 min following injection of the glycine stock solution into the Au reactor. Rapid cyclization of glycylglycine to the cyclic lactam diketopiperazine was followed by a pseudo-first order loss in both products with a rate constant $k_2 = 5.0\times10^{-5}$ $s^{-1}$ ($t_{1/2} = 3.8$ hours). At 260 °C and 200 bar with

hydrogen levels set at $3.0\times10^{-3}$ molar the glycylglycine hydrolysis rate was reduced to $k_2 = 2.7\times10^{-5}\ s^{-1}$ ($t_{1/2} = 7.1$ hr). Throughout experiments with and without added hydrogen the glycylglycine/diketopiperazine ratio remained constant with an observed standard free energy of cyclization for glycylglycine ⇔ diketopiperazine + $H_2O$ of $-1.1 kJmol^{-1}$ and $-0.9 kJmol^{-1}$ at 260°C and 200 bar in runs with starting glycine and glycylglycine, respectively, both values agreeing well with reported free energies[5] extrapolated to 260°C. Glycylglycylglycine formation exhibits a pseudo-first-order growth of approximately $k_3 = 1.0\times10^{-5} s^{-1}$, corresponding to a $t_{1/2} \sim 19$ hours. Although the glycylglycylglycine data exhibits growth over the period that glycylglycine declined, the levels of glycylglycylglycine are well below those predicted by the magnitude of glycylglycine loss.

Preliminary results from our study indicate that the rate of glycine decarboxylation is controlled by the reactor wall composition where the half-life of glycine at 260 °C is about two orders of magnitude larger in the presence of Au-Ti compared to stainless steel. Furthermore, our studies indicate that rates of glycine decarboxylation and peptide hydrolysis are reduced by a factor of around 3 and 2, respectively, when hydrogen was added to the reactor.

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# Abstract # 12949 - **Chirality of Sugars Synthesized Using Chiral Amino Acid Catalysts**

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Carbonaceous chondrites contain a complex suite of soluble organic compounds many of which are similar, even identical, to those found in the biosphere (amino acids, carboxylic acids and sugar alcohols are examples) (*1*). A large amount of this meteoritic material has undoubtedly showered the Earth through time (*2,3*), and it has been proposed that the organics accreted by this delivery could have contributed to the origin of terrestrial life and that some (such as the non-racemic α-methyl amino acids) possibly held an evolutionary advantage in early molecular evolution (*4*).

On the other hand, many origin-of-life theories are based on the "de novo" syntheses, and subsequent evolution, of simple organic molecules in an early Earth environment. Examples of this thesis have been the Miller-Urey hypothesis (*5*), the "hot" hydrothermal system scenario for the syntheses of organic compounds from simple inorganic precursors (e.g., $CO_2$, CO, metal sulfides) (*6*), and the "sugar model" that yields sugars, amino acids, and possibly peptides from formaldehyde and glycolaldehyde (*7*, *8*).
So far, these origin-of-life theories and related model experiments have presumed either endogenous formation or exogenous delivery of organics in early molecular evolution. However, it appears reasonable to suggest that the two processes may have coincided and, to various extents, collaborated in the origin of life. In this collaborative context, meteoritic amino acids could have provided the symmetry-breaking spark to pre-RNA evolution, not only directly by the formation of homochiral assemblages, but also indirectly as catalysts or promoters of asymmetric syntheses leading to RNA.

We are currently studying this latter possibility by investigating the effect of chiral amino acid catalysts on the chirality of sugar products synthesized by the formose reaction. Specifically, these studies examine the chirality of tetrose sugars formed from glycolaldehyde using both chiral and racemic alanine as catalysts. Previously, amino acids, such as alanine, were found to catalyze sugar synthesis from formaldehyde and glycolaldehyde under mild conditions (8).

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# Abstract # 12980 *(Oral Presentation)* - A Rapid Route to Functional Peptides on the Early Earth

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It is widely presumed that life's origins are tied to the early oceans, and that the key reactions leading to functioning peptides and polynucleotides were water-based. The story is not without its difficulties, however, with thermodynamic and perhaps kinetic barriers to their formation stemming from the inherent favor of amide and ester hydrolysis relative to formation. This water-based obstacle leads to the consideration of a dry, bulk solid alternative that provides a surprisingly facile route to peptides, while at the same time accounting for the rapid emergence of life after the period of heavy bombardment (PHB).

The model's basis is the supposition that during the PHB some of the incoming organic material, including amino acids, survived and was subject to a period of desiccation. The setting could have been either in an era before water collected on the earth in which case the aridity would have been extreme, or perhaps in arid desert areas after the oceans had formed. In either case calculations employing available thermodynamic data for glycine and glycylglycine for amino acid A and peptide $A_n$ in the equilibrium

$$A\ (\text{solid}) + A_n\ (\text{solid}) = A_{n+1}\ (\text{solid}) + H_2O\ (\text{vapor})$$

show that the system is favored to the right for relative humidities < 0.6 (0°C) to < 11% (80°C), a range of values not unexpected for this era on the early earth. Rough estimates of the reaction rates provide relatively rapid half-lives on the order of 0.8n Myr down to about 9n yr, respectively, values we show are considerably faster than competing decarboxylation at the lower temperatures. Thus during or essentially immediately following the PHB, the deposited amino acids would be converted to large polymers, the large fraction of which would have been racemic, uncoiled or randomly coiled strings.

A rapid sequence to functioning biochemistry could then have emerged. It begins with the polymer's ultimate encounter with an aqueous environment, at which point the equilibrium position is immediately reversed. Presuming early ocean temperatures of 25°C, the substances should rapidly hydrolyze fully down to the individual amino acids with a half-life we estimate to be on the order 200n yr.

Competitive hydrolytic rates should play a role to limit the degradation, however. Thus, while overall racemic, the strings will by chance contain homochiral segments, and simple statistical analysis shows that these segments should be present at not insignificant

levels. Thus 3% of the linked acids should be in homochiral segments 6 acid residues long, while almost 1% will be in 8-acid portions. Homochiral peptides of these sizes are at lengths where helical character begins to develop, and the internal hydrogen bonding and hydrophobic shielding in such segments will stabilize them and lower the rates of their hydrolyses. At 25°C the leverage afforded by almost nominal energetics can be substantial; a stability of 2 kcal/mol per hydrogen bond (Myer and Pace, 1996) will translate to rate differences of a factor of almost 30. A homochiral 8-acid segment should have five internal H-bonds and thus its "kinetic protection" is on the order of a factor of 150. It can be seen that further stability will increase with growth, so that while the likelihood of still larger homochiral segments falls with size, the stabilities of those that are formed grow correspondingly. Thus, with proceeding hydrolysis of the heterochiral portions of the chains, the mixture will be increasingly enriched in hydrolysis resistant, homochiral peptides.

Finally, their coupling to still larger peptides would in due course lead to some fraction of the peptides developing protobiological functionality, i.e., self-replication and capabilities to include auto- and cross-catalysis. Further production would then be amplified, bringing the growth process ultimately to a point where hydrolytic rates were essentially noncompetitive. The most primitive stages of life would thus be at hand.

# Abstract # 13018 - **Attempted Asymmetric Heterogeneous Catalytic Hydrogenation of 2-Acetamidoacrylic Acid on Massive Palladium under an Applied Static Magnetic Field**

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Analytical reports of significant non-zero enantiomeric excesses contained in the complements of small-molecule chiral organic species extracted from various carbonaceous chondritic materials present an ongoing and curious chemical question of obvious astrobiological relevance. Literature claims for primary exogenous and abiogenic non-zero enantiomeric excesses in meteoritic sources of chiral organics delivered onto the prebiotic Earth are currently entertained in the light of the demonstrated efficacy of the enantio-biassed photochemical degradation of initially racemic mixtures by circularly-polarized ultraviolet radiations. Among the other various potentially causative factors which might be considered, these reports raise a 'backwater' problem in dark-thermal physical organic chemistry as to the effect, if any, of static magnetic fields on prochiral reactions occurring at both catalytic and electrode surfaces. The chemical experimental literature in this area is considerably muddied, and claims of measurable effects have generally been accepted as being due to various kinds of artifactual experimental errors, and, in one particular case, the perpetration of an outright and deliberate fraud. Reported investigations of the heterogeneous reduction of various unsaturated prochiral organic substrates under an applied static magnetic field have generally employed a liquid mercury reaction surface, mainly for reasons of experimental convenience, and have required considerable post-reaction handling of analytical samples prior to the determination of their optical activities and the quantification of their enantiomeric excesses. The present work describes the *in situ* polarimetric monitoring of the closed-system reduction of 2-acetamidoacrylic acid [$H_2C{=}C(NH.CO.Me)COOH$] on a massive (bulk metal) palladium surface oriented plane-parallel between opposing permanent magnetic poles. This particular organic substrate was chosen because it has been previously employed in this area by other laboratories, and because it is prochiral for α-alanine [(*R*,*S*)-$Me.CH(NH_2)COOH$; α-Ala being the simplest biological chiral α-amino acid], after hydrolytic work-up cleaves the protecting acetyl group and releases the amino function.

In the field of physical organic chemistry, the case of dark thermal (*i.e.* non-photochemical) prochiral organic reactions in heterogeneous systems under applied static magnetic fields remains unclear. In both industry and academia, samples of enantiomerically-pure (or -enriched) molecules quite generally contain stereochemical information that will have been fundamentally derived (at some stage) from living systems, which have themselves been recognized as constituting convenient, renewable, and highly enantiospecific storehouses of chiral chemical information, since the

discovery of optical isomerism (" *l'hémyédrie* " ; " *la dissymétrie* [moléculaire] ") by Pasteur in 1848. The chemical industry has thus never had to face the problem of generating non-zero enantiomeric excesses in samples of laboratory-synthesized chiral molecules without recourse to chiral information acquired (at some point) from the biosphere itself; there has therefore never been any forcing industrial need to drive basic chemical research into the *de novo* generation of an enantiomeric excess in a prochiral chemical reaction. But accounting for observations of apparently non-biogeneric enantiomeric excesses in meteoritic extracts requires just such fundamental chemical inquiries, towards the goal of understanding these unexpected and quite curious analytical reports.

# Abstract # 13039 - **2003 Origin of Life Gordon Research Conference**

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The next Origin of Life Gordon Research Conference will take place on July 13-18, 2003 at Bates College in Maine. The Origin of Life GRC conferences provide an excellent opportunity for scientists new to this area of interdisciplinary research to get an update on new and exciting developments that recently occurred in these different areas. Research on the Origin of Life takes place in a wide variety of disciplines ranging from *Astronomy*, *Astrochemistry*, and *prebiotic chemistry* via *in vitro evolution* and *microbial geobiology* to *molecular phylogenetics* and *comparative genomics*.

Preliminary Program:

- **The subsurface as an abode and potential cradle for life's origin on Earth and other bodies in our solar system**
  (**M. Meyer** / D.R. Lovely/ J.D. Farmer **)**
- **How late/early could the most recent common ancestor have lived? Fossil, molecular and geological evidence**
  (**S.J. Mojzsis** / C.H. House / R.E. Summons / M.A. van Zuilen)
- **Weird Life - possible alternative chemistries for extraterrestrial life**
  **(J.P. Ferris** / S.A Benner / A. Weber)
- **The early atmosphere and early archean environments on Earth**
  (**B. Runnegar** / J. Farquhar / NN / G. Byerly )
- **Solar and extrasolar planets**
  (**B.M. Jakosky** / P. Butler / J.L. Beauchamp)
- **Extent of lateral gene transfer in early evolution**
  (**J.L. Siefert** /W.F. Doolittle / G. Olsen / A. Lazcano)
- **Origin and amplification of biomolecular chirality**
  (**S. Pizzarello** / K. Soai / D.K. Kondepudi)
- **Sequence evolution in the RNA world and beyond**
  (**D.H. Burke** / J.W. Szostak / NN / NN )
- **Evening lecture on "The Role of Natural Selection in Cosmology"**
  (L. Smolin)

Bold represents Discussion Leaders

An updated program can be found at the conference's web page at:
http://sp.uconn.edu/~gogarten/GRC2003OL/ or at:
http://www.grc.uri.edu/programs/2003/origin.htm

# Abstract # 13055 - **Alien Genetic Systems: The Impact of Incorporating Multiple Nucleotide Analogs**

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When searching for biosignatures in non-terrean environments, we must consider alternative molecular structures for genetic systems that do not share common ancestry with the life on Earth that we know. When attempting to generate a synthetic biology ("artificial life"), it is also necessary to consider these alternative structures which leads us to the direct questions: (1) Are the nucleotides known in terrean life universally found in all life forms, regardless of genesis? (2) Is their universality a consequence of prebiotic reactions that are a constraint of the raw materials available to the first life forms? (3) Or, is their structure contingent upon historical accidents on Earth that might not have occurred elsewhere. These are experimental questions that combine synthetic organic chemistry, molecular biology, and biophysics to ask "What if?" and "Why not?" when preparing non-standard analogs of DNA and testing their performance both intrinsically (to ask about biosignatures) and in interactions with terrean biological systems (as a step towards a synthetic biology). Here, we have examined two of the features of terrean nucleic acids to learn if alternative structures might be tolerated, first by terrean polymerases and second by duplex structures in general. These are:

- C-glycosides, wherein the nucleobase is joined to the sugar via a carbon-carbon bond, instead of the carbon-nitrogen bond found in terrean DNA.
- 3-deazapurines, which lack an unshared pair of electrons in the minor groove of the DNA that is found in all terrean nucleobases.

To represent C-glycosides, we synthesized and studied pseudo-thymidine triphosphate (ψTTP), an analog of thymidine. We found that when multiple ψTTPs were incorporated opposite template adenosine in a sequence, the polymerases could easily incorporate strings of up to seven of these analogs in a row before halting. To represent nucleobases lacking the minor groove unshared electron pair, we synthesized and studied an adenosine analog, 3-deaza-2'-deoxyadenosine 5'-triphosphate ($c^3$ATP). When challenged

to incorporate $c^3$ATPs opposite template thymidine, the DNA polymerases examined could not incorporate more than two subsequent analogs before being unable to continue.

We have no evidence that suggests that these results reflect an intrinsic inability of duplexes containing ψTTP and $c^3$ATP to form, but prefer instead to explain these results as a consequence of the interaction of a terrean polymerase with a non-terrean substrate. These results indicate nucleotide analogs that lack a minor groove electron pair are not good candidates for a synthetic biology that would exploit standard terrean polymerases, while the C-nucleosides could be considered for this purpose. Both, however, remain candidates for non-terrean genetic systems that have terrean-like backbones in their genetic molecules.

# Recognizing and Interpreting Biosignatures Abstracts

# Abstract # 12592 - **Energetic Processing of Interstellar Ice as a Source of Functionalized Aromatics in Meteorites**

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The tons of organic molecules brought to the Earth each day by meteorites and interplanetary dust particles are thought to have helped to make the early Earth habitable. Although some of these prebiotic organic molecules are believed to have resulted from reactions in liquid water on the asteroid or comet parent body, others are more difficult to rationalize in this manner. Given that the D-enrichment of meteoritic aromatic hydrocarbons (PAHs) suggests low temperature origin, and telescopic observations are

consistent with PAHs being present in presolar ices, we are studying the chemistry of PAHs in interstellar ice analogs in the laboratory.

We have previously reported on oxidation photo-reactions of various PAHs in solid $H_2O$ (1) and a regio-chemical study of naphthalene oxides (2). We will now describe three major advances in this area. First is the addition of methyl ($-CH_3$), methoxy ($-OCH_3$), amino ($-NH_2$), cyano (-CN), and carboxylic acid ($CO_2H$) side groups (3) onto PAHs in ice. Second is a comparison of UV photolysis and MeV proton irradiation of ices containing PAHs (4). Finally, we will describe the regio-chemistry of anthracene photo-oxidation to produce anthraquinone and anthrone, which have been detected in Murchison extracts (5).

These new results bolster the contention that at least some of the functionalized aromatics are the direct result of ice photochemistry, perhaps predating solar system formation. Ice photochemistry would also easily accommodate deuterium enrichments of aromatics in meteorites. You can learn more about the astrochemistry lab at <http://www.astrochem.org>

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# Abstract # 12641 - **Biogenic Magnetite Crystals in Martian Meteorite ALH84001**

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The landmark paper by McKay *et al*. [1] cited four lines of evidence associated with the Martian meteorite ALH84001 to support the hypothesis that life existed on Mars approximately four billion years ago. Now more than five years later, attention has focused on the magnetite ($Fe_3O_4$) grains embedded within carbonate globules in fracture zones of the ALH84001 meteorite as biogenic precipitates. The biogenic magnetite hypothesis is based primarily on the work described in [2-6]. It has been suggested that a population of ALH84001 magnetite crystals (up to ~ 25%) are biogenic [2-4]. Based on a classification scheme described in detail by [7], the presence of these Martian magnetite crystals is interpreted as a category I/II biosignature. The properties displayed by these magnetites, when taken collectively, can be used to differentiate biogenic from abiogenic crystals of magnetite. Briefly these are: (i) narrow size range with a non-lognormal size distribution centered in the single-domain size range; (ii) restricted width-to-length ratios optimized for maximum overlap with the single-domain region of the Butler-Banerjee diagram of magnetite; (iii) chemical purity; (iv) very low density of crystal defects, with the exception of occasional twinning perpendicular to the [111] axis of elongation; (v) unusual truncated hexa-octahedral geometry described by the intersection of six {100} cubic faces, eight {111} octahedral faces, and only six of the possible twelve dodecahedral {110} faces (namely those satisfying the relationship $\{110\}\cdot[111] = 0$); and (vi) elongation along the [111] axis. These criteria comprise a *restrictive and robust biosignature*, for example ~30% of magnetites produced by MV-1 would not collectively

display all these properties and therefore would not be identified as biogenic precipitates. Approximately up to 25% of the ALH84001 magnetite crystals collectively display all six of the properties defined to be solely the provenance of biological activity. The remaining ~75% of the magnetites lack sufficient characteristics to constrain their origin as either biogenic and/or inorganic; this population of ALH84001 magnetite crystals likely formed by inorganic processes including, but not limited to, chemical precipitation from a hydrothermal fluid and/or allochthonous accumulation during carbonate formation. To date no inorganic population, whether produced by a natural or synthetic process, is known to simultaneously display all six properties.

The papers of Thomas-Keprta *et al*. were criticized by [8] arguing that the three dimensional structure of magnetite crystals can only be unambiguously determined using electron tomographic and holographic techniques. Recent work by [5] has confirmed their earlier determination of the truncated hexa-octahedral crystal form in magnetotactic bacterial strain MV-1 using electron tomography, and, has demonstrated the validity of the multi-tilt classical transmission microscopy technique initially used [4].

The abiotic hypothesis of ALH84001 magnetite formation is based on the thermal decomposition of Fe-bearing carbonate through impact shock heating in ALH84001 to produce magnetite [e.g., 9, 10]. However, inorganic processes have yet to reproduce the truncated hexa-octahedral geometry observed in both a subpopulation of ALH84001 magnetites and crystals produced by MV-1. Furthermore, the magnetites in ALH84001 carbonates show no divalent cation substitution by $Mg^{+2}$, yet they are embedded in a Ca:Mg:Fe (~1:4:4) carbonate [e.g., 1, 2]. A solid solution carbonate $(Fe_x,Mg_{1-x})CO_3$, as found in ALH84001, will decompose to form a mixture of phases, not pure a magnetite [e.g., 11]. Hence, the formation of the magnetites in ALH84001 carbonate cannot satisfactorily be explained as a product of carbonate thermal decomposition.

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# Abstract # 12643 - **Detection of Primary Amines in Interplanetary Dust Using Fluorescent Molecular Probes: Implications for Astrobiology**

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**Introduction:** The presence of organic matter in interplanetary dust particles (IDPs) is of interest because the abiotic organic evolution of early Earth and Mars was likely to have been strongly influenced by dust accretion [1]. Unfortunately, while elemental and isotopic analysis of nano/picogram geological samples has achieved a high level of development, molecular analysis of these same samples remains a formidable challenge. To address this problem, we have developed a procedure to spatially resolve the distribution of organic species on IDP thin-sections at sub-micron resolution. We report here the first observation of primary amines ($-NH_2$) in IDPs. Furthermore, we note that this procedure should be applicable to a host of other geologically significant samples such as globular carbonates from the Martian meteorite ALH84001 and terrestrial Archean carbonates.

**Concept:** Our approach is to target specific organic monofunctional groups and tag them with a fluorescent molecular probe. Once a sample surface has been tagged the spatial distribution of those monofunctional groups can be determined by fluorescence microscopy. This same surface can then subsequently be analyzed by two-step laser microprobe mass spectrometry ($\mu L^2MS$) to determine the specific molecular species tagged. Since a single fluorphor molecule is typically capable of being consecutively cycled through the fluorescence "excitation-emisson" sequence many times (that is, it has

a low-photobleaching quantum yield), single molecule detection can routinely be achieved by fluorescence microscopy [2,3]. The spatial resolution limit is determined by the wavelength of the light emission from the fluorophor and is typically sub-micron. Furthermore because most fluorphors are conjugated and/or aromatic species they are also ideally suited to analysis by $\mu L^2MS$. Use of $\mu L^2MS$ is a powerful technique for spatially resolved analysis of sub-attomole concentrations of complex aromatic molecules [4]. By using a fluorescent molecular probe to selectively tag particular organic molecules, species ordinarily not amenable to $\mu L^2MS$ analysis (i.e. non-aromatic species such as amino acids) become readily detectable. Moreover, since it is the fluorphor of the molecular probe that undergoes multiphoton resonant ionization the photoionization cross sections for tagged molecules are approximately constant, allowing for direct quantitation of the results from $\mu L^2MS$ analysis.

**Results:** The molecular probes we have chosen are 4-phenylspiro[furan-2(3H),1'-phthalan]3,3'-dione (fluorescamine), and fluorescein-5-isothiocyanate (FITC). To date, several dozen thin-sections from three IDPs have been investigated. Preliminary results suggest only hydrated IDPs show evidence of primary amines and/or α-amino acids. Figure 1 shows the distribution of organic $-NH_2$ in a thin section of the C-rich hydrated IDP L2005 J14 as determined by *in situ* derivatization with FITC (~$10^{-5}$ M.) in an aqueous $PO_4^{3-}$ buffer at pH 7.4. Note the heterogeneous distribution with three hot-spots. The observation of primary amines and/or α-amino acids on hydrated particles is consistent with Strecker-cyanohydrin synthesis, which is believed to be the dominant pathway for the formation of amino acids found in carbonaceous meteorites such as Murchison (CM2) [5].

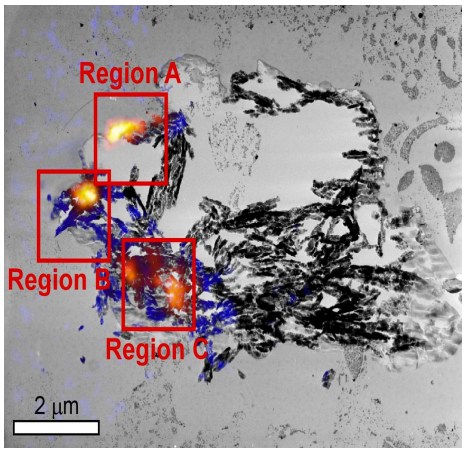


Figure 1: TEM image of a thin section of IDP L2005 J14 overlaid with fluorescent image of $R–NH_2$ distribution using FITC.

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# Abstract # 12652 - **Microbial Fossils Detected in Desert Varnish**

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Mars Global Surveyor Thermal Emission Spectrometer data indicate regions with significant levels of hematite ($\propto Fe_2O_3$). Fe oxides, including hematite, can form as aqueous mineral precipitates and as such may preserve microscopic fossils or other biosignatures. Future efforts to search for life on the surface of Mars will be more focused if they target lithologies similar to those that preserve microbial fossils on Earth. One such candidate lithology is desert varnish, which may, in some respects, be analogous to martian hematite. Desert varnish is a thin coating on rocks in semi-arid to arid regions (1,2). The coloration, thickness, texture, and chemical composition of desert varnish varies spatially down to the nanometer-scale. Desert varnish is composed primarily of Mn-oxides, Fe-oxides, and clays but also contains trace amounts of organic and detrital components. The most likely elemental source for desert varnish is wind-blown dust. The metal constituents of the dust are taken into solution and then selectively precipitated onto the substrate or attached clays at concentrations orders of magnitude higher than normal dust concentrations. This process may be aided or completely mediated by a variety of microorganisms that inhabit the varnish surface and matrix (1,2). The most common desert varnish inhabitants are epilithic, slow-growing, melanin-pigmented microcolonial fungi (MCF), and typical soil inhabiting actinomycetes and nonmotile endospore-forming gram-positive cocci (1,3).

The purpose of this study is the examination of the potential of desert varnish in preserving microfossils or other biosignatures. Two previous studies have found evidence of fossilization. A study by Krinsley (2) determined small coccoid and granular structures within the varnish matrix have a much higher concentration of Fe and Mn than the surrounding matrix and may in fact be bacterial casts, hyphae, buds, or bacterial precipitates. Probst *et al.* (4), found "biofabric," which appeared to be varnish that surrounded voids, possibly areas where bacteria formerly resided.

This study utilizes a JEOL 6340F field emission scanning electron microscope (SEM) and a JEOL 5910 SEM. Both systems were equipped with IXRF energy dispersive spectroscopy (EDS) analysis operating at 15KV accelerating voltage. The study examines samples from two regions, where the rates of varnish formation appear to be quite different. The first set of samples were a Tertiary volcanic tuff unit collected from bluffs exposed by construction in the mid-1930's above the shores of Lake Mead, near Hoover Dam in southern Nevada. The pore spaces between the volcanic tuff substrate and the varnish layers were actively infilling with caliche ($CaCO_3$). The second set of samples are coated rocks of foliated granitoid composition from the Pilbara region of Western Australia. These rock surfaces have been exposed to weathering and, presumably, desert varnish formation for thousands of years.

**Characterization of Varnish:** The varnish from the Pilbara region was lamellate, typically 75-150 _m thick, and was on a heavily weathered rind. The surface layer was smooth and consisted of clays with low concentrations of Fe-oxides. The concentrations of Fe and Mn varied within the depth of the varnish. The varnish from the Hoover Dam region was also lamellate and was 1-30 _m thick. On the surface, layers were often reminiscent of slightly detached pancakes on top of the surrounding varnish. Unlike the samples from Pilbara, Mn was often observed at the surface layer. MCF were observed inhabiting varnish from both regions, although the Pilbara samples had much greater concentrations and diversity. The MCF were often partially of completely encased in clays with low amounts of Fe-oxides. While fungi were common, visual confirmation of a bacterial presence within desert varnish was rare.

**Fossilization:** Bacterial casts and fossilization of fungal bodies were observed on samples from the Pilbara region; however none were found in the samples from the Hoover Dam region. One completely intact bacterial cast was observed but appeared to be have been formed recently. A significant amount of carbon was detected within the cast and the cast was on an exposed surface of the varnish. Similar partial casts were also observed. Complete mineral replacement of a fungal sporoform appeared to be occurring on the surface of the Pilbara sample. The mineralized spore had only low levels of Fe-oxides and no Mn-oxides, which was consistent with surface varnish. One side of the spore was weathered away, revealing complete internal mineralization. Additionally, a portion of a hymenium of a MCF was undergoing mineral replacement. The hymenium was 20 _m below the surface and was probably exposed at a natural microfissure. EDS mapping of the most dominant elements revealed the concentrations of carbon were relatively low in comparison to the concentrations of Al, Si, O, Mn, and Fe. The amount of carbon detected was not much higher than typical levels detected in varnish from Pilbara. The "biofabric" observed in the Sonoran Desert samples by *Probst et al*. (4) was not observed in the study. However in the areas of the samples where the bacterial casts and the fossilized hymenium were detected, a more complex texture was seen that is suggestive of a former bacterial presence.

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# Abstract # 12676 - **The Relevance of Bacterial Biomarkers in Astrobiological Research – Setting a Standard**

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"The need to be able to recognize the signature of life in rocks from Earth's fossil record as well as in extraterrestrial materials" is stated as goal 7 in the NASA Astrobiology Road Map. The difficulties associated with this need have lately become prominent due to scientific controversies over the earliest evidence of life on Earth (Schopf, 1993; Mojzsis et al., 1996, Brasier et al., 2002; Fedo and Whitehouse, 2002; Schopf et al., 2002) and the continuing discussions over possible evidence of biogenic activities in Martian meteorite ALH84001 (McKay et al., 1996; Jull et al., 1998; Golden et al., 2000; Steele et al., 2000; Thomas-Keprta et al., 2001). The common denominator these debates ground on is the underlying difficulty or inability to demonstrate conclusively the biogenicity of the respective evidence, which in any of the above cases would have to be seen in evidence of fossil microbial life. A consensus that has emerged from these discussions, and is now seen as a critical requirement, is the demand for chemical/molecular evidence in addition to the morphological evidence to support those extraordinary claims.

Efforts are being made in order to fulfill the requirement to combine morphological microbial fossils with proof of their molecular remains. Carbon isotopes have successfully been correlated with individual Proterozoic microfossils (House et al., 2000) and FT-RAMAN spectra were obtained on supposed early Archaean microfossils (Schopf et al., 2002), although this evidence is far from being conclusive (Brasier et al., 2002). Notably, Toporski et al. (2002) demonstrated the possibility to correlate more comprehensive molecular information with fossil bacterial biofilms using Time of Flight –Secondary Ion Mass Spectroscopy (ToF-SIMS), a technique that has been shown to be capable of detecting unambiguous biomarkers of the hopane class, in complex organic mixtures (Steele et al., 2001; Toporski, 2001).

These examples show that by means of a multi-disciplinary scientific approach, the questions raised above find themselves on the verge of being answered, although clearly further work is needed to be able to draw unambiguous conclusions. Additionally, they

emphasize the importance of understanding bacterial preservation and the characterization of bacterial biomarkers, morphological as well as chemical/molecular, relevant in the search for traces of bacterial activity in rocks, in order to fulfill goal 7 of the NASA Astrobiology Road Map.

We present a summary on molecular bacterial biomarkers supported by a case study on fossil bacterial biofilms of established bacterial origin (Toporski et al., 2002) to demonstrate the use - and need - of a multi-technical approach to approximate satisfactory data sets.

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# Abstract # 12679 *(Oral Presentation)* - **Mass-Dependent Oxygen Isotope Fractionation Laws: Markers for Biological Processes?**

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Recently, it was suggested that kinetic (including biological) and equilibrium processes could be distinguished on the basis of the law that governs the fractionation of three stable isotopes of a participating element (Young et al. 2002, Geochimica et Cosmochimica Acta 66, 1094) . The basis of this discriminator is the range in values for the exponent β in the three-isotope fractionation equation $\alpha_{2/1} = (\alpha_{3/1})^{\beta}$ for isotopic species with masses $m_1<m_2<m_3$ and fractionation factors $\alpha_{i/j}$. The theoretical prediction for a kinetic β value was verified for isotopes of Mg using mineral evaporation experiments.

In the case of the three stable isotopes of oxygen (masses ~16, ~17, and ~18), rocks and waters were shown recently to define a β of 0.525+/– 0.002 (Miller 2002, Geochimica et Cosmochimica Acta 11, 1881), in close agreement with predictions for equilibrium fractionation among rocks ($\beta=(1/m_1 - 1/m_2)/(1/m_1-1/m_3)$, $m_i$ ~ 16, 17, or 18) and kinetic fractionation for waters ($\beta=\ln(\mu_1/\mu_2)/\ln(\mu_1/\mu_3)$ where $\mu_i$ are the reduced masses for O-H). Based on their analysis of the potential range of β values, Young et al. suggested that negative deviations in $\delta^{17}O$ between tropospheric $O_2$ and rocks and waters ($\Delta^{17}O$) could be explained if respiration were characterized by a kinetic β. A kinetic β value of ~ 0.508 is consistent with the kinetic fractionation of $O_2$ predicted by the kinetic formulation of β given by Young et al. ($\beta=\ln(M_1/M_2)/\ln(M_1/M_3)$ where $M_i$ are molecular masses for $^{16}O^{i}O$ ) and is sufficient to explain the observed $\Delta^{17}O$ of tropospheric $O_2$.

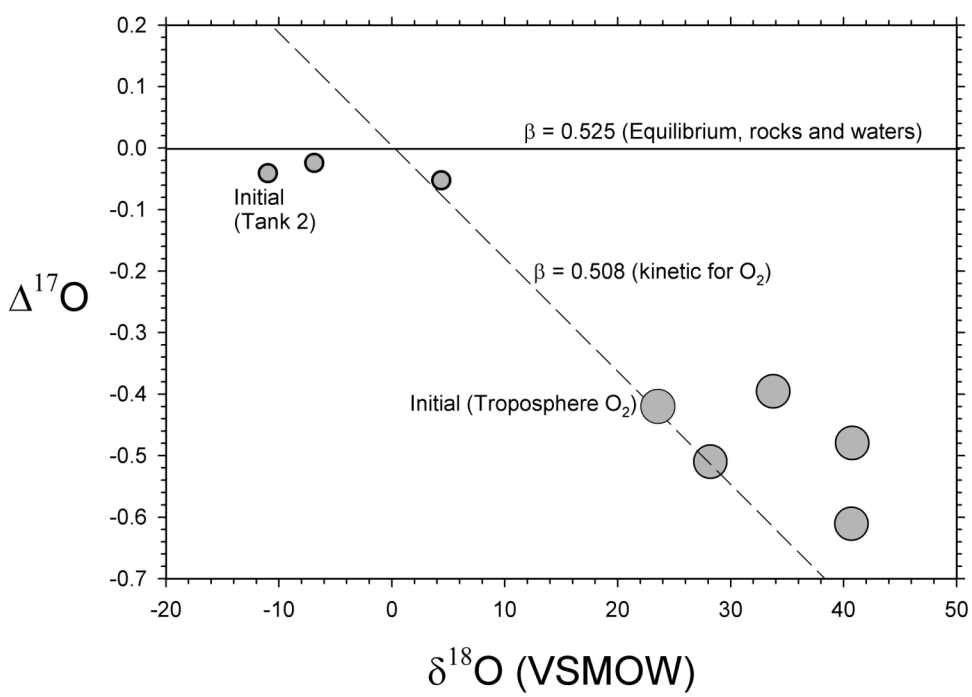
If β values associated with respiration were to be characterized and shown to be distinct from equilibrium processes, then it might be possible to use $\Delta^{17}O$ as an indicator of biological processing in some O-bearing systems. Also, small deviations in oxygen $\Delta^{17}O$ would need to be examined in the context of the range of established β values.

In order to test the hypothesis that respiration might have a kinetic β, the oxygen isotopic fractionation associated with processing of oxygen by potato tubers was measured by both conventional isotope ratio mass spectrometry (irms) and gas-chromatography isotope ratio mass spectrometry (GCirms, He carrier flow) methods. Potato tubers were packed with silica gel in isolated chambers filled either with air (our measured value for tropospheric $O_2$ is $\delta^{18}O$ = 23.45 and $\delta^{17}O$ = 11.85 per mil relative to VSMOW) or an internal laboratory $O_2$ standard ("Tank 2"). The conventional irms measurements have

superior precision (+/– 0.003 per mil in $\Delta^{17}O$) while the GCirms measurements yield pure $O_2$ analytes free from potential interfering effects of $N_2$ and other gases.

Preliminary results are shown in the figure. In the experiments $\delta^{18}O$ increased as [O2] decreased (O2 consumption was presumably dominated by respiration). Conventional irms measurements of Tank 2 oxygen processed by the potatoes show little or no change in $\Delta^{17}O$ despite large shifts in $\delta^{18}O$ of ~ +16 per mil over the course of 8 days (upper three points in the figure). These samples contained up to 19% partial pressure of $N_2$, representing a potential interference due to scattering in the flight tube of the mass spectrometer, but comparisons between GCirms and conventional techniques showed that this $N_2$ concentration does not affect the measured $\Delta^{17}O$ values in our system (but further investigations are underway). GCirms measurements of tropospheric $O_2$ (in air) processed by the potatoes shows indications of a negative slope on the $\Delta^{17}O$ vs. $\delta^{18}O$ plot (lower five points in the figure). Negative slopes on this plot correspond to $\beta < 0.525$ (an evolution line with $\beta = 0.508$ passing through tropospheric $O_2$ is shown for reference). However, the precision of these measurements is inferior to that for conventional methods and can be improved with adjustments in injection methods (in progress).

A program of research dedicated to characterizing the $\beta$ value of biologically processed $O_2$ is under way. Samples targeted for study include soil gases where oxygen isotope fractionation due to subsurface microbial activity can be extreme (Hendry et al. 2002, Geochimica et Cosmochimica Acta 66, 3367). Based on these preliminary results, the respiration $\beta$ value appears to be > 0.508 and < 0.525, but more work is warranted in well-characterized systems where the process of respiration can be isolated.



# Abstract # 12689 *(Oral Presentation)* - **Deciphering Fe Isotope Biosignatures from the Rock Record through Experimental Determination of Isotopic Fractionation Factors**

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Sufficient Fe isotope data now exist for the major Fe reservoirs in the Earth, as well as in extraterrestrial samples, such that it appears to be a robust conclusion that significant Fe isotope variations are only produced in the presence of liquid water, and the largest variations occur during redox cycling of Fe. Although large isotopic fractionations occur in abiologic aqueous systems between ferric and ferrous Fe, it seems likely that separation of these isotopically distinct pools of Fe is most likely to occur during biologic activity. Successful application of Fe isotope geochemistry to problems in astrobiology, however, rests on detailed experimental determination of Fe isotope fractionation factors for both biologic and inorganic systems. Although predicted isotopic fractionations based on spectroscopic data provide useful guides, the uncertainties in calculated reduced partition function ratios remain relatively large, as compared to the range in Fe isotope compositions that have been observed in nature.

The largest range in $^{56}Fe/^{54}Fe$ ratios yet measured for ancient terrestrial rocks, approximately 4 per mil (‰), occurs in Banded Iron Formations (BIFs), which arguably represent periods of profound Fe cycling in the Earth. $\delta^{56}Fe$ values for BIF minerals decrease in the order hematite ~ magnetite > siderite > ankerite; $\delta^{56}Fe$ values for pyrite are the lowest yet measured, down to -2.5 ‰. New data for Fe isotope fractionation during formation of magnetite and Fe carbonates through reductive dissolution of hydrous ferric oxide by *Geobacter sulfurreducens* and *Shewanella putrefaciens* indicate that Fe carbonates will have $^{56}Fe/^{54}Fe$ ratios that are lower than Fe(II) in solution or the ferric oxyhydroxide starting material, whereas magnetite will have Fe isotope compositions that are approximately equal that of Fe(II) in solution. This is the same

relative order of $\delta^{56}$Fe values as observed in BIFs. Iron isotope fractionation factors measured during formation of magnetite by *Geobacter sulfurreducens* were dominated by kinetic effects in the initial ~20 days, followed by approach to equilibrium over the long term (164 days). Long-term (~ 1 _ years) experiments with *Shewanella putrefaciens* are interpreted to reflect Fe(II)-Fe carbonate fractionations that are close to those of equilibrium conditions in these biologic systems.

Integration of our new data with previous results reported for Fe isotope fractionation produced by anoxygenic photosynthetic Fe(II) oxidation allows us to constrain Fe isotope fractionation factors due to biological processing of Fe for the system Fe(III)-Fe(II)-hematite-magnetite-Fe carbonate. Comparison of biologic fractionation in the system Fe(III)-Fe(II)-ferric (oxy)hydroxide with that in "equivalent" abiotic systems suggests that there is an Fe isotope "vital" effect that is unique to biologically processed Fe. Such effects may be recorded in the moderately positive $\delta^{56}$Fe values measured for some hematite and magnetite minerals from BIFs, which might be explained through photosynthetic Fe oxidation of Fe(II) derived from mid-ocean-ridge (MOR) hydrothermal sources; inorganic oxidation of MOR-derived Fe(II) would produce $\delta^{56}$Fe values that are at least 1.5 ‰ higher than those yet measured in oxide minerals in BIFs.

The values for Fe(II)-mineral fractionations measured in the *Geobacter sulfurreducens* and *Shewanella putrefaciens* experiments differ from those inferred from natural samples or calculated from spectroscopic data, raising the possibility that Fe isotope fractionations in the system Fe(II)-magnetite-Fe carbonate, when mineral formation is catalyzed by biologic activity, may reflect "vital" effects as well. Some of the moderately negative $\delta^{56}$Fe values measured for magnetite and Fe carbonates in BIFs are consistent with a biogenic formation, but this conclusion cannot be robustly made until equilibrium Fe isotope fractionation factors have been determined for abiologic experiments in the system Fe(II)-magnetite-Fe carbonate. In addition, initial experiments suggest that Ca and possibly other divalent cation substitution into siderite have large Fe isotope effects that must be experimentally determined.

These issues notwithstanding, however, it seems clear that Fe isotope geochemistry can serve as a biosignature for metabolic processing of Fe, as well as revealing the presence of liquid water and redox cycling of Fe on ancient planetary bodies. We contend that the isotopic effects of such processes are often best explained by life.

# Abstract # 12762 - **Detection and Significance of Molecular Fossils of Chlorobiaceae in Paleoproterozoic Sediments**

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Lipid biomarkers provide informative and recalcitrant biosignatures in well-preserved ancient sedimentary organic matter, and these molecular fossils can be used for retracing the evolution of living organisms on Earth over geological time. Here we report the presence of free and macromolecularly-bound source-specific lipid markers of green sulfur bacteria (i.e., *Chlorobium* sp.) in Paleoproterozoic (1.64 Ga) sediments of the Barney Creek Formation, McArthur Basin, northern Australia. These biomarker signals constitute the oldest, presently known, molecular evidence for Chlorobiaceae input to sediments and provide further constraints on the sedimentary environment.

Eight Barney Creek Fm. sediment samples were selected from between 51m and 306m in core from the well GR-10 and were exhaustively extracted with a solvent mixture of dichloromethane/methanol (3/1 v/v). Aliphatic and aromatic hydrocarbon fractions were isolated from these extracts using silica gel adsorption chromatography and analyzed in detail using gas chromatography-mass spectrometry (GC-MS). Resin and asphaltene fractions were also prepared from portions of the bitumen, and each of these were *hydropyrolyzed* separately along with the insoluble sediment residue. *Hydropyrolysis* involves the temperature-programmed heating of organic matter in an open-system reactor utilizing a high pressure hydrogen gas environment and a sulfided molybdenum catalyst to maximize pyrolysate yields whilst preserving the molecular information in biomarker products (Love *et al*., 1995). By applying this method to resins, asphaltenes and insoluble residues (effectively, kerogen) the biomarker content of each component of the total organic matter in these sediments could be compared and contrasted.

The principal organic compounds detected in solvent extracts and hydropyrolysates included *n*-alkanes, isoprenoids, other branched alkane series, hopanes, steranes, and polynuclear aromatic hydrocarbons (PAH) containing a variety alkylation patterns. For a distinct organic facies (and a carbonate-dominated horizon between 90 and 140m within

the total depth interval studied), intact isorenieratane (a $C_{40}$ diaromatic carotenoid derivative) was detected in the free aromatic fractions (Figure 1) and in trace levels in the corresponding bound fractions. Isorenieratane is, indisputably, a source-specific molecular marker for green sulfur bacteria. Series of tetra-alkyl-substituted aryl isoprenoids (in *m/z* 133 and 134) are detectable in all the sediments studied, but they are particularly prominent in the samples where the isorenieratane signals are also most pronounced. Compound-specific stable carbon isotopic measurements are underway to establish whether or not the aryl isoprenoid series bear a distinct C-isotopic signature consistent with the reverse TCA cycle carbon assimilation.

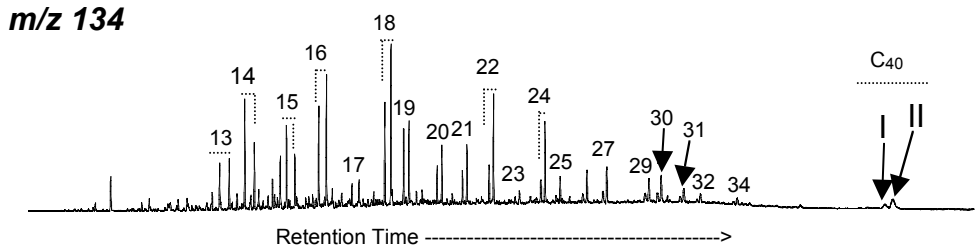


**Figure 1**. Distribution of aryl isoprenoids in the free aromatic hydrocarbons of a Barney Ck. Fm. sediment. Numerical labels refer to the number of C atoms constituents per molecule. Compound II is isorenieratane.

The Barney Creek sections that yielded the elevated concentrations of biomarkers for the anaerobic phototrophic Chlorobiaceae are also characterized by low 2α-methylhopane indices (~1 to 3%; common values for the Precambrian are ≥ 10%) consistent with reduced primary productivity by oxygenic cyanobacteria, and by unusually high 3β-methylhopane indices (~6 to 12%; common values for the Precambrian are < 5%), indicating elevated activity of microaerophilic proteobacteria, probably methanotrophs.

In summary, our results show that Chlorobiaceae existed at least 1.64Ga ago and that the McArthur sediments were deposited in a marine environment that was, at times, euxinic into the photic zone. Biomarkers can make a major contribution to our understanding of ocean redox evolution during the Proterozoic.

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# Abstract # 12774 - **Utilizing Compound Specific Isotopes as Bio-indicators of Prokaryote Metabolism**

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Prokaryotes are the most diverse form of life on the planet. A key manifestation of this diversity is observed in the wide array of pathways utilized to assimilate and break down carbon. The various means for carrying out the metabolic duties of prokaryotes leave distinct isotopic signatures in the various macromolecules that make up the cell components (e.g., lipids, proteins, nucleic acids). A key sink for carbon taken up by prokaryotic cells are the amino acids, which by weight account for roughly 50% of the cellular carbon in a typical prokaryotic cell. Here, we show that the $\delta^{13}C$ of individual amino acids provides a powerful tool for identifying prokaryotic processes. Furthermore, the examination of correlation matrices generated (utilizing the $\delta^{13}C$ of 11 amino acids for 25 prokaryotes) has allowed us to distinguish between the various pathways utilized for replenishment of central metabolic intermediates utilized in amino acid biosynthesis.

# Abstract # 12779 - **The Preservation of Molecular Biomarkers for Billions of Years**

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As kerogen thermally matures, released hydrocarbons can remain associated with the kerogen as either free compounds or molecules trapped within or bound to kerogen matrix. Free and bound hydrocarbons often include molecular biomarkers of varying specificity for biological inputs and environmental conditions at the time of deposition and during diagenesis. We are exploring the relationship between free and bound hydrocarbons in rocks of late Archean (2.8-2.6 Ga) age in order to evaluate their authenticity and preservation history.

Shale and carbonate rock samples from three diamond drill cores collared in the Hamersley Basin, Western Australia were extracted with organic solvent to isolate the first bitumen component. Carbonate, silicate, and oxide minerals were then digested in acid before extraction of a second bitumen component. The residual kerogen was subjected to hydrogen pressure pyrolysis (hydropyrolysis) to cleave bound hydrocarbons with minimal structural/stereochemical alteration. Finally, the char remaining from pyrolysis was extracted once more with solvent.

The first bitumen fraction contains *n*-alkanes dominated by $C_{14}$-$C_{18}$ and sometimes lesser $C_{20-22}$, typical of bacterial and algal contributions respectively. These alkanes do not show a predominance of even or odd chain length, consistent with their thermal maturity. Other compound groups detected include monomethylalkanes (MMAs), several series of dimethyl- and diethylalkanes (DMAs and DEAs), diverse hopanes and steranes, aromatic steroids, and squalane. Aromatic hydrocarbons having up to 5 rings are detected in much less abundance than the saturated hydrocarbons. Similar patterns of *n*-alkanes and MMAs

and relatively low abundances of aromatics are observed in the bitumen II fraction but are obscured chromatographically by unresolved complex mixtures of branched hydrocarbons. Bitumen II contains 10-100x more material than bitumen I and contains compounds originally bound to kerogen then released by acid-hydrolysis and/or compounds that were trapped in mineral or kerogen matrices. Unresolved complex mixtures of branched hydrocarbons are also present in the bitumen II and may be related to DMAs and DEAs in the bitumen I.

Cleavage of weak linkages (i.e., at temperatures below 500°C) during hydropyrolysis released a distribution of alkanes that is similar to those found in associated bitumen I and II components. Saturated hydrocarbons dominate the ≤500°C fraction of products and the char extract, whereas aromatics are cleaved from the kerogen at ≥500°C. The repeated appearance of even $C_{14}$-$C_{18}$ *n*-alkanes in bitumen fractions and pyrolysis products may reflect the strong bacterial biomass input into these Archean organic materials. The trace presence of *n*-$C_{22}$ and MMAs in pyrolysis products suggests that the $C_{20}$-$C_{22}$ n-alkanes in bitumen I are derived from the kerogen. Traces of steranes and hopanes were detected in the char extracts only. A doping experiment demonstrates that the hydrocarbons found in the char are strongly adsorbed to the kerogen matrix and are not released by high hydrogen pressure and heat. It is unclear what aspects of the kerogen physiochemistry are responsible for the sequestration properties observed here. NMR analysis of both kerogens and their associated chars is in progress and will help to further characterize the compositional changes that occur because of hydropyrolysis.

Hydrocarbons in the bitumen I and II fractions are likely derived from thermal cracking of the kerogen and subsequently sequestered by kerogen or mineral matrices as demonstrated by: 1) structural similarities and relative abundances of saturated and aromatic hydrocarbons in different organic components, 2) high abundance of hydrocarbons in the bitumen II and pyrolysis products, and 3) the strong adsorption properties inferred by the doping experiment. The sequestration property of the kerogen allowed for preservation of free hydrocarbons over billions of years -- even after exposure to high temperatures and pressures. This implies that the biomarkers in the bitumen I are of Late Archean age. Biomarkers present indicate biomass contributions from bacteria, archea and eukaryotic domains. Cyanobacteria were important contributors. Lithofacies-specific presence of DMAs and DEAs in laminated shales from a shallow water carbonate platform is a possible indicator of microaerophilic sulfide-oxidizers living at an anoxia-dysoxia interface (Logan et al., 2001, GCA, v.65, 2317-2336; Kenig et al., 2002, GCA, v.66-supp., A393). If this demonstrated to be robust, this finding implies that biological sulfate generation likely sustained sulfur cycling in the late Archean.

# Abstract # 12780 *(Oral Presentation)* - **Ozone and UV Fluxes on Earth-like Planets Around Other Stars**

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The 9.6-(m band of ozone is considered to be a possible spectroscopic biomarker for life on extrasolar planets (Des Marais et al., 2002). The depth and shape of the band depend on the vertical profiles of ozone and temperature in a planet's atmosphere. These, in turn, depend critically on the amount of O2 present. The strength of this spectral band has been calculated previously for atmospheres containing different amounts of O2 (Schindler and Kasting, 2000). Their model, however, was only approximate because temperature and ozone profiles were not generated self-consistently. Instead, the stratospheric temperature profile was specified to be the present one at 1 PAL (Present Atmospheric Level) of O2. This was replaced by an isothermal stratosphere at lower O2 levels.

We have improved on these previous results by performing a self-consistent calculation of vertical ozone and temperature profiles. The photochemical model is that of Pavlov and Kasting (2002). The radiative-convective climate model is adapted from that of Pavlov et al. (2000). However, we have replaced the infrared absorption routine with one from Mlawer et al. (1997). The Mlawer et al. code does a good job of resolving the Doppler cores of absorption lines and, hence, gives more accurate temperatures in the stratosphere.

Calculated ozone and temperature profiles for an Earth with different O2 levels are shown in Fig. 1. The peak ozone density moves downward as O2 decreases and the ozone column depth also decreases strongly below 10-2 PAL of O2. The stratospheric temperature bulge disappears as O2 decreases from 1 PAL to 10-2 PAL. Similar calculations have also been performed for an Earth-like planet around a K2V star and an F2V star. Using the calculated planetary atmosphere temperature and constituent mixing ratio profiles, we have also generated synthetic spectra of these planets using a line-by-line radiative transfer program developed by Crisp (Meadows and Crisp, 1996). The

synthetic spectra have been used to assess the detectability of the 9.6-um ozone feature for Earth-like planets of varying composition around stars of different spectral types.

In addition to finding the strength of the 9.6-(m absorption feature, our model is capable of predicting the surface UV flux on an Earth-like planet around various stars. This calculation has also been performed previously (Kasting et al., 1997), but not self-consistently. Like the previous study, we find that at 1 PAL of O2 surface UV fluxes are relatively small, even around an F star because of increased ozone concentrations. At low O2 concentrations, however, the F-star UV fluxes are much higher. This may pose evolutionary problems for organisms on F-star planets with low-oxygen atmospheres. F stars also have shorter main sequence lifetimes than does the Sun; hence, biological evolution has less time to proceed. We conclude that G and early K stars are better environments in which to look for inhabited planets.

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# Abstract # 12785 - **Measurement of Microbial Contaminants in Compromised Lunar Material by LAL**

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Whether one is concerned with collection of data to support spacecraft cleanliness, archived rock or meteorite sample integrity, or life detection techniques, major desirable criteria include methods that are accurate and sensitive. Furthermore, the ability to report data near the point of collection and in near "real-time" is highly desirable. We have employed the Limulus Amebocyte Lysate (LAL) assay, an enzyme cascade that amplifies the biomarkers found in the cell wall of bacteria, to assess microbial contamination in samples of lunar material known to be compromised. The technique is capable of measuring picogram quantities of bacterial lipopolysaccharide (LPS) and fungal beta glucan in an assay that is typically performed in less than one hour with swabs of environmental surfaces (Wainwright and Child, 1999) and with mineralogical samples (Allen, et al, 2000).

The LAL cascade evolved as part of the innate immune system of the ancient horseshoe crab (Limulus polyphemus). Minute quantities of microbial cell wall materials, present ubiquitously in the environment, trigger the enzyme cascade that results in blood coagulation and subsequent wound healing. The commercial LAL reagent employed links this enzyme cascade to chromogenic substrates that can be accurately quantified by conventional spectrophotometric instruments (Charles River Endosafe, Charleston, SC).

Lunar materials were requested which were exposed to potentially contaminated environments during handling. Samples were prepared by extraction with ultra-clean (LPS-free) water. The pre-weighed (~0.10 g) samples of crushed rock or dust were mixed with 0.5 ml of water and vortexed 30 seconds every 15 minutes for one hour. An exception to this protocol was the pristine sample of lunar soil (#15007) used as negative control. For this sample, the volume of water was adjusted to 0.2 ml per 0.040 g to yield a sample:water ratio equal to all other samples.

The following results were obtained. LPS values are reported against a standard curve of purified endotoxin and expressed as Endotoxin Units (EU/ml or EU/g).

| | Sample Number | | | | | LPS Value | |
|---|---|---|---|---|---|---|---|
| | **Generic** | **Specific** | **Parent** | **Container** | **Weight, g** | **EU/ml** | **EU/g** |
| 1 | 13999 | 341 | 62 | PV | 0.104 | 1.83 | 17.6 |
| 2 | 13999 | 342 | 264 | PV | 0.108 | 2.25 | 20.8 |
| 3 | 14999 | 134 | 115 | 10 1100 | 0.101 | <0.01 | <0.097 |
| 4 | 15459 | 458 | 194 | 9 11945 | 0.106 | 0.01 | 0.094 |
| 5 | 60025 | 827 | 185 | 9 3128 | 0.103 | <0.01 | <0.097 |
| 6 | 69999 | 98 | 58 | 9 3143 | 0.111 | <0.01 | <0.090 |
| 7 | 79999 | 95 | 7 | PV | 0.108 | 2.90 | 26.9 |
| 8 | 79999 | 102 | 15 | 9 3116 | 0.107 | 0.016 | 0.150 |
| 9 | 15007 | 1074 | 1057 | 9 11943 | 0.040 | <0.01 | <0.250 |

The most highly contaminated samples, #13999 and #79999,95 (rows 1,2,7) are dust obtained from vacuuming space suits and freon rinses of flight hardware. Samples obtained from much cleaner environments, i.e., glove box sweepings (#69999, #14999, #79999,102) and band saw fines (#15459, #60025) show much less contamination (0.01 EU or <0.01EU) approaching that of the negative control, a sample of clean, uncontaminated soil core interior (#15007).

Data collected on a similar suite of samples by several physical techniques (such as fluorescence microscopy, Time of flight secondary Ion Mass Spectrometry, X-ray photoelectron spectroscopy, and SEM) will also be presented.

The method will continue to be refined to optimize sensitivity and to expand its application as a general microbial life detection tool.

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# Abstract # 12787 - **Theoretical Support for Biological Activity in Ancient Stromatolites**

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Stromatolites, by which we mean certain laminated sedimentary deposits, appear very early in Earth's history. These structures (measuring tens of centimeters in height and width) are sometimes found in striking elementary shapes, such as convex upward domes or nearly right circular cones. Although Archean and many Proterozoic stromatolites do lack any remnants of microbial units, they have (until recently) been interpreted as fossils and products of microbiological communities.

The case for an abiotic origin was forcefully advanced by Grotzinger and Rothman (Nature 383, 423-425, 1996) through a power spectrum analysis of a selection of Paleoproterozoic stromatolite profiles, together with the weight given to specific factors in a model of the growth mechanism. The power law scaling exponent ($2.01 \pm 0.03$) and fractal dimension ($2.50 \pm 0.02$) obtained from the spatial frequency data are, however, different from their model of choice, the classical KPZ (Kardar-Parisi-Zhang) equation (Phys. Rev. Lett. 56, 889-892, 1986). In 2+1 dimensional surface growth, the KPZ equation yields a power law scaling exponent of about 1.76. This discrepancy is significant as shown by applying the data analysis methodology to a set of synthetic self-affine surfaces with known power law scaling exponent. Recognizing that a height averaging protocol has been used to consolidate intervals where the stromatolite profile has overhangs and is multi-valued, it is most likely a lower bound value of the power law scaling exponent that is extracted. Furthermore, the KPZ equation (and any variation of it anchored to a planar substrate) generates single valued surfaces. The application of this class of models to situations where overhangs are observed is therefore a precarious enterprise. Noting this caveat but assuming the general model building approach to be valid, it is possible to account for the discrepancy of the power law scaling exponent values while retaining the modeling framework and allowing for a reinterpretation of the terms of the KPZ equation. Singling out one particular term in the KPZ equation and letting its functional form vary provides for a way of altering the power spectrum. This can be done while keeping the self-affine signature of the growth surface and adjusting the value of the scaling exponent at will. But the choice of this altered mechanism has profound implications for the agents in the model.

Whereas the classical KPZ equation provides for a growth process of solely local origin, our model eases this restriction. We believe that our generalized KPZ equation is a better model for the data set mentioned. It is also a natural extension of the classic KPZ growth model since it implicitly incorporates nonlocal effects. It shows a straightforward procedure for modifying the interface topography to fit a variety of observed stromatolite morphologies. Our modification procedure is conveniently interpreted as a scheme for concerted activities over extended neighborhoods. Albeit some abiotic processes may, in special settings, display muted versions of such long-range interactions, we are alerted to the fact that, quite naturally, this is a fundamental attribute intimately associated with the activities of microbial mat communities.

# Abstract # 12805 - **The Relevance of Trace-Metal Content in Identification of and Preservation in Siliceous Sinters**

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Siliceous rocks host the earliest and best-preserved microfossils. Fundamental questions about early Earth could be addressed through study of these ancient rocks, but many biological, chemical, and physical signatures are lost during diagenesis. It is possible, and seems likely, that environmental conditions would impart some structural or chemical signature to silica that may be preserved in the geological record. We have used a combination of statistical and laboratory studies to investigate structural and chemical signatures of siliceous sinters over a range of thermal environments. Structural signatures include defects in the atomic environments of silicon aluminum, and/or other elements in the silica structures. These defects affect the reactivity, energetics, and oxygen exchange rates of silicate minerals. Understanding the origin and persistence of these defects would provide insight into the differences between diagenetic and primary quartz and hydrous silica phases. Rapidly crystallizing phases would be expected to exhibit more of these defects and may show rapid exclusion of accompanying network modifiers during very early diagenesis. Differences in the atomic environments of silicon, boron and aluminum were investigated using solid-state MAS nuclear magnetic resonance spectrometry at the PNNL Environmental and Molecular Science Laboratory in Richland, WA. For example, aluminum was detected dominantly in tetrahedral coordination (Figure 1).

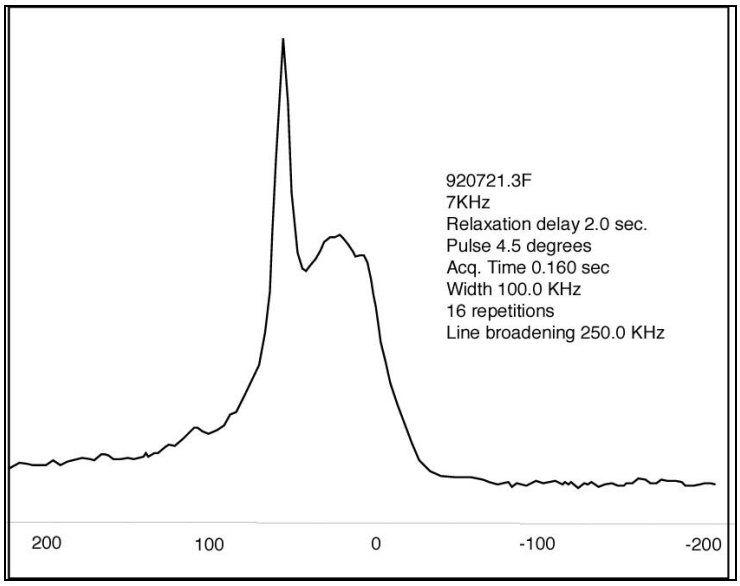


Figure 1. Chemical signatures include differences in concentrations as a function of chemical and thermal environment. Discriminant analysis indicated concentrations of structural water, aluminum and calcium can be used to distinguish between siliceous sinters originating at high and low temperatures. Structural and chemical differences are clearly related. The combined signatures have the potential to distinguish thermal and chemical environments.

# Abstract # 12817 - **Identifying Life in New Environments: Examples and Conundrums**

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Although Life exhibits a number of classical attributes, many are not unique among the natural, abiotic phenomenology of real worlds. The set of minimum conditions for confirmation of Life can be specified a priori, but first-time-screens may nonetheless need to utilize a number of promising, but less certain attributes for detection of life-indicative activities, such as chemical equilibria, reaction pathways, mechanistic movement, and/or organizational complexity. To declare a detection, however, we must know how we define what constitutes living entities and activities. Many definitions have been offered. Devising exploration strategies with a reasonable probability of acceptance by the scientific community at large should proceed along the steps needed for detection and verification of the minimal properties which define Life itself, but makes room for evidential measurements to seek attributes which provide initial indications of biologic functionality. Even though "attributes" are not equivalent to essence, they may nonetheless be taken, if properly interpreted, as indicators or signatures of the possible presence of organisms.

Confusion in the past has arisen from an over-emphasis on indicators without consideration of the full requirements that must be levied to verify that observed phenomena are due to actual life. From chemical reactions it has been concluded by some that there was metabolizing life in the soils of Mars, but organisms are counter-indicated from the relative lack of organic compounds and the realization that the surface environment is inimical to life as currently understood on Earth because of extreme UV, extreme desiccation, powerful oxidants in the atmosphere and in the soil, and rare occurrence of water in the liquid phase. These conundrums and a number of terrestrial examples of newly appreciated life forms (endosymbionts to transposons) may be used to constrain the ability and willingness of astrobiologists to claim that life either exists or does not exist in some foreign setting. Additional conundrums arise along the entire panoply of possible evidences, from detection of intelligent behavior (machines?) to detection of thermodynamic instabilities (improperly understood environments?).

# Abstract # 12820 - **Microfluidics for Astrobiotechnology**

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Automated life-detection experiments for Solar System exploration have been previously proposed and used onboard the Viking Mars Landers, although with ambiguous results. Recent advances in biotechnology, such as biosensors, protein microarrays, and

microfluidics, alongside increased knowledge in biomarker science have led to vastly improved sophistication and sensitivity for a new approach in life detection. The MASSE (Microarray Assay for Solar System Exploration) project, funded by NASA, is working to integrate this knowledge into a new generation of interplanetary flight instrumentation. MASSE's primary objective is to search for extant and/or relic biogenic activity on Mars. This will be achieved by integrating several analytical techniques such as immunochemistry, LAL assays and PCR into a single low power, low mass instrument.

A key enabling technology that the team has become increasingly aware of is microfluidics. The MASSE team developed the initial conceptual design for the MASSE instrument relying on traditional macro fluidic technologies and though this initial prototype was innovative in concept it was still too large and cumbersome to integrate into an unmanned interplanetary mission. As a result members of the MASSE team have invested time and effort to learn about microfluidics technology and how it is an asset to this new paradigm of scientific instruments.

For example, one of our proposed modules will employ the Limulus Amebocyte Lysate (LAL) assay. LAL is a sensitive enzyme cascade that is triggered by microbial cell wall material (Cooper, et al, 1997; Wainwright and Child, 1999). The test has been miniaturized and run in a simple, linear micro fluidic chamber that sequentially 1) hydrates a dry, stabilized reagent, 2) incubates the sample and 3) reads color development spectrophotometrically. Data from a preliminary run is shown below:

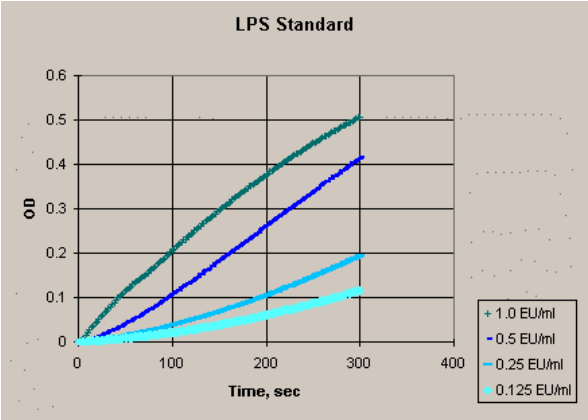


Figure 1: Each line represents the kinetic chromogenic development of one channel of a microfluidic chamber. Four channels are shown at 1.0, 0.5, 0.25 and 0.125 EU/ml (endotoxin units/ml). Data may be stored or interpreted by onboard software.

This paper will be a review of current microfluidics technology such as that used for the LAL Assay, how it is being applied to the MASSE project, and how it can benefit Astrobiotechnology in the long term.

# Abstract # 12825 - **Inter-Mineral Fe Isotope Fractionation and the Precision and Accuracy of Fe Isotope Measurements**

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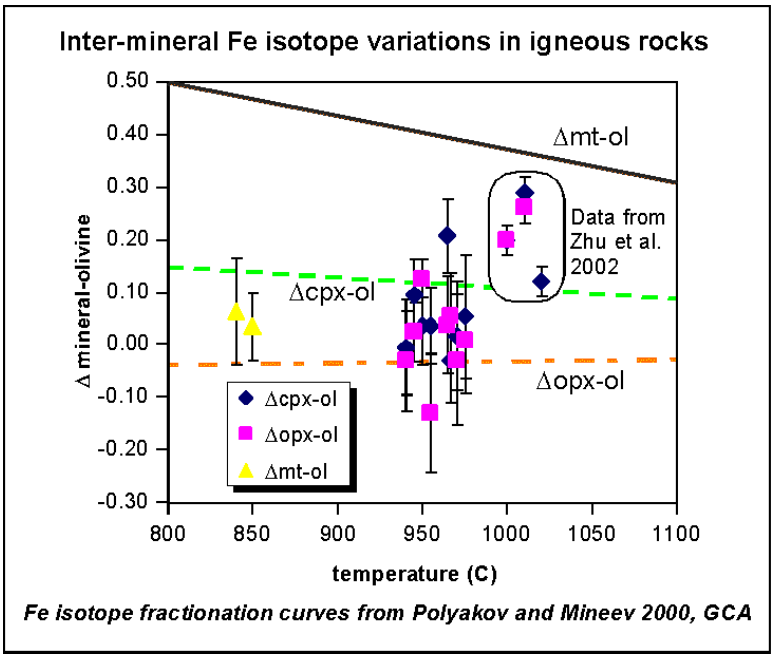
Iron isotope fractionation between high temperature igneous minerals in mantle rocks (olivine, orthopyroxene, and clinopyroxene) has been reported by Zhu et al. (2002; EPSL 200:47-62). Such a finding is surprising, considering the lack of Fe isotope variation in igneous rocks. Over 50 igneous rocks have been analyzed by our group, including mid-ocean ridge basalts, oceanic island basalts, and continental flood basalts as well as more evolved igneous rocks, including high silica rhyolites and granites. The Fe isotope composition of this suite of igneous rocks is homogenous to within $\pm$0.05 per mil for their $^{56}Fe/^{54}Fe$ ratio. As such, we proposed using the average of igneous rocks as a baseline to compare naturally occurring Fe isotope variations. Such a baseline is similar to other stable isotope systems that use a large-scale terrestrial reservoir in reporting isotopic variations. For example, oxygen isotope variations are reported relative to standard mean ocean water (SMOW). Considering the homogenous Fe isotope composition measured in igneous rocks, it would seem rather fortuitous that there were significant inter-mineral fractionations and that these fractionations would cancel one another out during partial melting and crystallization processes to leave the bulk rock composition of igneous rocks at a constant Fe isotope composition.

We have analyzed mineral separates of olivine, orthopyroxene, and clinopyroxene from 8 spinel peridotite xenoliths. There are no differences between the Fe isotope composition of olivine and orthopyroxene (Figure), in agreement with the calculated Fe isotope fractionation of Polyakov and Mineev (2000; GCA 64:849-865) that predicts no difference in Fe isotope composition between olivine and orthopyroxene. Clinopyroxene and olivine from seven of the eight samples have the same Fe isotope composition, but in one sample clinopyroxene has a $\delta^{56}Fe$ value that is 0.2 per mil greater than olivine from the same sample (Figure). The calculated Fe isotope fractionation, based on spectroscopic data, between clinopyroxene and olivine is 0.1 per mil at a temperature of 950 degrees C (Polyakov and Mineev, 2000). In addition to these mantle xenolith analyses, we have analyzed magnetite and olivine from two dacites from a continental arc. The predicted Fe isotope fractionation between magnetite and olivine at a temperature of 800 degrees C is 0.5 per mil for $^{56}Fe/^{54}Fe$ (Polyakov and Mineev, 2000). This 0.5 per mil difference is large enough to be easily resolved analytical. The precision of an Fe isotope analysis using our analytical method is 0.05 per mil for $\delta^{56}Fe$ values,

which is based on replicating every mineral through the entire analytical procedure. The measured $\delta^{56}$Fe value of olivine and magnetite from these dacites is the same (Figure).




We have found, however, some differences in the Fe isotope composition between garnet and clinopyroxene in garnet peridotite, pyroxenites and eclogite. Clinopyroxene has a higher $\delta^{56}$Fe value by 0.1 to 0.4 per mil relative to garnet. In the seven samples that we have analyzed, there is no apparent correlation between the temperature of equilibration and the magnitude of the difference in Fe isotope composition of garnet and clinopyroxene, nor is there any apparent major element compositional dependency.

Except for these small differences in the Fe isotope composition between garnet and clinopyroxene, there does not appear to be any significant inter-mineral fractionation between common rock forming minerals at high temperatures. Based on the homogenous Fe isotope compositions measured in igneous rocks, we must conclude that if there are inter-mineral Fe isotope fractionations that they are homogenized out during magmatism.

Critical to our interpretation, is the accuracy of Fe isotope compositions. Iron isotope compositions measured by multi-collector inductively coupled plasma mass spectrometry are corrected for instrumental mass bias by normalizing Fe isotope ratios to an ultra-pure metal standard run under the same conditions as the sample. However, impurities in the sample can have a considerable influence on instrumental mass bias, and therefore the sample must be as pure as the standard in order to achieve accurate results. For example using the University of Wisconsin MC-ICP-MS, contamination of 10ppb of an element in a sample can produce shifts of 0.2 per mil in $^{56}$Fe/$^{54}$Fe relative to that of the standard. Importantly, we note that this bias in Fe isotope ratios occurs along a mass dependent trend for $^{56}$Fe/$^{54}$Fe and $^{57}$Fe/$^{54}$Fe ratios and is associated with changes in instrumental mass bias between sample and standard, it is not a result of isobaric interferences. Our procedure to ensure accurate Fe isotope analyses is to prepare synthetic samples which match the matrix of unknown samples with Fe of a known isotopic composition. These synthetic samples are processed through our ion exchange chromatographic columns to ensure that we can recover accurate Fe isotope measurements.

# Abstract # 12832 - **Iron Isotope Fractionation Between Aqueous Fe(II) and Siderite and Implications for Fe Isotope Biosignatures**

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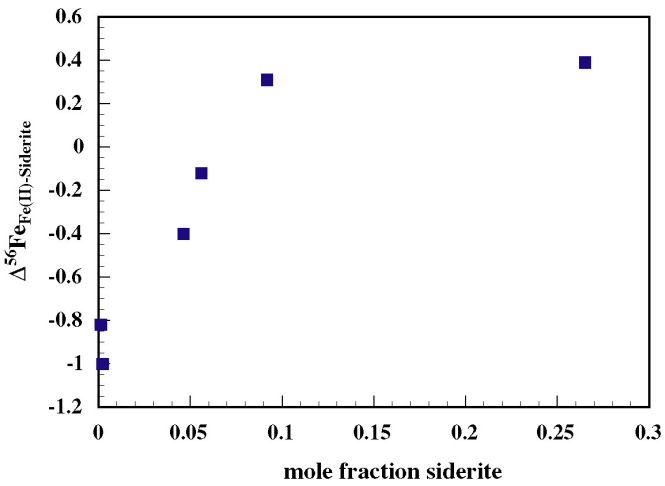
Recent investigations of Fe-isotope systematics of natural rocks and experimental systems have found significant variations in Fe isotopes. In particular, chemically precipitated sediments such as late Archean to Early Proterozoic banded iron formations (BIFs) have highly variable Fe isotope compositions (a range of 4 ‰ in $^{56}Fe/^{54}Fe$). Significantly, Fe isotope variations in BIFs are a function of mineralogy, where $\delta^{56}Fe$ values in minerals decrease in the order hematite ~ magnetite > siderite > ankerite. These variations may contribute to our understanding of the evolution of the early atmosphere or whether Fe isotope fractionations were related to organic or inorganic processes. Additionally, it is not clear if measured Fe isotope variations are the result of kinetic or equilibrium isotope effects. Equilibrium isotope fractionations may be estimated from spectroscopic data, from well constrained natural samples, or by experimental methods.

In this contribution we report the first experiments that are designed to estimate the equilibrium Fe isotope fractionation between aqueous Fe(II) and siderite through slow precipitation from an aqueous solution of sodium bicarbonate and ferrous iron perchlorate. Because perchlorates are a weak ligand, ferrous Fe should be entirely hexaquo complexes under these experimental conditions. Using a procedure that is analogous to that which has been used for C and O isotope fractionation studies in the carbonate-water system, we have performed preliminary experiments at room temperature using variable partial pressures of carbon dioxide that were bubbled through the solutions to control the rate of precipitation. Extrapolation to very slow rates of precipitation should minimize kinetic isotopic effects, allowing us to estimate the equilibrium isotope fractionation factor.

Siderite synthesis experiments were performed using fast and slow precipitation rates, where complete precipitation occurred in ~ 60 min and ~ 1400 min, respectively. Rapid precipitation was accomplished by adding a predetermined amount of sodium bicarbonate to an oxygen-free iron perchlorate solution. Nitrogen was continuously bubbled through the solution to keep any oxygen out. Slight siderite precipitation started ~ 30 s after combining the solutions and the solution was sampled for aqueous Fe(II) and precipitated

siderite 10 min afterwards. In the slow precipitation experiments, the same procedure as described above was used, except that initially, a mixture of $N_2/CO_2$ (90:10) was bubbled through the solution to lower the pH to ~ 4. After about 60 min, pure $N_2$ was bubbled through at very slow rates to increase the pH (and precipitate siderite). The first precipitate was visible after ~ 200 min. Solution and siderite were sampled during the next 20 hrs.




Iron isotope determinations were made using an MC-ICP-MS (*Isoprobe*). Fast precipitation (as described above) produced almost no fractionation between aqueous Fe(II) and the precipitated siderite ($\Delta^{56}Fe_{Fe(II)-Siderite}$ = +0.03‰, and 4% of the total Fe had been precipitated as siderite). In contrast, during slow precipitation, the isotopic difference between Fe(II) and siderite was large (-1.0‰) during the initial precipitation of siderite, but changed to $\Delta^{56}Fe_{Fe(II)-Siderite}$ = +0.4‰ (Figure). These fractionations are significantly different than those predicted by Polyakov and Mineev (2000) and Schauble et al. (2001), where $\Delta^{56}Fe_{Fe(II)-Siderite}$ =+2.0‰ at 25°C. However, the measured isotope fractionation lie closer to the range predicted from natural data ($\Delta^{56}Fe_{Fe(II)-Siderite}$ = -1.7 to +0.3‰; Johnson et al. 2002a). Moreover, the measured fractionations are significantly different than those measured from biogenic siderite formation, where $\Delta^{56}Fe_{Fe(II)-Siderite}$ = +1.3‰ (Johnson et al., 2002b). These results confirm the limitations of predicted isotope fractionation factors and highlight the need for experimental determinations. Although these data are preliminary, they suggest that Fe isotope fractionation that occurs during siderite precipitation in inorganic systems may be distinct from those in biologic systems.

**REFERENCES:** Johnson et al. (2002a): Contri. Min. Petrol., in press; Johnson et al. (2002b): GCA, submitted; Polyakov and Mineev (2000): GCA 64, 849-865; Schauble et al. (2001): GCA 65, 2487-2497.

# Abstract # 12833 - **Fe Isotope Fractionation in Modern Microbial Mats**

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Analysis of natural rock and sediment samples, as well as experimental work, have demonstrated that large variations in the $^{56}Fe/^{54}Fe$ ratio are produced when Fe is precipitated from solution or has undergone a change in redox chemistry (either biologically or abiotically mediated). In order to understand the possible role of microorganisms in Fe isotope fractionation during biogeochemical cycling of Fe in nature, we are investigating Fe isotope fractionation associated with biogeochemical cycling of Fe, C, N, O, and S in microbial mats.

Samples of cyanobacteria-dominated microbial mats were collected from hypersaline ponds and intertidal areas from Guerrero Negro, Mexico. Mat samples collected from the pond consist of ~ 5 cm thick laminated structure dominated by the cyanobacterium *Microcoleus chthonoplastes* in the upper zones of the mat, and *Beggiatoa sp*. and purple sulfur bacteria below the photic zone (Canfield and Des Marais, 1993; Hoehler et al., 2001). The mats collected from the intertidal regions are ~ 1 cm thick and dominated by the filamentous cyanobacteria *Lyngbya sp*. Core samples of sediment below the mats were also collected. Mat samples were sectioned into slices ~ 2-3 mm thick or ~ 1 cm thick and reacted with a series of strong acids to obtain total Fe or 0.5 M HCl to determine 'easily leachable' or 'bio-available Fe'. Fe concentration was determined by the Ferrozine method. Aliquots of the extracted Fe were purified by ion exchange chromatography and analyzed for Fe isotope composition using a Micromass IsoProbe, a multi-collector, inductively-coupled-plasma-mass spectrometer.

The total Fe contents of the *Microcoleus* sp. mats (~ 5 cm thick) were low and variable, ~0.1 to 2 $\mu$g Fe/mg wet weight. Below the mat, Fe contents increased significantly ~ 2 to 8 $\mu$g Fe/mg wet weight of sediment (Figure 1a). Analyses of the $\delta^{56}$Fe on total Fe extracts from 1 cm thick sections of the *Microcoleus sp*. mat across the oxic/anoxic interface and underlying sulfidic sediments showed there is no significant variability in the measured $\delta^{56}$Fe with depth. The $\delta^{56}$Fe ranged from –0.15± 0.08 to +0.06± 0.08 ‰ (Figure 1b). The $\delta^{56}$Fe of total Fe from a second mat sample cut in ~ 2 mm intervals showed similar variability in $\delta^{56}$Fe with depth, with the exception of a larger variation, ~0.4‰ between a reddish layer relatively enriched in Fe (2 $\mu$g Fe/mg wet weight, $\delta^{56}$Fe = -0.1 ± 0.06 ‰) and the layer directly below it (0.1 $\mu$g Fe/mg wet weight, $\delta^{56}$Fe = +0.27 ± 0.06 ‰). This presumably represents the transition across the oxic/anoxic interface.

Although there was little variability in the $\delta^{56}$Fe of the total Fe in the mats and underlying sediments, there was however, significant variation in the 'bio-available Fe' fraction. Fe extracts from the *Microcoleus sp*. mats were ~ 0.3 ‰ lighter than the total Fe (Figure 1b). In the sediments below the mat, the $\delta^{56}$Fe of the extracted Fe was extremely variable, from ~ -1 to –3 ‰ indicating the presence of a small pool of very reactive isotopically light Fe which correlates with percent of Fe leached. This isotopically light Fe fraction is probably a FeS phase.

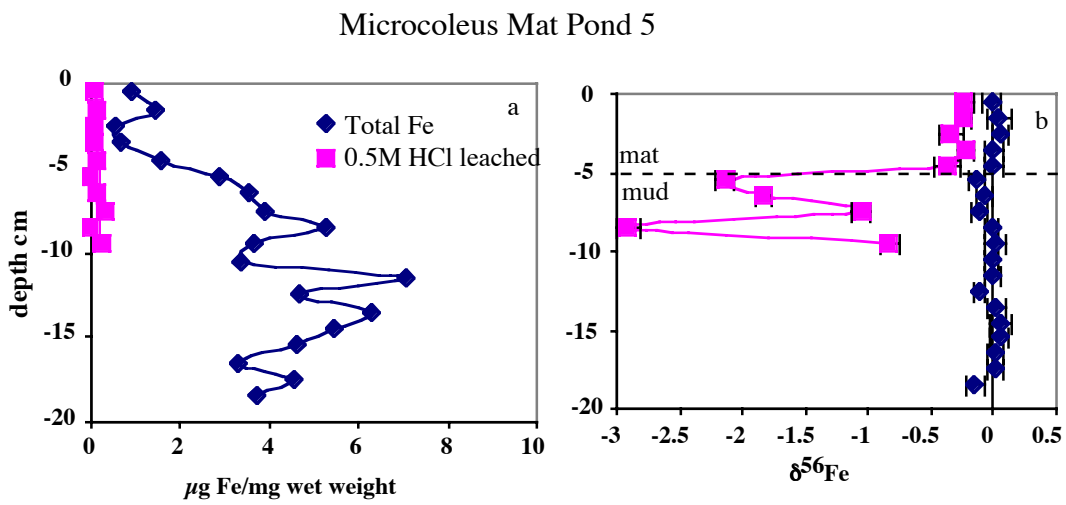


Figure 1 (a) Total Fe content (◆) and 0.5M HCl extractable Fe(■) in *Microcoleus sp*. mat (upper 5 cm) and sulfidic sediments. (b) Measured $\delta^{56}$Fe for total (◆) and 0.5M HCl extractable Fe(■).

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# Abstract # 12845 - **Multi-Spectrum Analysis of Geochemical Alteration Through Natural and Artificial Fossilization**

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During diagenesis and fossilization, the organic constituents of living systems are degraded and geochemically altered. A thorough understanding of how such constituents change over time would allow us to extrapolate, from fossil evidence, aspects of the original biochemistry.

Toward this end, we are using UV-Laser Raman spectroscopy (LRS), nuclear magnetic resonance spectroscopy (NMR), and pyrolysis gas chromatography-mass spectrometry (GC-MS) to analyze the organic chemical composition of an exceptionally well preserved fossil fern species (*Dennstaedtiopsis aerenchymata* Arnold and Daugherty) permineralized in the ~45-million-year-old Eocene Clarno Chert of Oregon (USA) and a modern analogue fern (*Dennstaedtia cicutaria* (Sw.) T. Moore). These three techniques, when combined, allow us to have a much more thorough understanding of the chemical nature of our samples than any of them alone.

Results of all three of these studies have thus far been very promising – showing differences in the chemistry of the structural molecules between the modern and fossil ferns. Preliminary analysis of the NMR data reveals an enormous increase in the fraction of aromatic carbon in the fossil rhizome tissue relative to the modern tissue. This increase is accompanied by a loss in the polysaccharides and a distinct increase in aliphatic carbon (Table 1). Such changes strongly suggest that the polysaccharides (hemicelluloses in particular) are being converted to variously functionalized aromatic compounds. We have

also measured differences in the original chemistries of the visibly distinct tissues (xylem, phloem, cortex, epidermis, etc.) within each of the species (using only LRS; NMR and GC-MS are bulk sample techniques and therefore their use on individual tissues is precluded). Additional analyses are currently underway to determine exactly what these chemical differences tell us about the changes induced during fossilization.

**Table 1. Functional group concentration via $^{13}C$ CPMAS NMR samples**

| Functional Groups | Modern *Petiole* | Modern Rhizome | Fossil Rhizome |
|---|---|---|---|
| *COOH* | 5.0 | 11.5 | 10.6 |
| *Aromatic Carbon* | 22.1 | 24.5 | 63.6 |
| *Glycosidic Carbon** | 11.9 | 13.2 | - |
| *Secondary Alcohol or Ether* | 55.7 | 43.3 | 10.7 |
| *Aliphatic Carbon*** | 5.2 | 7.5 | 15.0 |
| *Average OH/Ring**** | 1.6 | 2.1 | 1.0 |
| *Hemicellulose:Cellulose*† | 40:60 | 75:25 | - |

*Glycosidic carbon resonates at 100-106 ppm whereas secondary alcohols resonate from ~50 to 90 ppm
**Aliphatic carbon is defined as call carbon with resonant frequencies below 50 ppm
***Oxygenated aromatic carbon lies at frequencies of 140–160 ppm, protonated and alkyl substituted aromatic carbon lies at ~105–140 ppm.
†Hemicellulose is distinguished from cellulose by the characteristic resonance frequency of the glycosidic carbon which lies at ~105 ppm for cellulose and ~101 ppm for hemicellulose.

In addition to studying these two endpoints (modern and fossil), we are also studying the continuum of change through which organisms progress during fossilization. We are in the process of artificially "fossilizing" modern fern samples by heating them under anoxic conditions (the type of environment seen by the fossils during permineralization) to different stages of degradation to produce just such a continuum of chemical forms. When the heating experiment is concluded we will use LRS, NMR and GC-MS to better understand the natural process of organic maturation that occurs between modern and fossil organisms. We will also pursue the use of complexity analysis techniques to produce an estimate of relative fossilization within this continuum. These techniques are currently under development as part of a project to quantify degree of diagenic change in natural fossils.

# Abstract # 12850 - **Intact Polar Lipids as Tracers of Ecology and Diversity in Microbial Ecosystems**

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The Earth's deep subsurface is an extreme environment of low energy and, yet it is home to significant communities of prokaryotes. The study of such communities provides a useful terrestrial analog for astrobiologists engaged in the search for extra-terrestrial life. Modern molecular techniques including phylogenetic analysis and isotopic studies of diagnostic lipid biomarkers have advanced our understanding of naturally occurring microbial communities; examples include the significant advances in our understanding of the ecology of archaeal methanotrophs and planktonic crenarchaeota. The deep biosphere challenges conventional techniques unable to distinguish between living or dead matter. Intact polar lipids (IPLs), *i.e.*, glyco- and phospholipids are cell membrane components of all living organisms but are rapidly degraded after death. Cell membranes are an organisms' primary interface with the environment, and so it follows that organisms from different environments will have membrane lipids suited to life in that environment. A study of the IPLs of a wide variety of cultured bacteria and archaea allows us to compare the phylogenetic and chemotaxonomic relationships between the microbes. This information can then be used to determine the size, structure, and function of microbial communities in the deep subsurface and other extreme environments by examining the profiles of IPLs found in sediments from the deep subsurface.

Our analytical approach is based on and advances the pioneering work of Rütters and co-workers (*e.g.,* J. Microbiol. Methods, **48,** 149-160, 2002). We utilized a high-performance-liquid-chromatograph coupled *via* an electrospray ionization interface to an ion trap mass-spectrometer (HPLC-MS) to examine the distribution of IPLs from microbial isolates and sediments that are relevant for the study of deep subsurface biospheres. Figure 1 below shows the IPL fingerprints of the sulfate reducing bacterium (SRB) *Thermodesulfobacterium commune* and the methanogenic archaeon *Methanococcus thermolithotrophicus*. The archaeon is easily distinguished from the bacterium by the presence of archaeol-based lipids. While the phospho-ethanolamine head group is common to both, the presence/absence of more unusual head groups like phospho-N,N,N-trimethylamino-pentanetetrol allows unambiguous distinction between

taxonomically closely related groups. Broad structural features of bacterial and archaeal-derived IPLs are identified on the basis of their fragmentation in the ion trap. The electrospray interface is a 'soft' ionization technique that essentially gives molecular ions, the ion trap mass spectrometer then allows specific ions to be trapped and fragmented in a sequential fashion. Data from multiple fragmentations in both positive and negative ion mode provide several dimensions of data that together provide valuable structural information. Structural features revealed by this technique include the nature of the polar head group, the length of the glycerol-bound alkyl chains, and their degrees of unsaturation (number of double bonds or rings). Additional structural details are obtained from a series of chemical degradations designed to release functional units of the IPLs rendering them analyzable by conventional gas-chromatography mass-spectrometry (GC-MS).

This presentation examines the relationship between the phylogeny and chemotaxonomy of a broad range of prokaryotes (*e.g.*, methanogens, SRBs) that are relevant for deep subsurface biospheres.

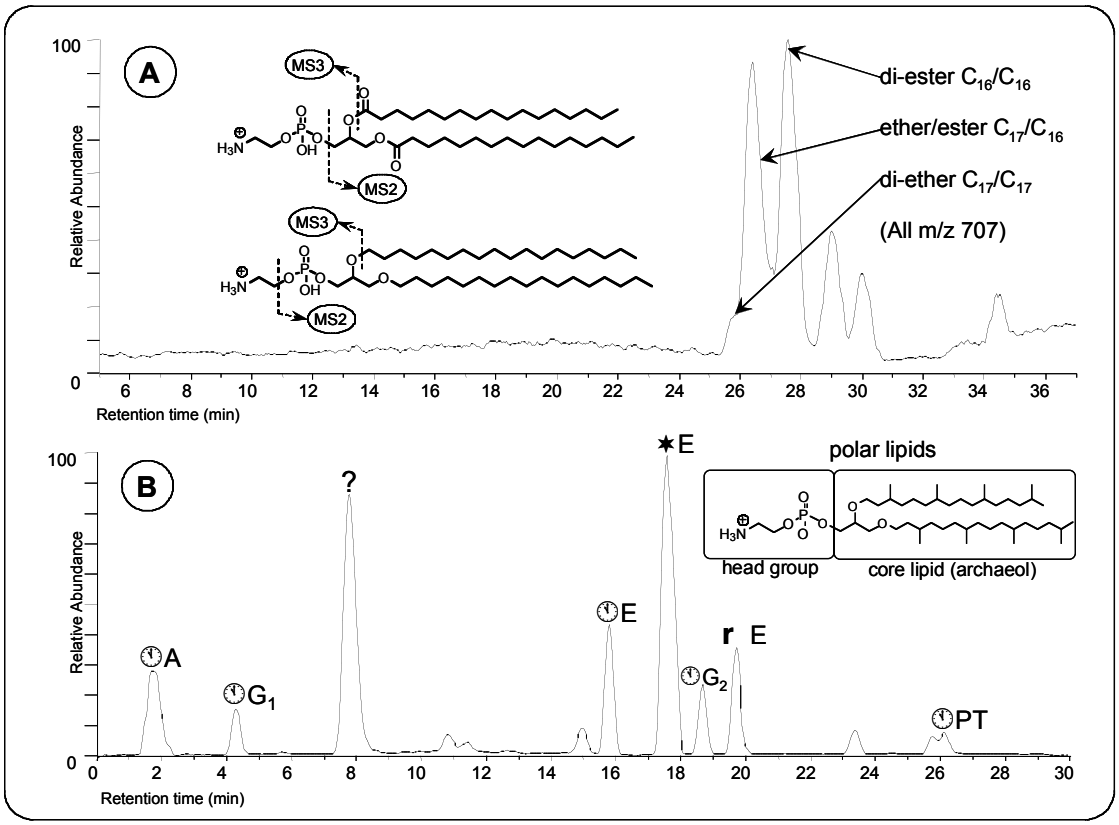


Figure 1. Total ion current chromatograms (positive ion mode) of total lipid extracts from A: *Thermodesulfobacterium commune*, showing a mixture of di-ether, di-ester and mixed ether/ester core lipids with a phospho-ethanolamine headgroup. Inset shows sequential fragmentation (MS → MS2 → MS3) of a di-ether and a di-ester. Identification is based on mass spectral data and relative retention times. B: *Methanococcus thermolithotrophicus*, showing several core lipids (○ = archaeol, □ = hydroxyarchaeol, ρ = dihydroxyarchaeol) with a variety of head groups (A = phosphatidic acid, $G_n$ = mono- and diglycosidic, E = phosphoethanolamine, PT = phospho-N,N,N-trimethylaminopentanetetrol). Identification is based on mass spectral data and comparison with published data based on other techniques.

# Abstract # 12866 - **Lipid Biomarkers for Methanogens in Hypersaline Cyanobacterial Mats from Guerrero Negro, Baja California Sur**

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Analyses of sediments from the vicinity of active methane seeps have uncovered a particular suite of lipid biomarker patterns that characterize methane consuming archaea and their syntrophic, sulfate reducing partners. These isoprenoid biomarkers, largely identified by their anomalously light carbon isotopic signatures, have been a topic of intense research activity and are recorded in numerous methane-rich environments from Holocene to Cenozoic. This phenomenon has implications for depleted kerogens at 2.7 Ga on early Earth (Hinrichs 2002). In contrast, the lipid biosignatures of methane producing archaea are not readily identified through distinct isotopic labels and have received comparably little attention in analyses of archaea in environmental samples. Indeed, environmental analyses generally detect only free archaeal lipids, not the intact, polar molecules found in the membrane of living organisms. As part of the Ames NAI, the 'Early Microbial Ecosystem Research Group' (EMERG) is working to understand microbial processes in the hypersaline cyanobacterial mats growing in the salt evaporation ponds of the Exportadora de Sal at Guerrero Negro, Baja California Sur, Mexico. The aim of this study was to develop methods by which we could identify the organisms responsible for methane generation in this environment. While the ester-bound fatty acids, hopanoids and wax esters provide a means to identify most of the bacterial components of these mats, the archaea which are evidently present through genomic assays and the fact of intense methane production (Hoehler et al. 2001), have not been identified through their corresponding lipid signatures.

Archaeal core lipids present a number of analytical challenges. The core lipids of methanogens comprise $C_{20}$ , $C_{40}$ and sometimes $C_{25}$ isoprenoid chains, linked through ether bonds to glycerol. As well as archaeol ($C_{20}$), *sn*-2- and *sn*-3-hydroxyarchaeol are associated particularly with methylotrophic methanogens. Recently, we have also identified a dihydroxyarchaeol in a hyperthermophilic methanogen (Summons et al. 2002). Additional structural diversity is encoded into the polar head groups that are

attached to the glycerol ether cores. The $C_{20}$ core lipids are readily analyzed by GC-MS as their volatile trimethylsilyl derivatives while compounds with intact polar head groups can only be detected using LC-MS approaches. Our approach was to utilize the alternative of an ether cleavage reagent ($BBr_3$ vs. HI) and a hydride reducing agent to convert all ether lipids to hydrocarbon in order to provide a vertical profile of quantitative information that might be matched to methane fluxes. We have found that while conventional acid hydrolysis and HI treatment will destroy hydroxyarchaeols, molecular information remains intact through use of $BBr_3$ for ether cleavage. This method revealed the presence of traces of biphytane and various ether alkyls associated with some sulfate reducing bacteria within the mat structure. An interesting, and potentially valuable, byproduct of the method utilizing HI was the identification of abundant homohopanoids after superhydride reduction. Evidently present as sulfur-bound diagenetic products these hopanoids are likely cyanobacterial biomarkers in the early stages of diagenetic preservation.

ACKNOWLEDGEMENTS
We would like to thank M. Baugartner and J. Trent for supplying archaeal cultures. Additionally, we gratefully acknowledge the logistics support of David Des Marais, Brad Bebout and the entire EMERG team in obtaining field samples from Guerrero Negro.

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# Abstract # 12873 *(Oral Presentation)* - **The Classification of Biosignatures**

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If we are trying to detect extant or extinct life on Mars, Europa, or another planetary body, we must first identify biosignatures and then infer from the biosignatures that life is or was present. This is true for robotic missions with remote instruments, remote sensing sensors, and returned samples analyzed in our laboratories on Earth. We therefore need to be concerned with biosignatures: What are they? Can we identify them? Are they proof of life? How reliable are they? We propose the following definition: **A biosignature is any measurable property of a planetary object, its atmosphere, its oceans, its geologic formations, or its samples that *suggests* that life is or was present.** A short definition is a "fingerprint of life". Biosignatures are sometimes termed biomarkers, but the term biomarker has long been used in the geological literature to refer specifically to organic compounds derived from once-living material and now found in geologic formations. This usage has precedence and should be retained. Biosignatures as defined above include biomarkers as a subset.

One of the major goals of astrobiology is to find life beyond earth, and only the most reliable and useful biosignatures will give confidence that we have done so. Other biosignatures may be less reliable and only hint that we have found life beyond earth. Still others may be equally well produced by non-biologic processes and therefore may provide us with no real information on whether we have found life or not. *The reliability or usefulness of a biosignature is inversely proportional to how difficult it is to produce by non-biologic processes*. Clearly, a category classification system is needed which rates biosignature reliability-- *defined as the probability that the specific properties were formed by biologic processes*.

The following system contains five reliability categories for biosignatures:

- **Category I Biosignatures**

*The detected property is nearly indisputable evidence for life and has characteristics which cannot be produced by any known non-biologic process in nature. Defined as having a >98% probability that this property indicates present or past life.*
Examples of Category I biosignatures: Actual unambiguous living forms capable of metabolism and reproduction (people, trees, insects, living bacteria); complex fossils such as trilobites, skeletons, and other forms with indisputable morphologies (extremely challenging with single-cell life); distinctive magnetite produced by some magnetotactic

bacteria (used as a certain biosignature on earth for many years); DNA; RNA; most proteins; some complex organic compounds (e.g., hopanoids, other classic biomarkers).

- **Category II Biosignatures**

*The property is strong to very strong evidence for life, and is less likely to be produced by known non-biologic processes, but is not indisputable. Probability that these properties mean life is defined as 65-98%.*

Examples of Category II biosignatures: Many kinds of less complex organic compounds; amino acids with strongly non-racemic compositions; some kinds of mass-dependent isotopic fractionation of carbon, sulfur, etc.; presence of ozone and methane in a planetary atmosphere; complex morphologies resembling known fossils, biofilms, mineralized microbes.

- **Category III Biosignatures**

*The property is known to be produced by life but is also known to be produced by non-biologic processes. Defined as 50-65% probability that it was formed by biology.*

This is a permissive category; it allows the property to be biogenic, but gives no convincing information on whether it is or is not.

Examples of Category III biosignatures: Presence and enhancement of nitrogen, phosphorous; ratios of certain elements such as phosphorous to uranium; iron isotopic fractionation; sulfur isotope fractionation (mass dependent); polycyclic aromatic hydrocarbons (PAHs); racemic amino acids; micrometer-size spherical or ovoid objects of appropriate composition; many low temperature minerals (carbonates, phosphates, hydrated metal oxides, etc.), and non-equilibrium mineral co-existence or zoning.

- **Category IV Biosignatures**

*The property most likely formed by non-biologic properties. Defined as having a 2-50% probability that the property was formed by biology.*

Example of Category IV biosignatures: Micrometer-size spheres of NaCl; other cell-shaped minerals of inappropriate compositions for fossilized cells.

- **Category V Biosignatures**

*The property is almost certainly formed by non-biologic processes and may even rule out biology. Defined as <5% probability that the property was formed by biology.*

Examples of Category V Biosignatures: Characteristic only formed at high temperature; non-mass dependent isotopic fractionation of sulfur.

Numerical probabilities can be assigned to biosignatures based on literature surveys, new analyses, or experiments. Biosignatures can be upgraded to higher categories by combining probabilities using a rigorous mathematical treatment. Assigning biosignatures to categories may provide a good basis for instrument selection for remote missions. For astrobiology missions, instruments should concentrate on detecting Category I and II biosignatures; Category III or lower may provide excellent geologic data, but provide little or no information on life detection.

For both robotic and sample return missions, it should only require one or two Category I biosignatures to convince the scientific community that life has been detected. A larger number of Category II biosignatures will be necessary, perhaps 5 or 10.

# Abstract # 12888 - **Biogenicity of Putative Microfossils in Precambrian Cherts: Distribution and Crystallinity of Carbon**

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The evidence for the earliest life on Earth occurs in the form of microfossils, predominantly in chert. The primary biomarker for such material has been the morphological similarity to extant microorganisms, as defined by the distribution of kerogen or oxide minerals. Once an organism dies, the carbon it contains is altered through diagenesis and metamorphism. Most organic material is removed or remineralized, but insoluble amorphous carbon, known as kerogen, may remain. With additional heating and pressure, this kerogen is transformed into crystalline graphite, eliminating the structural biosignature of the material. No known biological process creates graphite directly as a product. Many microfossils are defined not by kerogen but by arrangements of small iron or manganese oxide crystals, even though kerogen may still be associated with them.

Currently, much of our oldest evidence of life on Earth has been called into question. Although morphological criteria for biogenicity are well established, complex forms may be interpreted differently by different researchers. For example, the cyanobacteria-like filamentous forms described in the 3.5 Ga Apex Chert [1] have been reinterpreted to be complex branching forms of an abiogenic origin [2]. The controversy over the biogenicity of features in the Apex chert also hinges on nature of the material that defines these filamentous forms. Whereas Schopf et al. [3] use Raman spectroscopy to argue that the microfossils consist of partially graphitized kerogen of a biogenic origin, Brasier et al. [2] interpret nearly identical Raman spectra to indicate highly disordered graphite of an abiogenic origin. The distinction between amorphous and graphitic carbon in microfossils is an essential part of using kerogen as a biosignature. Transmission electron microscopy (TEM) combined with electron energy loss spectroscopy (EELS) provide a powerful tool to distinguish kerogen from graphite and to quantitatively measure the extent of graphitization of kerogen in natural samples [4]. EELS analysis has been performed on Gunflint Formation cherts from Schreiber Beach (2.0 Ga), which contain well preserved kerogenous microfossils. These microfossils consist of kerogen along grain boundaries in a matrix of microcrystalline quartz. EELS spectra indicate that the kerogen is amorphous with no evidence for graphitization. Samples of black chert breccia from the Apex Chert

of the Warawoona Group are now under investigation. We are using TEM imaging, EDS and EELS to characterize the distribution and crystallinity of carbon in Apex Chert. The degree of graphitization will be measured to test for a biogenic origin of these 3.5 Ga samples.

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# Abstract # 12895 *(Oral Presentation)* - **Morphologies and Structures of Microfossils in HF-Etched Samples of Gunflint Chert**

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The evidence for the earliest life on Earth occurs in the form of microfossils, predominantly in chert. The primary biomarker for such material has been the morphological similarity of microfossils to extant microorganisms. Etching of chert samples in hydrofluoric acid (HF), combined with scanning electron microscopy (SEM) is a common method for investigating morphological details of ancient microfossils. Although interesting morphologies are commonly observed in etched samples, it may be difficult to interpret the biological forms unless one understands what materials are present in the sample and how they behave during HF etching. To better understand HF etching of fossiliferous cherts, we are combining etching and SEM with TEM characterization of mineralogy and microstructure in samples of Gunflint Chert. We have compared samples from the Schreiber Beach locality with samples from Mink Mountain. Samples were etched in HF vapor for periods ranging from 30 minute to seven days, then rinsed in distilled deionized water. Etched samples were characterized using a field-emission SEM for high spatial resolution in secondary electron images. TEM characterization was performed on unetched samples that showed abundant microfossils. Samples were ion thinned to electron transparent while optically tracking microfossils through the thinning process. The mineralogy, microstructure and kerogen distribution were determined by TEM imaging, diffraction, and EDS.

The samples from Schreiber beach consist of kerogenous microfossils in a matrix of well crystalline microquartz grains which are less than 10 µm in size. Some filaments consist of sub-µm quartz grains in a matrix of kerogen, whereas other microfossils consist of thick kerogen masses along grain boundaries and in interstitial pockets. After HF etching, Schreiber Beach samples show both kerogenous filaments and coccoids surrounded by granular remnants of etched quartz grains. In some cases, the observed morphologies

reflect the presence of sub-µm quartz grains within the kerogen. In other cases, filamentous forms appear to be flattened or split open. This degradation of forms my either represent degradation of cells prior to fossilization or displacement of kerogen during diagenesis and recrystallization. There is no evidence for extracellular biofilms in either TEM data or in etched samples.

The Mink Mountain samples are more oxidized than the Schreiber Beach samples and contain microfossils that are dominated by oxide minerals ranging from red to brown and black in thin section. TEM imaging shows that the oxides are all hematite, with the color variations resulting from variable amounts of kerogen in close association with hematite. The quartz in these samples is much finer grained than the microquartz of the Schreiber Beach samples. TEM also shows an abundance of small pockets of kerogen outside of the oxide-defined filaments. The morphologies observed in etched samples from Mink Mountain are much more complex than those observed in Schreiber Beach samples. Numerous nm-scale platelets of kerogen appear to correspond to the disseminated extracellular kerogen observed with TEM. Additional etching of Mink Mountain samples is underway and will be discussed.

# Abstract # 12900 *(Oral Presentation)* - **Tracing the Co-Evolution of Nitrogen Metabolisms with the Chemical Evolution of the Atmosphere**

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The nitrogen isotopic composition of ammonium can be used to trace the emergence of life on Earth and to follow the subsequent evolution of microbial nitrogen metabolisms in response to global changes in the redox state of the atmosphere. The modern nitrogen isotopic composition of organic matter is controlled by biological nitrogen fixation, taking $N_2$ from the atmosphere to form organic nitrogen compounds, and by denitrification ($NO_3$ _ $N_2$), which returns nitrogen to the atmosphere. The nitrogen isotopic record over geologic time appears to show a shift in _$^{15}$N from negative values in the Early Archean (range: -6 to +6‰) to near present values (range: +4 to +10‰) in the Early Proterozoic. We propose that this shift could have resulted from a change in the dominant form of nitrogen metabolism during or shortly after the Great Oxygenation Event (GOE) between 2.4 and 1.9 Ga.

Multiple lines of evidence show that biological nitrogen fixation evolved early and that the Last Common Ancestor (LCA) was capable of nitrogen fixation. Many lineages in both the domains of Bacteria and Archaea can fix nitrogen indicating that it could also be the case for the LCA relating these two domains of life. Phylogenetic analysis of nitrogen-fixing (Nif) genes from lineages of Bacteria and Archaea suggest that the Nif genes originated in a common ancestor of the two domains. Other phylogenetic analyses have demonstrated that the paralogous duplication of the *nifDK* and *nifEN* operons (central to nitrogen fixation) predated the divergence of Archaea from Bacteria, further supporting the hypothesis that N fixation occurred prior to the LCA. The occurrence of biological nitrogen fixation can be investigated in Precambrian sediments by examining the $^{15}N/^{14}N$ composition of ammonium as nitrogen fixation discriminates against $^{15}$N and leads to a negative fractionation (_$^{15}$N ~ -4‰).

The progressive increase of atmospheric oxygen during the Early Proterozoic ultimately resulted from oxygenic photosynthesis by cyanobacteria. The rapid rise in $O_2$ might imply a population explosion of these organisms around 2.4 to 1.9 Ga. Bacteria dominate the types of organisms capable of denitrification, with only two Archaeal lineages known. We propose that the change in the global redox state of Earth's atmosphere resulted in

conditions more favorable to denitrifying organisms by stabilizing a greater quantity of oxidized nitrogen compounds in the environment. Our hypothesis is therefore that nitrogen fixation was the dominant nitrogen metabolism during the Archean, until the rise of oxygen in the atmosphere in the Early Proterozoic led denitrification to dominate. Denitrification is geochemically distinguishable from nitrogen fixation in that it releases isotopically light $N_2$ back to the atmosphere leaving the organism enriched in $^{15}N$ (_$^{15}N$ ~ +20‰). Hence, it is possible to differentiate nitrogen fixation and denitrification in the rock record.

We have sampled an extensive section of well-characterized metasedimentary rocks spanning 2.4 to 1.9 Ga from the Rovaniemi district, northern Finland. Metasedimentary rocks containing micas generally contain some substituted $NH_4$+ in the K-sites, which presumably originated from the degradation of organic matter. The substituted ammonium can survive metamorphic transformation to mica due to its high thermal stability. We have established a method to evaluate [$NH_4^+$] in micas from the Finland samples and report a high-resolution record of [$NH_4^+$] spanning the GOE and correlated with previously published carbon and oxygen isotopic studies on these same samples. On the basis of these measurements, we selected the samples with the highest ammonium concentration for nitrogen isotopic analysis. Due to the minute quantity of nitrogen in our samples, the analyses have to be performed at the CRPG-CNRS in Nancy, France, where a newly developed laser extraction method coupled to a static mass spectrometer allows the extraction and analysis of volatiles at the sub-ng ($10^{-9}$g) $g^{-1}$ level. Grain fractions typically weighting 0.2 to 5 mg are loaded in a chamber and pre-heated. The volatiles are then extracted with a $CO_2$ laser and the isotopic analyses are performed by a mass spectrometer originally designed for high precision isotopic analyses on rare gases. We present new measurements of nitrogen isotopes by this laser mass spectrometry technique and interpret the nitrogen isotopic values during the transition from an anoxygenic to an oxygenated atmosphere. These results test hypotheses regarding the preservation of ammonium in a variety of geologic settings and contribute to the understanding of the evolution of the nitrogen cycle and the possible relations between global redox changes and metabolic evolution of nitrogen.

# Abstract # 12911 - **Toward Modeling Fe-Isotope Fractionation During Organic Uptake**

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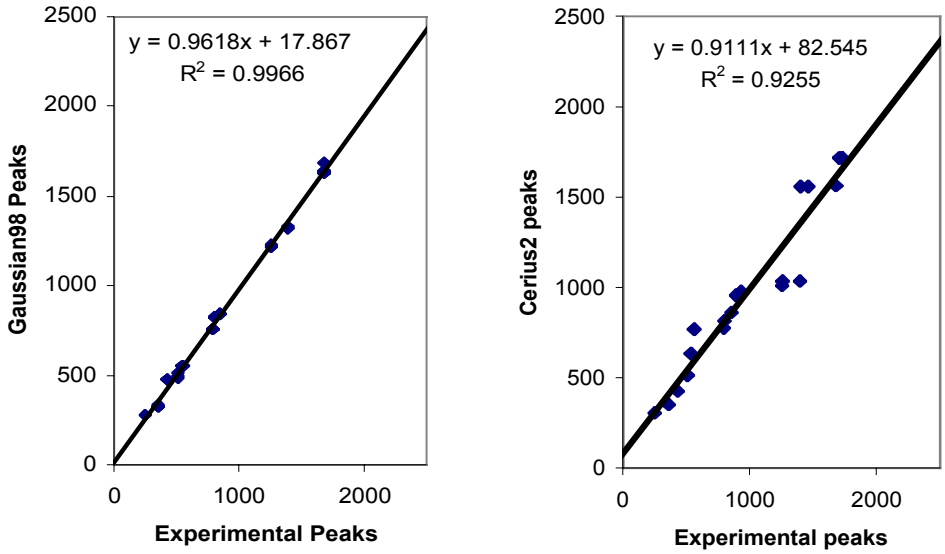
Fe isotope fractionation has been proposed as a potentially useful biomarker (1). Biological processing of Fe is complicated and involves a series of reaction pathways. Recent laboratory experiments suggest that fractionation occurs during the uptake of Fe from a solid substrate (2). This study seeks to examine the theoretical basis for fractionation during uptake of Fe. This may be done by predicting the vibrational frequencies of aqueous Fe species and of Fe in complex with siderophores for different Fe isotopes. Siderophores are a class of molecules used by some bacteria for Fe uptake. They are high molecular weight, complicated molecules that may prove difficult to model on an *ab initio* level. Therefore, Fe-ligand complexes that simulate the Fe-O bonds in the more complicated siderophores will be modeled first in order to optimize the efficiency of our techniques. Specifically, the use of a classical mechanical model is preferred to an *ab initio* model due to the lower cost of classical mechanical calculations. We have finished preliminary models of $Fe(oxalate)_3^{3-}$ in vacuum using both *ab initio* and classical mechanical models. The criterion used to test the accuracy of the different models will be the comparison of the classical model structures to the *ab initio* structures, and comparison of the predicted IR and Raman spectra from both model types to IR and Raman spectra from experiments. These preliminary models show that the *ab initio* models will likely have the required accuracy to continue these studies, while classical mechanical simulations are suspect enough to require careful choice of the force field utilized and rigorous comparison of any classical mechanical results to both experimental and *ab initio* results.

*Ab initio* calculations were done using the Gaussian 98 software package (3). We used a hybrid molecular orbital/density functional theory (MO-DFT) in this study due to its relatively good accuracy and moderate computational cost (4). Specifically, our models were optimized using the B3LYP (5, 6) functional with a 6-311G* basis set (7). Initial models did not include hydration effects on the molecule (i.e., gas-phase complexes), but hydration effects will be tested using both explicit and implicit hydration models.

The classical mechanical energy minimizations were carried out on the Cerius$^2$ software package (7). We modeled the molecules using the Universal Force Field 1.02, (UFF, (8)). This force field has no $Fe^{3+}$ atom type, so models were constructed using $Fe^{2+}$

atoms. Future work will hopefully rectify errors in the force field geometries and IR spectra by utilizing the Merck Molecular Force Field (MMFF, (9)), which is designed for modeling organo-metallic complexes and includes $Fe^{3+}$ as an atom type.

**Figure 1** – Plot of predicted IR peaks from this study versus experimental peaks (Jaber et. al., 1979), with best fit trend line.




The correlation between *ab initio* peaks and experimental peaks is good, whereas the match between force field peaks and experimental peaks shows significant errors (*Fig. 1*). The larger errors in UFF calculations are likely due to the use of a force field that does not include $Fe^{3+}$ as an atom type, and the subsequent use of $Fe^{2+}$ in the force field models. The smaller errors in the *ab initio* calculations occur mostly at high frequencies and are likely due to ignoring hydration effects, which will be considered in future models.

The structure and vibrational spectrum of $Fe(oxalate)_3^{3-}$ has been modeled in vacuum, using both *ab initio* and UFF models. We plan to model $Fe(oxalate)_3^{3-}$ in solution and on the surface of Fe-rich minerals, as well as other Fe-ligand and aqueous Fe complexes. We will also calculate frequency shifts that result from Fe isotope substitution in these complexes. With these results, fractionation factors for the uptake of iron by organic ligands may be predicted from a theoretical basis.

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# Abstract # 12935 - **Disk-Averaged Synthetic Spectra of Mars**

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The principal goal of the Terrestrial Planet Finder (TPF) mission concept is to detect and characterize extrasolar terrestrial planets. TPF is expected to survey nearby stars and directly detect planetary systems that include terrestrial-sized planets in their habitable zones. These measurements may also determine whether these planets harbor life. Characterization of terrestrial planets can best be achieved via remote-sensing spectroscopy. Given the spectrum of a planet, it is possible to derive information about the chemical composition, thermodynamics and kinetics of its atmosphere, the composition of its surface, and to use this information to infer its habitability.

The NAI Virtual Planetary Laboratory (VPL, Dr. Victoria Meadows, Principal Investigator), seeks to understand the extent to which the environments of extrasolar terrestrial planets can be characterized from disk-averaged visible and infrared spectra. As the first task in this effort, we are using a spectrum resolving (line-by-line) atmospheric/surface radiative transfer model and atmospheric and surface data for Earth, Mars, Venus and Titan to generate a database of spatially resolved synthetic spectra for a range of illumination conditions (phase angles) and viewing geometries. These results are then processed with a model that resamples the spatially-resolved spectra to create a synthetic, disk-averaged view of the planet from a specific viewing geometry.

In this poster, we will present the first results of this modeling effort. The radiative transfer model (Meadows and Crisp, 1996) was used to generate synthetic radiance spectra for Martian atmospheric and surface properties derived from Mars General Circulation Model results. These results are being validated via comparison with the experimental data coming from the Mars Global Surveyor Thermal Emission Spectrometer (MGS TES). Initial results from this model include disk-averaged synthetic spectra and images, and light-curves showing variability at visible + MIR wavelengths as a function of viewing angle.

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# Abstract # 12952 *(Oral Presentation)* - **Stromatolite Complexity as a Biosignature**

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Stromatolites are most commonly defined as laminated organo-sedimentary structures built by the trapping and binding and/or precipitation of minerals via microbial processes, most importantly photoautotrophs such as cyanobacteria. Stromatolite morphology varies widely in scale and shape, but most are decimeters to meters tall and share a laminated, domical/conical, possibly branching morphology. However, abiotic precipitates have been shown to mimic stromatolite morphology, and common stromatolitic forms have been modeled on the computer using simple diffusion limited models (Grotzinger and Knoll, 1999). These studies could cast serious doubt on the usefulness of many stromatolites as biosignatures.

The ability of inorganic processes to produce stromatolitic structures commonly attributed to microbial (i.e., life) processes, has been under-appreciated. Since stromatolites are macroscopic structures easily recognizable in the field on Earth or by remote sensing/rover camera on Mars or other extraterrestrial locale, it is critical to differentiate between those produced by abiotic processes and those produced with microbial input if we intend to use them as biosignatures. The biotic versus abiotic nature of a stromatolite is easier to discern at the microscopic level if certain crystallographic features and/or microfossils are present. However, most stromatolites simply do not record this information due to post-depositional recrystalization (or perhaps its initial absence is now obscured by diagenetic processes). Nor is it straightforward to examine samples at the microscopic level via remote means on other planets. Thus, the use of stromatolites as evidence for life on early Earth and extraterrestrial destinations will remain in doubt without some other criteria with which to evaluate them. (This has been identified as one of the most critical questions in the emerging field of geobiology.)

We are currently testing the hypothesis that stromatolites formed with biotic input differ in some fundamental way from stromatolites formed by purely inorganic processes. Our

test of this hypothesis employs complexity analysis, a method for quantifying the information content or entropy contained in an image (Gell-Mann and Lloyd, 1996). The technique may provide a novel and straightforward way to differentiate between biotic and abiotic stromatolites. In this work we present the results from employing a Huffman linear lossless compression algorithm to estimate complexity. [For a discussion of more advanced algorithms, see the accompanying study by Storrie-Lombardi, et al.]

The data analyzed include RGB reflectance images of polished stromatolites at multiple macroscopic and microscopic scales, petrographic thin sections, and scanning electron micrographs. The results from this study have obvious implications for the study of early life on Earth, since stromatolites are one of the most common structures in shallow marine deposits of pre-Cambrian age (3.5 Ga-.544 Ga), and they form some of the oldest putative fossils in Archean time. Our study has additional implications if stromatolites are found on other planets.

Determining the biotic-abiotic nature of stromatolites is critical for NASA efforts to:

1. Define useful biosignatures accessible to detection by a Rover exploring the Martian surface
2. Study life on early Earth
3. Build a Virtual Planetary Laboratory capable of predicting the spectral signature of an inhabited planets prior to development of a Terrestrial Planet Finder.

In this work we present one possible way to begin the quantification of the abiotic-biotic etiology of stromatolites.

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# Abstract # 12961 - **Advanced Techniques in Complexity Analysis for the Detection of Biosignatures in Ancient and Modern Stromatolites**

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Stromatolites are laminated organo-sedimentary structures built by the trapping and binding and/or precipitation of minerals via microbial processes. Stromatolites may be decimeters to meters tall and show a laminated, domical/conical, or even branching morphology. However, a variety of abiotic precipitates have been shown to mimic stromatolite morphology, and some stromatolitic forms can be modeled using simple diffusion limited computational algorithms (Grotzinger and Knoll, 1999). These studies have cast doubt on the usefulness of some stromatolites as biosignatures [see the accompanying study by Corsetti, et al.].

If the origin of abiotic stromatolites is a random, diffusion limited process, and the origin of biotic stromatolites contains both diffusion and non-random (ordered) processes, then the possibility exists that a residual signature survives in the morphological and chemical matrix of stromatolite samples. We have embarked on a project to quantify the complexity exhibited by multiband images of a variety of putative abiotic and biotic stromatolites. While initial findings have been encouraging, it was immediately clear that the investigation demanded an exploration of novel and robust techniques available for quantifying complexity as a function of ordered and diffusion events. To this end we have embarked on an investigation into a new set of algorithms for analyzing image complexity and explored a series of preliminary encoding techniques for RGB images.

The statistical analysis of stromatolites presented here is based on the adoption of an approach known to the Complexity research community as the Compression and Diffusion (CD) method [1]. In this method a set of stromatolite surface features are converted into a sequence of symbols. The CD method yields results that are independent of the potential false correlations that any specific image conversion method might create. We apply the CD method to studying local properties, with consequently no conflict with the non-stationary nature of the geological process that led to the formation of stromatolites. The compression component of the method recognizes the existence of deterministic rules and the diffusion component measures the speed of transition from dynamics to thermodynamics. This transition may be the central characteristic capable of differentiating a biotic from an abiotic origin of the target stromatolite, the biotic origin producing a more significant departure from thermodynamics.

In this poster we present an advanced version of the CD method and demonstrate its heritage from and connection with other methods currently adopted to measure complexity, one of these being the multifractal distribution. Within the CD perspective the multifractal properties are connected to the condition of transition from dynamics to thermodynamics, thereby affording a double check of the condition that is expected to characterize the stromatolites of biotic origin.

We explore the possibility that the optimal transformation of a 2-D matrix (the original image) to a linear string prior to compression may be accomplished using the Peano curve technique, a strategy designed to spatio-temporally associate regions most likely containing related information content. We will also discuss the advantages of dividing the image space into regions of physically related colors to produce a symbolic 3-D matrix.

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# Abstract # 12964 *(Oral Presentation)* - **In Vivo "Breatholyzer" Testing of Sedimentary Microbial Communities**

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We are conducting laboratory and field measurements of metabolic biosignatures associated with layered microbial communities that live in rock and sediment in hot and cold desert environments. Those signatures that can be measured non-invasively are the present priority, because they can be used to pinpoint regions of interest for subsequent and potentially more destructive, confirmatory analysis. To that end, we have used a sensitive portable gas chromatograph to study the evolved hydrocarbons that are associated with the metabolic activity of these microbial communities. The instrument we are using, called a "Z-Nose," has an acoustic wave detector that allows us to collect data rapidly (in a few seconds) at ppb levels. The range of molecular sizes that can be observed is between C2 and C30, and our data show that we can not only differentiate between different species of organisms in pure culture, but also between different metabolic states of the same organism. The spectrum of volatiles associated with the environmental microbe, *Shewanella oneidensis*, is different depending upon whether the organism is respiring aerobically or anaerobically.

In this report we will show the initial results of portable GC data collected from layered sedimentary mixed microbial communities from Mojave Desert, CA. We will also show the comparison of these field data with data that we obtain from samples that have been returned to the laboratory for data collection under controlled conditions.

# Abstract # 12970 - **Fluorescence and Amino Acid Measurements in the Water Column of Antarctic Subglacial Lakes**

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The Dry Valleys in Antarctica could be used as a good model for testing of life detection systems for solar system exploration. All planets and their satellites from Earth outward are cold environments. Surface of the Dry Valley area could be used for modeling conditions on Mars, and Dry Valley lakes (covered with ice all year around) would be a good test place for systems designed to study Lake Vostok and Europa. One of these lakes – Bonney Lake – is a stratified saline lake. The salt concentration in this lake monotonically increases from the surface to the bottom. This lake is permanently covered with 4 m thick ice. Short light period and negative temperatures on the surface almost all year around makes *in situ* studies in this lake a very challenging enterprise. Salinity of the

lake adds additional difficulties for analysis of amino acid distribution through the water column of this lake.

Our preliminary data show that there is a very strong correlation between concentration of amino acids measured by the HPLC method (this method requires many preliminary treatments – desalting procedure, tagging with fluorescent sonds, etc.) and intensity of fluorescence induced by a 224 nm laser measured at different wavebands with a system of photo-multiplier tubes (PMT).

A self-contained instrument, capable of measuring intensity of fluorescence in real time as it goes down through the water column in such lakes, could serve as a good proxy to distinguish between lakes currently having life, or life in the past, or a sterile environment. Such an instrument could be used, not only to measure and monitor the content of amino acids in Dry Valley lakes, but in the future for remote studies of Lake Vostok. When the time comes to study the ocean underneath the ice on Europa, such experience and an autonomous instrument will be the first one to be put into action.

NASA applications for the technology we are developing include miniature, low power, and autonomous *in situ* sensors for detection of a wide range of organic molecules on Europa, Titan, and elsewhere in our solar system. In addition, this sensor technology is suitable for searching and monitoring the general microbial environment of terrestrial lakes and other water bodies.

The significance of this instrument is its ability to detect minute quantities of chemicals related to life and polyaromatic hydrocarbons (PAH) in a small, robust, self-contained, submersible package capable of a wide variety of NASA applications including Antarctic missions and missions to Europa, Titan, and elsewhere. We believe our approach offers the best trade-off of information capture in relation to size, weight, and power consumption of any instrumental combination for *in situ* detection of life.

# Abstract # 12976 - **Organic Signatures of Life in the Marine Subsurface**

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The identification of signatures of life in environmental samples is of great relevance for astrobiological research. One of the largest and virtually unexplored ecosystems on Earth is harbored in the deep marine subsurface. When attempting to extract information on life forms in this ecosystem from organic compounds, we are confronted with similar analytical challenges as in their utilization for the search for extraterrestrial life. In extraterrestrial systems, organic compounds must distinguish materials produced by *biological* vs. *abiological* pathways. By contrast, in the terrestrial subsurface, it is desirable to distinguish *dead* from *alive* prokaryotic matter, and *thermogenically* formed compounds from *biogenic* metabolites. We will discuss two relevant examples, both with significance to the subsurface cycle of hydrocarbon gases: (*i*) intact polar lipids (IPL) as tracers of living prokaryotes in deeply buried sediments to study microbial ecology and diversity; and (*ii*) the distribution and isotopic compositions of low-molecular-weight hydrocarbons.

(*i*) Intact polar lipids, i.e., glyco- and phospholipids from Archaea and Bacteria were examined in surface sediments at active methane seeps (Eel River and Guaymas Basin) and sediments of up to 100 m burial depth from the Peruvian margin. For all sediments, multiple lines of evidence indicate the presence of anaerobic methanotrophic communities. Unlike "normal" coastal surface sediments that exhibit IPL distributions indicative of bacterially dominated microbial communities, IPL distributions in both surface and subsurface samples suggest the predominance of a low-diversity archaeal community that synthesizes primarily tetraether-based glycolipids. The resemblance of IPL distributions in surface and subsurface samples suggests that taxonomically closely related archaea mediate methanotrophy in both settings.

(*ii*) During ODP Leg 201, an expedition dedicated to the study of the marine subsurface biosphere [*1*], a rigorous program was carried out to constrain the distribution of electron acceptors and donors in unprecedented vertical resolution and detail. Concentrations of methane in highly diverse environments sampled span a range of more than five orders of magnitude. Independent of the depositional setting, methane and its larger homologues appear to be primarily derived from biological processes. Importantly, in many

sedimentary settings, in particular those with abundant sulfate, the greatest fraction of hydrocarbon gases (often more than 99%) are present in an association with the solid phase rather than in a dissolved state (Fig. 1). The retention to the solid phase appears to increase with the hydrocarbon's chain length. The observations are consistent with hydrocarbons bound by sorptive interactions to clay minerals. Unlike previous reports that assigned a primarily thermogenic origin to sorbed hydrocarbons [*2*], our data strongly suggest that biological reactions control the distribution of methane and higher molecular weight hydrocarbons ($C_2$-$C_4$) in the range of environmental settings probed during ODP Leg 201. The evidence includes vertical distribution patterns of sorbed gases in relation to other biogeochemical data and isotopic information, i.e., the range of isotopic values and novel patterns of isotopic ordering among hydrocarbon species. Together, the data suggest the possibility of a hitherto unrecognized role of minerals as catalysts in biological methane (hydrocarbon) formation, in particular under conditions otherwise unfavorable for methanogens due to too large competitive pressure for substrates from other prokaryotes.

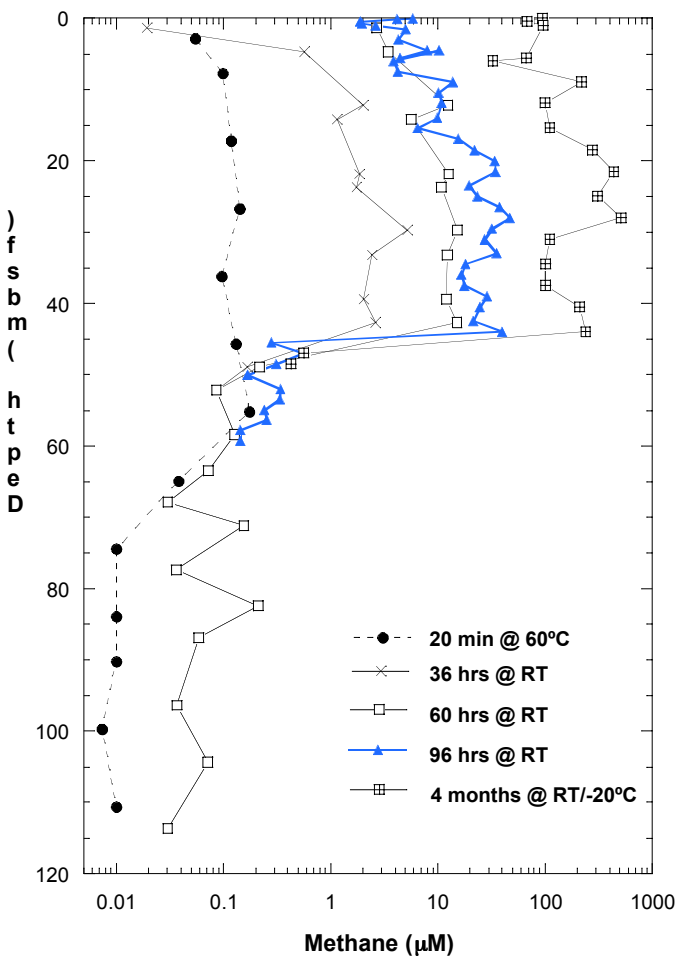


**Figure 1.** Concentrations of total methane (dissolved and sorbed) at ODP Site 1231 resulting fr different extraction times. Sulfate concentrations are close to seawater values through the ent sediment column. The concentrations obtained from the 20-min extraction at 60ºC are viewed as b approximation of the dissolved methane concentration. Although the largest fraction of metha (>99.9%) appears to be sorbed in the upper 50 meter below sea floor, all concentrations a normalized to volumes of interstitial water. 1 μM translates into ~1 μmol/kg dry sediment.

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# Abstract # 12977 - **The Distribution of Volatile Fatty Acids in the Marine Subsurface**

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ODP Leg 201 Shipboard Scientific Party

Volatile fatty acids are key intermediates in microbial food chains that can be produced by either fermentative breakdown of larger organic molecules or by reaction of $CO_2$ and $H_2$ (i.e., acetogenesis). In marine surface sediments, concentrations of acetate are typically the same order of magnitude (1-10 μM) despite significant differences in depositional settings. Limited observations from continental margin settings suggest that the variability in the deep subsurface is greater due to factors such as increased temperature and aceteogenesis becoming more important with increasing burial depth [*1*]. The diverse subsurface environments probed during Ocean Drilling Program (ODP) Leg 201 to the Equatorial Pacific (open ocean) and the Peruvian Margin (coastal upwelling) [*2*] provide an unprecedented opportunity to constrain the factors controlling the distribution of acetate and other volatile fatty acids in relation to environmental factors such as microbial activity, availability of substrates and electron acceptors, surface productivity, among others.

During ODP Leg 201, we generated the most comprehensive data set on distribution of formate, acetate, and lactate in the marine subsurface. Preliminary interpretation suggests that no simple *rule of thumb* (e.g., total organic carbon content, cell numbers, dominant terminal electron acceptor, sedimentation rate, etc.) can be used to predict concentrations of these biologically important compounds. For example, maximum concentrations of acetate were found at the two locations that (on the spectrum of microbial activities observed at Leg 201) occupy the two extremes (Fig. 1). It has been suggested that the concentration of intermediate products of fermentative metabolism such as the volatile fatty acids and hydrogen are controlled by the thermodynamics and energy conservation requirements associated with their catabolic metabolism [cf. *3*]. In addition to the fatty acids, we also analyzed the various terminal electron acceptors and respiration products of volatile fatty acid metabolism. Using these data, we will quantitatively examine to what extent the concentrations of volatile fatty acids in subsurface environments may be controlled by thermodynamics.

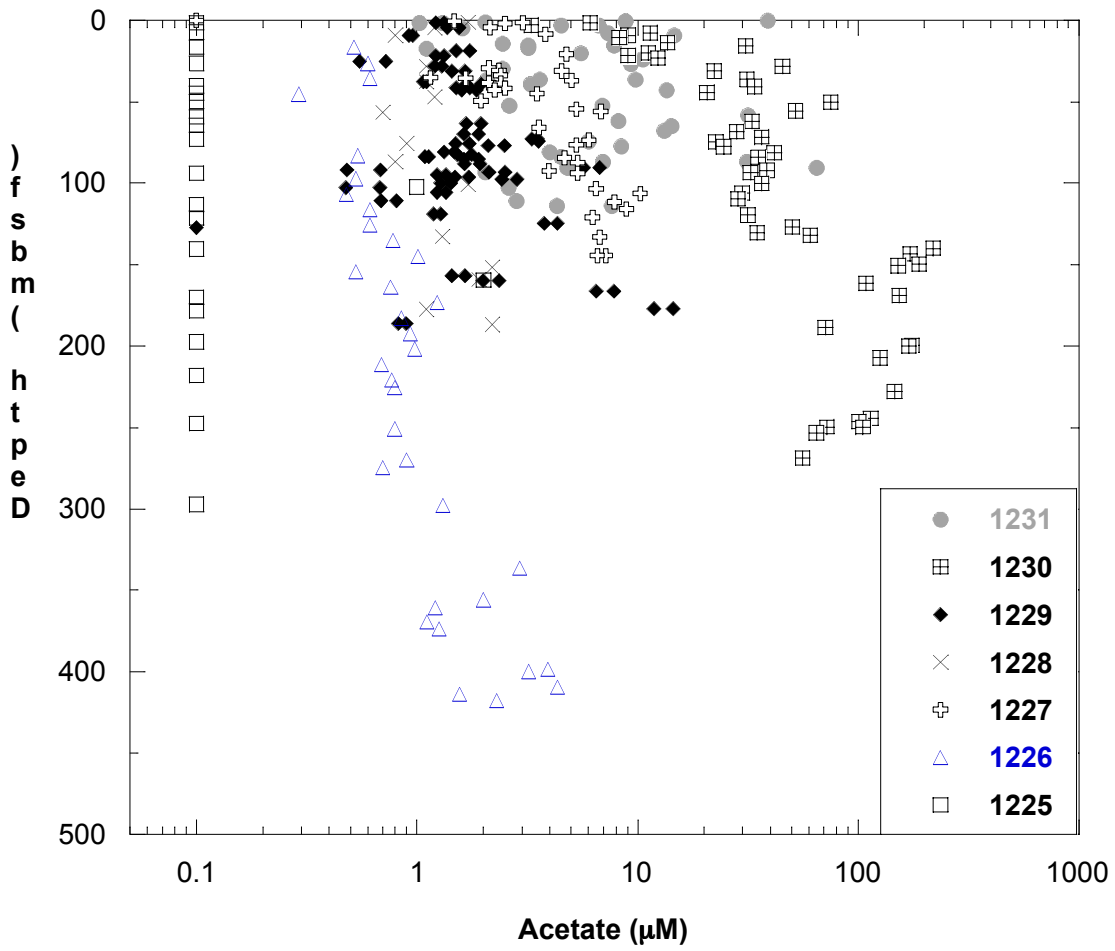


**Fig. 1.** Concentrations of acetate at Ocean Drilling Program Leg 201 locations. Using a protocol based on ion chromatography, the detection limit for acetate was 0.1 µM.

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# Abstract # 12979 - **Hyperspectral Mapping of an Ancient Hydrothermal System**

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Hydrothermal deposits have been suggested as locations of high importance in the search for fossilized forms of ancient biota on Earth [Walter and Des Marais, 1993; Farmer and Des Marais, 1999]. They occur where spatially confined warm ($50^{O}$) to hot ($500^{O}$) fluids are in disequilibrium with their host rocks [Piranjo, 1992]. By the action of such a system, solutes can be concentrated to form ores at certain horizons within or on the surface of a rock body. Such concentrations may be developed where a drop in temperature, pressure, or alteration of the permeability or chemistry of the host rocks created conditions suitable for the solute to be precipitated from the hot fluid.

It has been suggested by many researchers that alteration of host rock in hydrothermal systems typically produces halos of chlorites and white micas [Yang et al., 2000; Cudahy et al., 2002]. Hydrothermal systems can therefore be characterized by layered horizons of altered rocks which are able to be detected using hyperspectral remote sensing surveys [Huntington, 1996]. Such a survey has recently been carried out in the ancient Pilbara craton of Western Australia. The target of this survey was the North Pole Dome, a 600 sq. km region of the Pilbara which underwent alteration by a shallow marine low temperature hydrothermal system [Nijman et al., 1998; Van Kranendonk, 2000]. The survey was conducted over a half day period using the Hymap instrument [Cocks et al., 1998].

The North Pole Dome is home to many stromatolite horizons and has been featured in many papers on the subject [e.g., Walter, 1980; Hoffman et al., 1999]. The opportunity to correlate stromatolite horizons and alteration mineral occurrences is a primary future objective of this project.

The ancient age of the Archean rocks of the North Pole Dome makes them a compelling analog for similarly aged parts of the Martian surface. Hydrothermal deposits are postulated to explain many observed features on Mars [e,g., Gulick, 1998]. Remote surveys of proposed Martian hydrothermal deposits may be conducted in the near future, and comparison to terrestrially-sourced alteration mineral maps will be desirable. The collection, examination, and interpretation of such terrestrial data sets has now begun.

The initial results of this survey will be presented, including:

- initial maps of the alteration zones surrounding the North Pole Dome,
- initial assessments of geological processes causing rock alterations,

- possible linkages with known stromatolite horizons, and
- proposed further research for this data set.

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# Abstract # 13000 - **Direct Assessment of Calcification Rates in Modern Stromatolitic Oncolites**

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Calcifying stromatolitic microbialites, analogs for fossil stromatolites abundant in the Precambrian, occur nowadays in shallow waters of the marine tropical realm and in high calcium lakes and streams. A study of their functional characteristics offers the means to interpret the fossil record and to infer environmental conditions prevalent in early Earth. Stromatolite accretion in marine systems results mostly by the microbial mediation of, first, trapping of preformed carbonate sands, then, binding by organic polymers, and finally, cementation of the loose microbialite by carbonate boring microorganisms. Localized calcification there is though to be a secondary process linked to the activity of sulfate reducing bacteria. We present an experimental study of calcification in fresh-water stromatolitic oncolites in which we used bulk incubation experiments and microsensor profiling of boundary layers at high spatial resolution, to assess the rates and mechanism of microbialite formation. Real-time calcium transport to the system could be monitored and quantified by profiling for $Ca^{2+}$ ions across the benthic boundary layer. Analysis of this data set indicates that intense calcification occurs at maximal instantaneous areal rates around 1- 3 $\mu$mol $Ca^{2+}$ $m^{-2}$ $s^{-1}$, that this process is light-dependent (i.e., photosynthetically driven with close to a 1:1 stoichiometry to oxygen evolution) and that it buffers pH increases. Bulk analyses and mass-balance experiments agree with the microscale determinations and indicate that, on a yearly basis, the gross rate of calcite precipiation in these oncoids is 63 ± 10 g CaCO3 $cm^{-2}$, which is sufficient to account for stromatolite growth without trapping of allochtonous carbonates, and corresponds to a yearly vertical accretion rate of tens of centimeters. This clearly exceeds the accretion rates realized. Important loss factors including calcite dissolution and destructive metazoan grazing are being studied as possible explanations. The significance of these results for paleoenvironmental interpretation will be discussed.

# Abstract # 13006 - **Morphogenesis, Microbial Fossilization Processes, & Biomolecular Community Analysis of Modern Carbonate Oncolites, Mezquites River, Cuatro Cienegas, Mexico**

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The Cuatro Cienegas Basin is located in the Chihuahuan Desert of Central Mexico. It is a fault-bounded extensional basin that is part of the southern Basin and Range Province of Western North America. Bedrock is comprised of a thick sequence of fossiliferous marine limestones of Cretaceous age that are extensively exposed in the adjacent mountains. Quaternary-aged basin floor deposits consist of carbonate-rich alluvial fan deposits, interspersed with aeolian sands (dune fields), salt-pan (playa lake) deposits and carbonate spring, karst pit (posa) deposits. Along the western side of the basin, several hundred spring-fed posas and associated streams emerge from karst pits developed in the underlying limestones. Spring outflows of mildly thermal, alkaline groundwater conjoin to form tributaries which feed several larger trunk streams that drain to the deeper central portions of the basin where they accumulate to form shallow playa lakes and associated evaporite flats. Collectively, the springs and associated outflows provide a diverse range of habitat conditions which support highly diverse microbial communities and many endemic species of invertebrates, fish and aquatic plants. The high biodiversity and endemism of the Cuatro Cienegas Basin have been recognized internationally, and the region has been designated a biological refuge.

The Mezquites River is a major southerly-flowing, spring-fed stream present along the western side of the Cuatro Ciengas Basin. Carbonate oncolites, or ìoncoidsî (spherical stromatolites that accrete by rolling) are present all along the course of the Rio Mezquites, frequently occurring in dense accumulations along channel bottoms, separated by stretches of thick plant cover that enhance the sedimentation of fine sediment. We have been studying the morphogenesis of oncoids and stromatolites present along the Rio Mesquites, documenting their sizes and shapes in relationship to transport distance, depth, flow velocity and rate of sedimentation. Oncoids are typically subspherical, consistent with constant rolling during accretion. Size-frequency distributions for oncoids measured along a one km transect suggests that new oncoids are continually nucleating and accreting all along the course of the river. However, size data also reveals an overall trend of increasing oncoid size with increasing transport distance,

but only up to diameters of ~35 cm. At this size, oncoids appear to stabilize and accrete into composite forms that, with continuing precipitation, grow into irregular microbial bioherms and pavements. The observed trend of rolling transport and accretion of oncoids up to the threshold size for stabilization and bioherm formation, is repeated several times along the course of the river.

Two basic oncoid morphotypes have been recognized within the Rio Mezquites. Morphotype A is a densely-branched form that is highly spherical in shape and present in the deeper portions of channels where higher flow velocities and lower sedimentation rates prevail. Morphotype B is an unbranched form having a more flattened shape and denser microstructure which is associated with broad, shallow basins of lower flow velocity and heightened rates of fine-grained sedimentation. There are substantial differences in the microstructure of the two oncoid morphotypes. Type B is more regularly laminated. There also appears to be differences in the microbiota associated with the two oncoid morphotypes.

SEM observations of surface biofilms and the interior structure for Morphotype A are completed, based on an analysis of critical point dried, field fixed samples. In parallel with the SEM studies, we have also characterized carbonate microstructures and taphonomic (preservational) trends for Morphotype A using light (fluorescence, DIC and polarizing) microscopy. These observations indicate the presence of two communities: 1) A more weakly calcified surficial community, dominated by diatoms and larger (>10 um diameter) filamentous cyanobacteria; and 2) a densely calcified community located at ~ 1-2 mm depth that is dominated by finely-filamentous (2-3 um diameter), vertically-branching bacterial forms. The deeper community persists into the oncoid interior and comprises the major component of the microbial fossil assemblage present there. These observations suggest the existence of a narrow taphonomic window that largely excludes the surface community during fossilization.

Structure of the oncoid bacterial communities has also been examined at the mm-scale using molecular techniques. This was accomplished by decalcifying single oncolite florets with EDTA and then separating them into the two visibly distinct layers described above through micromanipulation. Genomic DNA was isolated from the individual layers and used to fingerprint the microbial communities via denaturing gradient gel electrophoresis (DGGE) separation of PCR-amplified 16S rDNA alleles. The mm-scale molecular analysis revealed that particular cyanobacterial and bacterial populations are confined to either the upper or lower layer of oncolite florets. Individual bands from the DGGE separation were excised and their DNA sequenced for molecular phylogenetic analysis. Microbial community structure determined from this analysis was then compared with that obtained by electron microscopy.

The interdisciplinary ìgeobiologicalî approach we use to study morphogenesis and fossilization processes of the Rio Mezquites oncoids has been yielding important new insights into mechanisms of accretion and preservation of these interesting biomediated sedimentary structures.

# Abstract # 13030 - **Etch Pit Formation and Metal Release During Siderophore-Promoted Dissolution of Iron-Silicate Surfaces**

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The formation of etch pits on mineral surfaces may significantly affect dissolution kinetics by changing surface area and reactivity. Additionally, microbially produced etch pits may have value as Type II biosignatures (Hofmann, 1972). However, before microbial etch pits can be properly identified and interpreted in the rock record, it is necessary to understand the mechanisms that produce them.

Atomic force microscopy (AFM), X-ray photoelectron spectroscopy (XPS), and vertical scanning interferometry (VSI) were used to investigate Fe-silicate surfaces after incubation in buffered growth medium for 46 days with the siderophore desferrioxamine mesylate (DFAM) or with a soil bacterium *Bacillus* sp. These bacteria use Fe as a micronutrient, adhere to surfaces, and release a siderophore that liberates Fe from hornblende when stressed for Fe (Kalinowski et al., 2000). In this work, a glass was synthesized to provide a homogeneous, smooth surface chemically similar to hornblende. The stoichiometry of dissolution of Fe and Al relative to Si was investigated by performing simple calculations using solution data and by comparing atomic ratios (Fe/Si, Al/Si) of incubated surfaces to those of untreated surfaces.

AFM and VSI analyses reveal widespread, small etch pits on the DFAM-exposed surfaces and localized groups of larger etch pits on the bacteria-exposed surfaces (Figures 1-2). Analyses of the filtered solutions revealed negligible Al and Fe release in abiotic control experiments and significant release of Al and Fe in experiments containing DFAM. Low Fe and Al concentrations in filtered solutions from the biotic experiments are consistent with uptake by bacteria or other components of the biomass. XPS results indicate stoichiometric dissolution of Fe with respect to Si from surfaces exposed to DFAM or bacteria. Modeling of the solution chemistry using Geochemist's Workbench 3.0 indicated likely precipitation of FeOOH in the control experiment only. Higher Fe/Si

measured by XPS on the control suggests that FeOOH precipitates may have attached to the surface. Preferential release of Al relative to Si is indicated by the XPS results for all but the DFAM-exposed surface, which shows congruent loss of Al and Si.

Stoichiometric dissolution and widespread pitting on DFAM-exposed surfaces demonstrates the ability of siderophores to promote dissolution and alter surface morphology. Groupings of microbial etch pits may reflect a relationship between pitting and colonization and may be formed by siderophores in the extracellular polymers produced by the bacteria.

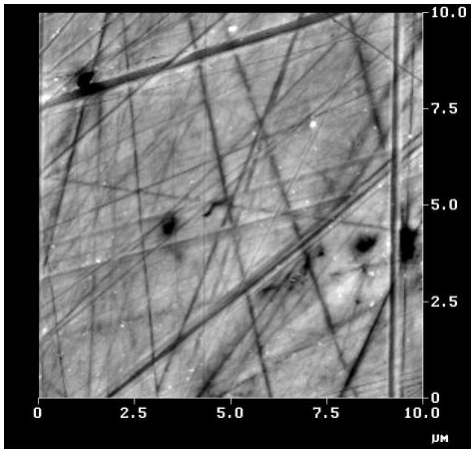


**Figure 1.** AFM image of etch pits formed in the presence of *Bacillus* sp.

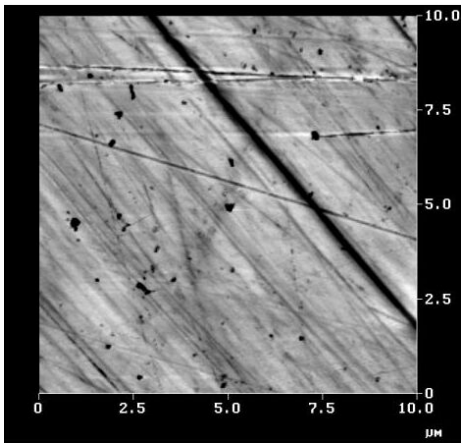


**Figure 2.** AFM image of etch pits formed in the presence of the siderophore DFAM.

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# Abstract # 13056 - **Alternative Life Styles for Extraterrestrial Chemists**

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Life is no more (and no less) than a special type of organic chemistry, one that combines a frequently encountered property of organic molecules (the ability to undergo spontaneous chemical transformation) with an uncommon property (the ability to direct the synthesis of self-copies) in a way that allows new molecular features arising through spontaneous transformation to themselves be copied. Any chemical system having this combination will undergo natural selection, evolving in structure to replicate faster through more efficient use of molecular resources and energy.

Axiomatically, life cannot exist in an environment at thermodynamic equilibrium. If it were, by the second law of thermodynamics, no net chemical transformation would be possible. Beyond this constraint, however, it is difficult to define environmental conditions or chemical structures that are necessary for life. Water is certainly not required for a chemical system to copy itself; in the laboratory, non-aqueous environments appear to support this behavior. Chemical transformations that might support energy and chemical metabolisms are known in environments as acidic as the aerosols in the atmosphere of Venus, or as basic as the atmosphere of Jupiter. Laboratory experiments with analogs of the nucleic acids, proteins, sugars, and lipids show that the particular molecular structures found in terrean life need not be universal, even those with life in water near neutral pH. Indeed, while both water and biological macromolecules are commonly regarded as essential for terrean-like life, water destroys terrean biological macromolecules.

These chemical realities create a complex decision environment as NASA attempts to design instrumentation carried by missions, select places in the solar system to send them, and chose laboratory studies on Earth to provide their scientific support. This poster will review a hierarchy of chemical possibilities and constraints that start with the chemistry of terrean life, and takes steps towards weird and weirder life. We shall consider alternative amino acid building blocks for proteins, alternative building blocks for nucleic acids, alternative structural features of genetic and catalytic molecules, alternative nucleophile-electrophile pairs to support metabolism, non-

polar reaction modes that might support metabolism, non-terrean pH (< 0, >14) and solvent environments, extreme temperature ranges (especially sub-zero Celsius), alternative thermodynamic design for metabolic pathways, alternative dimensionalities of genetic and catalytic molecules, and approaches for achieving isolation other than conventional cellular structures.

Each of these discussions combines experimental and theoretical information. The first involves organic chemical synthesis that creates new forms of chemical matter to ask "What if?" and "Why not?" questions. The second draws on a century of literature in physical organic chemistry to formulate general constraints on the structure and transformation of organic matter to provide constraints on possible Darwinian chemistries in the galaxy.

# Virtual Institute Abstracts

# Abstract # 12548 - **Using Video Conference Technology for Classroom Collaboration**

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By design, the NASA Astrobiology Institute (NAI) is a virtual institution, meaning that the research conducted by the Institute is spread across the world rather than taking place in one centralized area. Because research teams are spread at institutions worldwide, traditional methods of collaborating and teaching aren't appropriate for research conducted through NAI. Instead, electronic collaboration tools such as video conferencing, remote desktop sharing, and virtual meeting rooms are utilized to simulate the traditional gatherings in classroom and meeting room settings.

The Penn State Astrobiology Research Center, in keeping with the mission of NAI, has transformed its Astrobiology Seminar Series class from the traditional classroom setting (where students discuss the local research of Penn State astrobiology professors) to a video conference-based class that utilizes technology to" virtually" welcome additional astrobiology students and professors from the University of Pittsburgh and State University of New York at Stony Brook. Connected via video conference technology, students are taught by and discuss issues with professors and researchers from each of the three collaborating institutions.

This program, designed by Frank Kachurak and Jason Crosby of the Penn State Astrobiology Research Center, is funded by the NASA Astrobiology Institute, Pennsylvania State University, University of Pittsburgh, and State University of New York at Stony Brook. It was set up as a test-pilot program to determine the feasibility of such a class on a weekly basis. To date, the classes have successfully taken place with little difficulty, and both the professors/researchers and the students have warmly welcomed the ability to" be in three places at once."

# Abstract # 12708 - **Video Conferencing and Data Sharing Tools in the Daily Praxis of Science Laboratories**

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The NASA Astrobiology Institute is a virtual institute involving collaborative research conducted by investigators at different institutions and locations. In such situations, the Polycom system can be a powerful tool for facilitating discussion and data sharing between members of the research team.

To date, we have had experience with one application and are currently initiating a second.

In the first situation, an existing principal investigator moved from Michigan State to another institution. In this case, the Polycom system was used in conjunction with an LCD projection system to hold weekly project meetings that included members at the two research sites. The PowerPoint presentations used during the lab meeting were distributed via a shared FTP server. It was found that the Polycom and LCD projection system could be setup in such a way as to successfully bring together the lab members.

Using Polycom over IP can be used for one-on-one connections without quality restrictions. IP can have a large cost advantage. After an initial "breaking in" period, the TV monitor becomes just another participant on the table representing the lab members in the remote location. The Polycom picture shows the presenter and the projection. Laser pointers, however, should be replaced by a pointing instrument so the remote location can easily see what the speaker points out.

In a second application of the technology, we will present initial results of the Polycom ViaVideo project for NAI-MSU. This project takes the collaboration tool to the individual investigator's desktop further reducing reliance on techsupport, scheduling and reducing technology hurdles for the collaboration.

# Abstract # 12902 - **Another Cross-Platform Desktop Collaboration Solution**

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The NAI collaborative infrastructure has been hard to create for several reasons. Affiliates and collaborators are often located very far from main member institutions, the teams use a wide range of operating systems and platforms, and the support situation differs significantly between institutions.

These problems are encountered at all levels of NAI, and they created a challenging situation when designing a collaborative infrastructure at the MBL. The main requirements we set were cross-platform desktop video communication of reasonably high quality, high availability access to several types of data from affiliate institutions as well as field areas, a minimum of maintenance at the main campus, little or no support at field sites, and retained network security at all nodes.

After some research, we settled for a commercial, but cheap, solution which provides acceptable desktop video conferencing between Windows, Macintosh, and Red Hat Linux. As a welcome side-effect, the platform also allowed the integration of several collaborative tools into a customized web portal.

While probably not being applicable to all NAI centers, our solution demonstrates how relatively cheap tools can be combined into a surprisingly flexible system. The poster describes the basic design of the portal, plus the hard- and software used for the implementation of the collaborative toolset.

# Abstract # 12904 - **Cutting the Cord: Experiments in PDA Science Infrastructure**

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During the work with the "virtual NAI," it has repeatedly become clear that "personal hardware" is a crucial component of a successful virtual organization. For example, participation is significantly more likely if personnel can access video conferences from their own personal computers, rather than from a centralized video conference room.

In light of this, we have at MBL begun exploring the possibilities of using handheld computers for collaborative field and lab work.

Because of hardware limitations, the sharing of information will obviously be of a different character than when using full-size computers, but we believe the strengths of the platform (transportability, multimedia capability, etc.) make networked handheld devices a useful complement to already established NAI tools.

The poster describes the philosophy behind the work, hard- and software issues, and ways in which the handheld tools are currently being used.

# Abstract # 12966 - **Journals with NAI Publications: How They Represent NAI**

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Science journal publications are essential for dissemination of research ideas, methods, and results. NAI members publish a large number of journal articles. The publications database for the *NAI Annual Report* and other resources were used to investigate the journals in which NAI papers are published.

- Where are they published?
- What various astrobiology disciplines are represented ?
- What is the impact or influence and use of the journals with NAI articles?

A preliminary investigation with the NAI Year 3 database yielded information on 87 journals containing 253 NAI journal papers in print. Now, an additional study has been done using data from the *NAI Annual Report Year 4 (July 2001-June 2002)*.

Both the NAI Year 3 and Year 4 studies examined journals with NAI articles in print. NAI publication counts and science disciplines were determined for these journals. Additional aspects were explored for each journal using *Journal Citation Reports (JCR*) [1]. This resource has citation data generated for ~5000 science and technology journals indexed by *Science Citation Index*. *JCR* provides the following: 1) Journal Impact Factor, which represents a collective citation frequency for its journal articles, thus a measure of journal use (its impact); and 2) Journal Immediacy Index, which indicates how quickly its journal articles are cited within a publication year (thus providing perspective for cutting-edge research).

General findings from the NAI Year 3 journal study are:

• NAI members are publishing in prestigious journals and in significant numbers. Numerous NAI publications are in *Science* (17), *Nature* (17), and *Proceedings of the National Academy of Sciences, USA* (20). These "big 3" journals have high prestige, reflecting their broad multidisciplinary content and their ratings for Impact Factor and Immediacy Index. The other journals with 8 or more NAI publications are *Astrophysical Journal* (20), *Journal of Geophysical Research* (13), *Geochimica et Cosmochimica Acta* (8), and *Icarus* (8).

• Distribution of NAI articles in various journals reflects the multidisciplinary nature of astrobiology. Journals with 4 or more NAI journal articles represent 12 science disciplines: astronomy & astrophysics, biochemistry, chemistry, geology, microbiology,

environment, geochemistry, geophysics, planetary science, meteoritics, molecular biology, evolution, plus the multidisciplinary science of the "big 3" journals listed above.

Results of the NAI Year 4 (July 2001-June 2002) study of journals with NAI publications are presented at the NAI General Meeting. They are also posted on the NAI website <http://nai.arc.nasa.gov/> in the *About NAI* section.

REFERENCE & DESCRIPTIVE NOTE

[1] *Journal Citation Reports (JCR)*. ISI Web of Knowledge. Thomson Corporation. Philadelphia, PA. Website: <www.isinet.com>
*JCR* is compiled and published by ISI Web of Knowledge, using data from *Science Citation Index*, published by the Institute for Scientific Information (ISI), Philadelphia, PA. Website for more background and free tutorial: <www.isiwebofknowledge.com>

# Abstract # 12971 - **NAI Contributions to NASA Flight Missions**

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One of the long-term objectives of the NASA Astrobiology Institute (NAI) is to provide astrobiology input to the planning and execution of NASA flight missions. The NAI includes many members with diverse technical backgrounds, both scientists and engineers, who can focus their unique expertise on flight mission opportunities. From the foundation of the NAI, we have all agreed that one metric of the success of this Institute should be the degree that astrobiology is infused into and affecting NASA flight missions.

Part of the NAI contribution is provided by the mission-related Focus Groups. The Mars Focus Group has played a critical role as a forum for discussion of martian astrobiology in the context of the current mission planning, for encouraging astrobiologists to participate in a variety of Mars mission teams and planning groups, and especially in focusing attention on the selection of landing sites of high astrobiology potential. The Europa Focus Group has concentrated on long-term science questions concerning Europa and the search for life there. At present, when there are no other active Europa mission studies, this Focus Group plays a unique role in planning and advocating future Europa missions. The new Titan Focus Group will provide a mechanism for building bridges between the Cassini-Huygens flight team and the astrobiology community. Finally, several of the NAI Focus Groups are dealing with scientific issues that will eventually be critical for planning the search for biomarkers on distant planets using the Terrestrial Planet Finder (TPF) and Darwin missions.

The remainder of this abstract summarizes the Year 3 (2000-2001) participation by NAI members in flight missions and mission planning, organized by NAI Project. An NAI Project is defined as any of ~120 major research efforts as identified by the 15 Lead Teams. The source of the data is the reports of the Lead Teams and Focus Groups for Year 3 as submitted to NAI Central.

The NAI Year 3 results are summarized for three groups of missions:

Group #1: Missions Currently Flying or Funded and Under Development (phase B/C/D/E):

Total of 14 missions with 38 related NAI Projects. There are 13 NASA OSS (Office of Space Science) missions plus the International Space Station in this group.

Group #2: Missions Named and Under Active Study (phase A or pre-phase A):

Total of 8 missions with 71 related NAI Projects. These are primarily OSS missions. Most deal with Mars, especially the Mars '09 mission (with its potential for landed astrobiology instruments) and future Mars sample return.

Group #3: Long-Lead Science and Technology for Missions Beyond the Current Planning Horizon (*e.g.*, missions not yet named):

Total of 35 NAI research projects indicate possible connections to future flight programs.

Additional data for NAI Year 4 (2001-2002) will be presented at the NAI General Meeting. Further information on NAI mission involvement can be found on the NAI website <http://nai.arc.nasa.gov>

# Abstract # 12985 - **Identifying the NAI Community**

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The NASA Astrobiology Institute community encompasses approximately 900 people, including:

• scientists who are involved in the 136 research projects of the 15 NAI Lead Teams
• scientists from outside the lead teams who are participating in NAI Focus Groups
• educators, students, and technical and administrative personnel.

In addition, there are five international groups that extend the community worldwide. The community is large, and it is geographically and organizationally diverse.

The boundaries of the NAI community are permeable by design. The virtual institute concept is based on a collaborative research approach, encouraging open participation. In a practical sense, the mechanism for defining the community is simple: the NAI Lead Teams and Focus Groups, through their annual reports to NAI Central, define the community by providing lists of the people involved in their research. In this way, the community is not strictly defined by funding.

There are constraints, imposed by budget, that limit the number of Lead Teams and projects that can be directly funded by the NAI. However, the NAI community is broadened beyond these constraints by encouraging participation based on scientific interaction.

There are many ways in which the concept of community is made real. The biennial NAI General Meetings are one way in which a sense of community is built, and the vision of the Institute as a single entity is clarified. The *NASA Astrobiology Roadmap* establishes common goals; the NAI community supports diverse, and at times, contradictory approaches to achieving those goals. The community is strengthened by the visible presence of the NAI in the international arena of astrobiology; by research connections across NAI teams and with the larger astrobiology community; by the NAI annual reports, website, photo directory, focus groups, shared online tools, and seminar series; and by our working groups in education and public outreach, and information technology.

The nature of this large and diverse community will be illustrated.

# Abstract # 12998 - **Identifying the Social and Technical Requirements for NAI as a Successful Virtual Organization**

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NAI was conceived as an experimental approach to funding science whereby financial support is awarded to multidisciplinary teams selected through a rigorous peer-review process, and these teams are also provided with membership in a "virtual institute." The assumption behind NAI's design is that basic and mission-oriented research in the field of astrobiology, by definition, requires collaboration among scientists representing expertise in an array of disciplines who also are likely to be geographically separated from one another (located at many different universities, research institutes, and NASA Centers). The virtual institute was intended to promote a culture of collaboration among its members and facilitate communication and scientific collaboration utilizing leading edge information tools and technologies. It was assumed that the institutional and technological infrastructure of the virtual institute could promote new opportunities for scientific collaboration, benefiting both NASA and the emerging new field of astrobiology.

The work practices and technologies associated with effective virtual teams and organizations are currently being explored in many sectors of society. However, the social and technical requirements for a successful virtual organization specifically promoting scientific collaboration have not been widely researched. Thus the analytical approach taken, the methods utilized and the lessons learned as NAI continues to evolve are potentially important contributions to the theory and practice of developing successful virtual organizations and to the evolution of new ways for people to work together and conduct science in today's world.

We have followed the standard 4D protocol for systems design projects throughout this development project with NAI. The 4D process steps are: 1) Discovery, 2) Design, 3) Development, and 4) Deployment.

The discovery phase focuses the research exploration by identifying what currently exists to promote virtual collaboration within the organization and what current stakeholders say they need and want in the future. During the discovery phase, we applied

ethnographic research methods including face-to-face interviews and automated online surveys. As a result, a set of sociological and technical criteria were identified that included specific values, attitudes and behaviors important to building a culture of collaboration. It also included key user requirements and software features important to NAI members.

The design phase was made up of focused research and prototyping of possible solutions, based on a list of collaborative tools and technologies identified as highest priority during the discovery phase. This led to the selection of two particular collaborative tools for initial piloting, one for real-time meeting software and one for collaboration and knowledge management software.

The development phase is now being initiated and allows real-world testing of proposed solutions. During the development phase we began these two pilots. The development phase will conclude with an evaluation of pilot outcomes, identification of best collaboration practices, a plan for IT support and development of a deployment plan for the entire NAI population.

The deployment phase is an organized way to disseminate to the entire population the best solutions identified through the previous three phases. The deployment phase will consist of an institute-wide phased roll out accompanied by ongoing evaluation of deployment progress and success.

In this paper we will present the key findings from the discovery and design phase, report on the data emerging from the development phase, and comment on plans for the deployment phase.

# Abstract # 13024 - **Implementation of a Secure Wireless Network for Remote Data Collection Using Open Source Solutions**

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One of the biggest challenges crucial to the implementation of a wireless network is security. We are going to detail a possible solution to create and maintain a secure wireless network at a remote location. The design of our wireless infrastructure will be centered around physical and virtual security, and compatibility with various wireless clients.

Wireless networks are subject to numerous security holes, such as interception and monitoring of network traffic, intentional or incidental jamming of traffic by other wireless devices, attacks on authorized clients by unauthorized clients, brute force attacks against access point passwords and weak encryption methods, and finally, misconfiguration. There are also fundamental weaknesses in the Wireless Encryption Protocol (WEP), as defined by IEEE 802.11b, the standard for WLANs, and these weaknesses exist regardless of the length of the encryption key used. Therefore wireless networks are inherently insecure. Virtual Private Network (VPN) connection could be an acceptable alternative, but for a few types of wireless devices.

Our solution requires authentication from all wireless equipment requesting access to the remote wireless infrastructure. Since one of our main concerns is compatibility and interoperability, the solution does not rely on a specific platform, and works with most network operating systems that can negotiate a wireless network connection.

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