Project Report: Delivery of Organic Materials to Planets

Johnson Space Center
Executive Summary
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In their searches into the history, occurrence, and nature of life, astrobiologists and other scientists have developed a multitude of techniques for locating some of the telltale tracks that ancient microorganisms left behind. The tracks they search for are the residue of complex interactions that characterize those places in nature where the animate and inanimate met in times past. By learning how to recognize and identify those tracks of life, researchers not only advance their understanding of the processes that produced them, but are also able to use the identifying characteristics of life?s traces in their hunt for life signs in the Solar System and in other star systems.

Introduction

The Johnson Space Center (JSC) node of the NASA Astrobiology Institute is the Institute for the Study of Biomarkers, and is part of the Astromaterials Research and Exploration Science division at JSC. Our institute represents a diverse range of disciplines including geology, mineralogy, microbial physiology, geochemistry, organic chemistry, and planetology with a strong focus on the study of actual geological materials. The uniting theme is the study of the interface between biology and planetary materials. Our working assumption is that this interface is almost always the location of complex chemical and physical interactions, and these interactions can create a signature characteristic of biological activity. We refer to such a signature as a biomarker and may include properties of both organic and inorganic matter such as chirality, isotopic fractionation, chemical disequilibrium and physical morphology. While more complex life forms are not excluded, the features related to microbial life are our primary focus. Our aims are three−fold: (1) identify those interactions occurring between a microorganism and its environment that are inherently unique to biological, (2) develop an understanding of the processes behind these interactions, and (3) use this knowledge to develop new instrumentation and techniques to detect extant and/or relic biological activity. In this pursuit we employ a wide variety of micro−analytical techniques, including optical microscopy, scanning and transmission electron microscopy, electron and ion microprobes, secondary ion mass spectrometry (SIMs), laser microprobe mass spectrometry, and micro−raman spectroscopy. In addition, we are developing two new techniques to apply to potential biomarkers (see next section). To help keep diverse types of biomarkers in a systematic context, we have set up a three−part category system of biomarker reliability, and are in the process of assigning various kinds of biomarkers to these categories. While simple in concept, it is quite difficult to assign reliability or probability estimates to specific biomarkers. Yet, this categorization may have considerable value in helping to evaluate new instrument technologies, mission instrument packages, and laboratory allocation of new instrument funds. A manuscript is in preparation for this project.

Projects: Development of New Techniques and Instruments

(1) Microarray Assay for Solar System Exploration (MASSE)

We are developing a revolutionary new instrument called MASSE and intend to propose it for Martian robotic missions (see Fig. 1). It is designed to detect a wide variety of organic compounds such as amino acids, polycyclic aromatic hydrocarbons, nucleic acid, lipids, proteins, hopanes, and even simple molecules such as methane, in both surface and subsurface samples. MASSE will utilize fluorescent−labeled antibodies designed to bind with the specific organic compounds of interest, which can then be detected by laser induced fluorescence. By using micro−array and micro−fluidics technology, it will be possible to simultaneously analyze for thousands of different types of molecules. At present, approximately a dozen different antibodies and antigen combinations have been developed and are being tested. We are actively searching for additional funding in order to develop this technology to the point that a flight instrument is practical. We desire to reduce its size and mass by at least an order of magnitude. Our intent is to propose this instrument for the 2009 Mars Smart Lander mission.

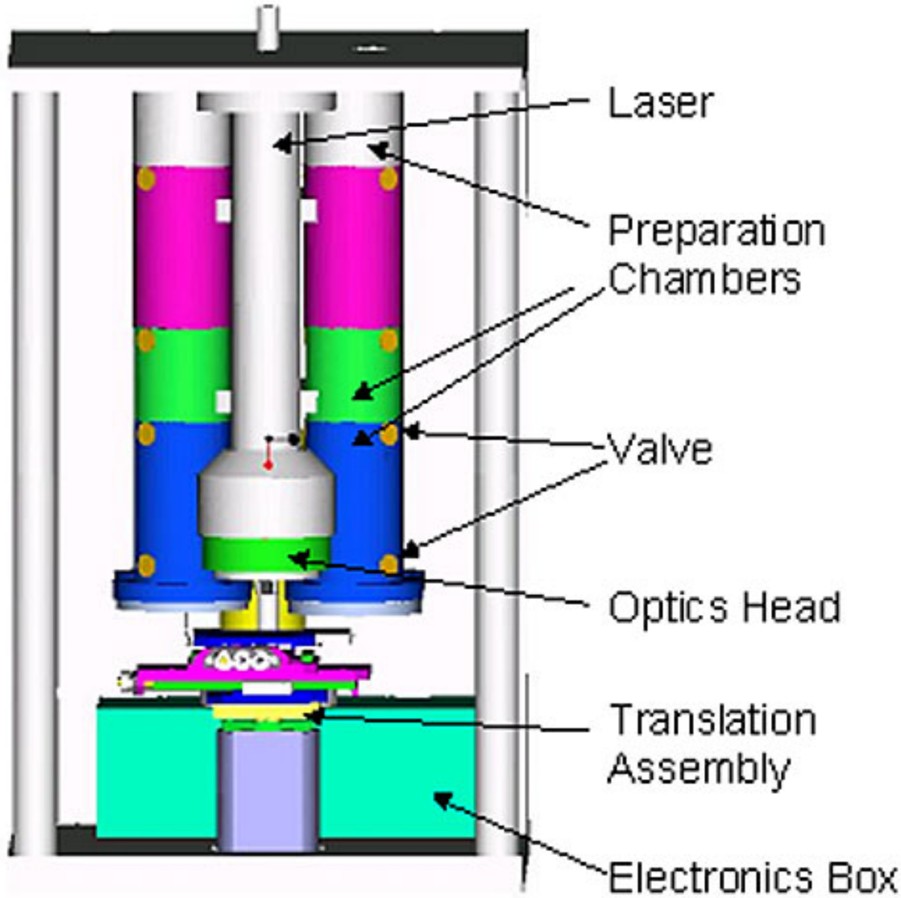

Figure. 1: Computer generated image of MASSE showing basic components. This design is currently being reconfigured using microfluidics in order to drastically reduce size and mass.

(2) Microprobe Two−Step Laser Mass Spectrometry We are developing a microprobe two−step laser mass spectrometer(μL^2MS) for the spatial resolved analysis of complex molecular species on rock substrates. μL^2MS is a powerful technique for spatially resolved analysis of sub−attomole concentrations of complex aromatic or conjugated molecules on heterogeneous and/or microscopic samples. The potential of this instrument will be enhanced by augmentation with fluorescent molecular probe technologies. This involves targeting specific organic monofunctional groups on a sample prior to μL^2MS analysis by selective derivatization with a fluorescent molecular probe. Since a single fluorphor molecule is typically capable of being consecutively cycled through the fluorescence "excitation−emisson" sequence many times, single molecule detection is routinely achievable. 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 subsequent analysis by μL^2MS to determine the nature of the specific molecular species tagged. By using a fluorescent molecular probe to selectively tag particular organic molecules, species ordinarily not amenable to μL^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 quanatitation of the results from μL^2MS analysis. This analysis system is under construction in our JSC laboratory and should be operational by the end of 2002. It will revolutionize the detection that many kinds of organic groups in astromaterials, and should enable great progress in the search for organic biomarkers. We have a plan to test both MASSE and the μL^2MS system on a new suite of archean rocks collected by our team in western Australia. This suite includes the controversial rocks reported by Schopf to contain the world's oldest fossils.

Projects: Studies of Terrestrial Biomarkers

(3) Hematite

Hematite is present in a variety of sedimentary rock types formed at low temperatures. Iron oxides including hematite are known to fossilize and preserve microbes and biofilms. Hematite is present as a secondary alteration mineral formed on Mars in some of the Mars meteorites. Based on terrestrial examples, the Martian hematite site identified by the Thermal Emission Spectrometer (TES) on MGS may be an excellent candidate site for a search for microbial life as an analog to rock varnish (see below). The likely selection of this hematite site as a landing site for one of the 2005 landers makes it imperative to understand possible biogenic occurrences of hematite in terrestrial settings, and that is the objective of this project. We are combining petrographic and electron microscope analysis with electron microprobe and hopefully μL^2MS analysis.

(4) Cold Regions Microbial Ecology and Biomarkers

This unique occurrence is the subject of intense study by our group and we have already identified a number of species using 16S−RNA techniques. The relationship of the microbes to the glacial geology is unique and undocumented in the literature but may have important implications for the search for life on Mars. Terrestrial psychrophiles may be good analogs to possible Martian biota since the present day surface temperature of Mars ranges from ~−40 to +20°C.

(5) Carbonate Globules in Igneous Rocks

Carbonate globules in igneous rocks are mineralogically complex and may be potential recorders of the history of the hydrosphere and atmosphere. Carbonate globules formed in sedimentary environments can be microbially mediated. Terrestrial carbonates from certain environments (e.g., Spitzbergen) may be analogs to the iron−rich carbonate globules in Mars meteorite ALH84001. Other carbonate globules are sometimes found in soil profiles, chert−rich occurrences, lake beds, and evaporate environments. We are analyzing several of these globules for comparison with those found in igneous rocks. We are investigating the role of lipids, and other organic compounds in the formation of carbonate precipitates to help establish criteria for selecting between biogenic precipitation and non−biogenic precipitation of carbonates as well as phosphates.

(6) Rock Varnish

Desert varnish on rocks from southwestern Arizona shows evidence for microbial life. Some rocks in Viking and Pathfinder imaging appear to have a smooth shiny surface with properties similar to terrestrial rock varnish (see hematite above). Varnish on Mars rocks may be a location for either fossil life, extant life, or both and this varnish should be a target for future missions and sample return. Using a combination of techniques, some not previously applied to this sample type, we have been able to find evidence of microbial/fungal activity in every single sample of desert varnish so far examined taken from a variety of locations and climates. Whether the microbial /fungal life is critical to the formation of the varnish or whether it is incidentally trapped is a question yet remaining to be answered. Additional details on each of these projects can be found in the project report or the published papers and abstracts.

Projects: Evaluation of Biomarkers in Martian Meteorites

(7) Martian Meteorite ALH84001

One of the strongest lines of evidence that microbial life once existed on ancient Mars is the presence of tens−of−nanometer sized magnetite [Fe_3O_4] crystals found within carbonate globules and their associated rims in the meteorite. This past year we made major progress in characterizing ALH84001 and biogenic MV−1 magnetite. Approximately one quarter of the ALH84001 magnetites have remarkable morphological and chemical similarities to magnetite particles produced by magnetotactic bacteria strain MV−1, which occur in aquatic habitats on Earth. This similarity has been confirmed using electron tomography. Moreover, these types of magnetite particles are not known or expected to be produced by abiotic means either through geological processes or synthetically in the laboratory. We have therefore argued that these Martian magnetite crystals are in fact magnetofossils. If this is true, such magnetofossils would constitute evidence of the oldest life forms known. In support of this interpretation we note that no experimental studies (including those by Golden et al. (2002) *LPSC and Meteoretical Society Abstracts*) have produced inorganically magnetite identical to those generated by magnetotactic bacteria strain MV−1. Features strongly resembling fossilized microbes and other biogenic materials have also been identified using high−resolution scanning electron microscopy in other Martian meteorites (e.g., Nakhla and Shergotty). Further work is in progress to determine whether the features are biogenic and, if so, of Martian origin. We are also scheduling work on the Martian meteorite Lafayette and on the three new Nakhlites from the Antarctic Survey of Japan. New data by our group also supports the interpretation that an Antarctic Martian meteorite, Elephant Morraine 79001, contains actual Martian soil mixed in with the igneous rock by the impact that ejected this meteorite from the Martian surface. We are in the process of determining the chemistry and some of the mineralogy of this purported Martian soil admixture. A better understanding of this material will help us evaluate the potential for microbial life in Martian soil.

Education and Public Outreach

Our Education and Public Outreach (EPO) program conducted 11 separate projects, including workshops, classroom activity product development, display events, CD production, public presentations, and the support of many undergraduate interns. We helped design and build the major museum exhibit called *Microbes!,* which is touring major U. S. museums. Members of the JSC Astrobiology Institute Team held more than 100 press interviews, TV and radio appearances, and other media events during the past 12 months. In addition, we made dozens of general public presentations and classroom presentations around the world. All Education and Public Outreach projects are documented in the EPO section of this report. We believe we have an exemplary program in this area and we intend to continue its rapid pace.

Collaborations

As indicated in our science project reports, we are continuing collaborations with universities. These collaborations have proven to be valuable and have provided our team with considerable expertise, which we originally lacked, in microbiology, genomics, microbial ecology, and field and laboratory procedures for sampling, culturing, preserving, and working with microbes. We have established a working relationship with the Madrid Center for Astrobiology for work on the MASSE project. They are helping to develop the array technology, and we are working on the antibody−antigen reactions. We will participate in both the final design and in the test program. They will be partners on any flight hardware that is chosen for a mission.

We have put together two teams from historically Black and Hispanic universities and have helped them get independent funding through proposals. We now have an Astrobiology group at Highlands University in New Mexico, which is a subunit of the JSC Astrobiology Institute. Three universities are now included in our active astrobiology group, including the University of Houston − Downtown and Texas Southern University in addition to New Mexico Highlands.

We have a Memorandum of Understanding (MOU) in negotiation between NASA Headquarters and a group at the Geological Survey of Canada, with the specific goal of collaboration in astrobiology and biomarker studies. We expect the MOU to be signed by the end of calendar year 2002. We are also continuing to establish an active partnership with the Carnegie Institution. Overall, we have made considerable progress this year and look forward to more collaboration with other NAI members in the coming year.

Publications

During the past 12 months, the JSC Astrobiology Institute team has published more than 90 scientific papers and abstracts; most of the abstracts were extended. Most of the abstracts were also presented at meetings as talks or posters. In addition to talks associated with the published abstracts, we gave many scientific talks to various meetings and technical groups. This tally does not include education and public outreach talks, which are listed separately.

Additional details for each of our projects can be found in the publications list.