Project Report: Delivery of Organic Materials to Planets

University of California, Los Angeles
Executive Summary
Principal Investigator: Bruce Runnegar

The interests of astrobiology reach outward to the vastness of interstellar space and inward on Earth to the rock−entrapped fossils of microorganisms that lived as long ago as 4 billion years. Because of the range of its endeavors and objectives, astrobiology is best characterized by the diversity of its multiapproach studies in which attempts are made to access fundamental information about the history of life and its progress on Earth, about the likeli;hood of extreaterrestrial life, and about the ways in which cosmic forces function to directly and indirectly influence the probability of life in other planetary systems.

Astrobiology research at UCLA is focused on six main themes: (1) geobiology and geochemistry of early Earth and Mars; (2) extrasolar planetary systems; (3) exploration for life in the Solar System; (4) evolution of Earth's early life; (5) genomic evolution and the Tree of Life; and (6) celestial influences on planetary environments. Over the past year, activities of the NAI Focus Groups and other interactions have allowed us to explore several of these themes in conjunction with partners across the astrobiology community. Mission−oriented achievements include the development of the Artemis Mars Multi−Scout mission concept for the 1 August 2002 proposal deadline; preparation of the airborne SOFIA infrared telescope for first−light observations in 2004; design of the next−generation secondary ion mass spectrometer, now under construction at UCLA, for the analysis of solar wind samples from the GENESIS mission; and active participation in the NAI's Europa, Mars, and Titan Focus Groups.

Education and Public Outreach are ongoing commitments of the UCLA Team. Principal activities include an off−campus bimonthly public lecture, the AstroBiology SuperStar Series; the student−run UCLA AstroBiology Society; a year−long undergraduate general education course, “Origin of the Cosmos and Life.” aimed at nonscience majors; and presentations by members of the UCLA team to various organizations and schools interested in knowing more about astrobiology. For details seehttp://astrobiology.ucla.edu.

A major initiative that combined collaborative research with undergraduate education took place during the winter of 2002. Students who were enrolled in a Rubey Colloquium, "Impacts and the Origin, Evolution, and Extinction of Life" prepared for, and discussed afterward, a highly successful international workshop with the same title, held at UCLA in February. Papers presented at

the Rubey Symposium will appear as a special issue of *Astrobiology* in 2002. Workshop participants enthusiastically supported the proposed NAI Impacts Focus Group.

Geobiology and Geochemistry of Early Earth and Mars

Ion microprobe analyses carried out in the Keck Center for Isotope Geochemistry continue to provide highest quality data for studies of the early Earth and Mars. As an extension of a pilot study aimed at finding the oldest terrestrial materials, some 5,300 individual zircon crystals from the Jack Hills conglomerate in Western Australia have now been dated. Two percent of these are 4.0 billion years old or older, thus providing a source for geochemical evidence that can be used to constrain models of Earth's earliest atmosphere and hydrosphere.

Discovery of substantial mass−independent fractionations of sulfur isotopes in rocks older than about 2.3 billion years, and the demonstration that these effects are produced in gas−phase reactions, implicates the atmosphere in sulfur cycling on early Earth. Understanding these mass−independent isotopic effects requires knowledge of a simpler and better−understood modern system. A new quantitative model for the behavior of mass−independently fractionated oxygen in the lower atmosphere and the stratosphere will lead to models and experiments aimed at a better understanding of the more complex sulfur system.

The possibility that organic matter on the early Earth was made inorganically is being investigated experimentally in a cross−team collaboration with Pennsylvania State University. The interaction of microbes with olivine and other mineral substrates is also being explored.. Preliminary results indicate that microbial activity greatly increases certain inorganic reactions by using reaction products for metabolic purposes.

In a remarkable example of the “emergent” properties of the NASA Astrobiology Institute, involving both cross−team and cross−discipline collaborations, isotopic and phylogenetic evidence has been provided for the anaerobic use of methane by highly organized microbial consortia composed of sulfate−reducing bacteria and methane−consuming Archaea. In a follow−up study, the same techniques were used to expose the complexity of microbial communities involved in methane oxidation in an anoxic cold seep environment.

Extra−Solar Planetary Systems

Last year, UCLA astronomers announced the discovery of a brand new target for extrasolar planet hunters?the Beta Pictoris moving group. These very near (~100 light years away) and very young (~12 million−year−old) stars are siblings of Beta Pic, “Themost famous dust−shrouded star in the sky.” This year, the catalog of youngest, nearest stars has been significantly expanded to ~200 members as a result of ongoing observations of the southern skies at the Siding Springs Observatory, eastern Australia, and at the Lick Observatory, University of California, Santa Cruz. Many of these very young stars are

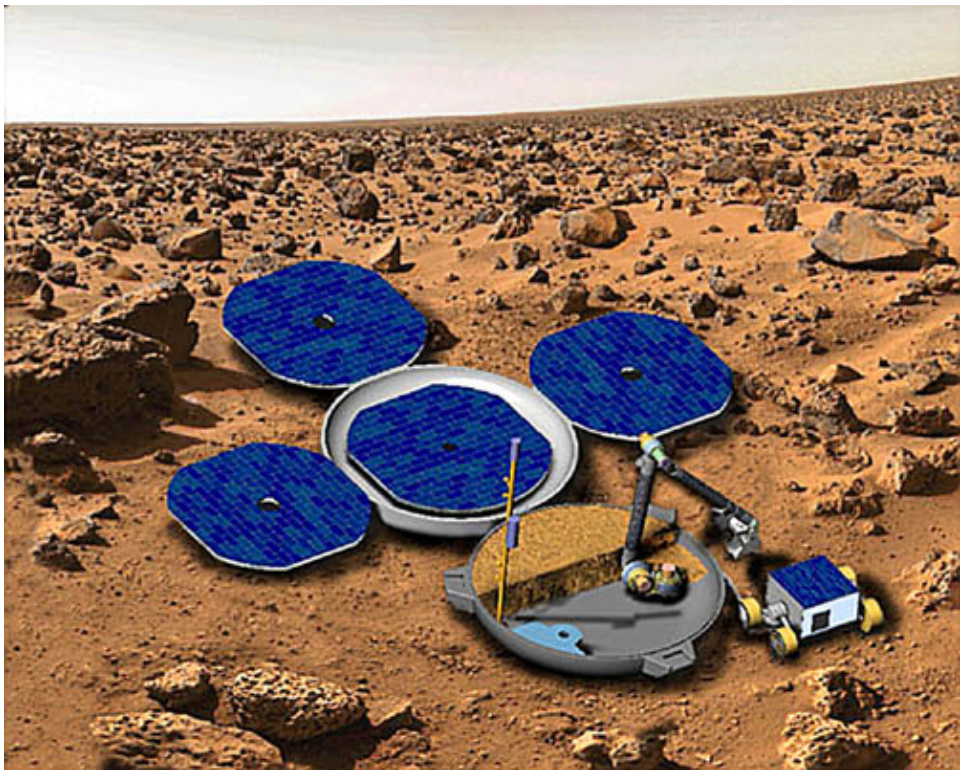
expected to have warm, Jupiter−class planets that should be visible in the thermal infrared using current NASA technology such as the Hubble Space Telescope.

Nearby stars that are surrounded by dust show an infrared excess in the spectrum of their starlight. This is because the dust is warmed by the star and reemits energy at infrared wavelengths. It has been observed that the infrared excess from the nearby star Zeta Leporis is produced within 6 astronomical units (AU) of the star. This result strongly suggested the existence of a circumstellar belt of asteroids, the first one that has been found outside our Solar System. Although this study was not funded by the NAI, it raised the possibility of future collaboration, now under way, between astronomers and cosmochemists. Their combined approach will be to use the early solar nebula as an experimental model for young stellar objects and their dusty circumstellar disks.

Astronomers have studied GG Tau, a young low− mass star surrounded by a massive circumbinary ring, for evidence of dust grain growth beyond that of the interstellar medium. Modeling shows that data obtained with the Hubble Space Telescope can be approximated by interstellar dust rather than by primordial planet−forming material. This means that a better understanding of GG Tau's role in the planet building process will require longer−wavelength studies of scattered light and a better knowledge of the starting material for stellar system construction.

Exploration for Life in the Solar System

The Artemis Multi−Scout project is an advanced Mars mission concept being developed for the 2007 NASA Mars Scout launch opportunity. The goals are to recover the science objectives of the Mars Polar Lander Mission and to scout out diverse landing sites of high scientific interest. The plan is to release several Beagle−style landers, each equipped with a small rover, from an orbiter over a period of one Mars' year. High priority objectives include polar and equatorial layered deposits and atmospheric measurements made from the orbiter and from the landers. The spacecraft will carry a general payload to study geology, climate, and life.



Artist's conception of a Beagle−style lander for the Artemis Multi−Scout mission concept. The trash−can−lid−sized lander opens to expose blue solar panels, a weather mast, a robotic arm, and a tiny solar−powered rover. Image courtesy of the Artemis team.

The presence of an ice−covered ocean on Europa seems certain, but the source of the heat remains unclear. Either Europa is tidally heated like Io or most of the heat comes from the rocky interior. Understanding the nature of the tidal interactions between Jupiter and its inner (Galilean) moons is the best approach to resolving this problem. Ultimately, a Europa orbiter should be able to detect the outward migration of the moon, if tidal energy is being transferred from Jupiter in substantial amounts.

Evolution of Earth's Early Life

Evidence of life on the early Earth (more than 3 billion years ago, or 3 Ba) comes mainly from four criteria: (1) putative microfossils; (2) “light” carbon isotope ratios in sedimentary organic matter; (3) “heavy” carbon isotope ratios in marine limestones; and (4) conical sedimentary structures known as stromatolites. Each of these criteria is being challenged and is in need of further verification.

The chemical composition of the earliest and best candidate microfossils has been established to be carbonaceous for the first time by means of laser−Raman spectral imaging at a microscopic scale. It now becomes important to measure in situ carbon isotope compositions using the ion microprobe technique pioneered at UCLA.

Although the source and biological significance of graphite particles within the 3.8−billion−year−old metamorphic rocks of southwest Greenland remain in question, the sedimentary origin of the host rocks on Akilia island has been demonstrated by detailed field mapping. This contradicts the postulation of a metamorphosed igneous origin for the host quartzites. The 3.83−billion−yearage of the metamorphosed sediments is well established by new zircon dates on cross−cutting granites.

Complex conical layering in a 100−kilometer−wide sedimentary unit known as the Strelley Pool Chert has been considered evidence for the earliest known microbial communities. These 3.5−billion−year−old stromatolites, seen in crosssection or as naturally weathered three−dimensional elements, are striking features of the Western Australian landscape. As such, they are obvious targets for Rovers on Mars. However, it has been argued that abiogenic processes could be responsible for equally complex stromatolites.

The UCLA team is developing quantitative methods to help in understand the evolution of complex surfaces in three dimensions (technically, 2+1 dimensions). Frequency spectra obtained from vertical slices through successive modeled surfaces are compared with spectra obtained from natural outcrops. Complex conical structures can be constructed in this way, but only by introducing properties, such as correlated noise (think of honking in a traffic jam), that require the spatial communication of information as might be carried out by microorganisms.

Until recently, it was thought that the sulfur isotope composition of early Archean seawater, and any sulfide derived from it by reduction of seawater sulfate, was close to Earth's mantle value of 0%. From working on intimately associated sulfate and sulfide minerals from the 3.5−billion−year−old North Pole area of Western Australia, it has been concluded that the broad spread of sulfur isotope values obtained is evidence for the early appearance of bacterial sulfate reduction. However, measurements made at UCLA on similar samples suggest a different interpretation. By measuring the four stable sulfur isotopes (^{32}S, ^{33}S, ^{34}S, ^{36}S) using an ion microprobe, UCLA geochemists were able to show that sedimentary sulfides could not have been made from seawater sulfate. The extra dimension provided by the ion microprobe measurements implicates atmospheric processes in Archean sulfur cycling, an effect which could not be observed when using only the two common isotopes of sulfur (^{32}S and ^{34}S).

Genomic Evolution and the Tree of Life

Trees constructed from whole−genome comparisons using the presence or absence of protein−coding genes continue to resemble those obtained from single genes, notably ribosomal RNA genes. However, the confounding effects of lateral gene transfers and genome size variations are being investigated in a cross−team collaboration that is an activity of the Evolutionary Genomics Focus Group. Although most analyses resolve the Archaea as a stand−alone (monophyletic) group, the presence of DNA−winding proteins (histones) intermediate in crystal structure between the ones in methanogens and eukaryotes lends some support to the idea that some Archaea are more

closely related to eukaryotes than are others.

Whole−genome comparisons yield useful information in different parts of the Tree of Life. A first−order comparison of four, fullysequenced, eukaryote genomes (human, fly, worm, and yeast) fails to support the currently favored “ecdysozoa” hypothesis that all molting animals (arthropods, nematodes, priapulids, etc.) share a common ancestry separate from the non−molting animal phyla.

A study of the complete genome of the microaerophilic archaeal hypothermophile, *Pyrobaculum aerophilum,* provides an explanation for a surprising intolerance of elemental sulfur in this metabolically versatile microorganism: frameshift mutations have disrupted two crucial sulfur−metabolizing genes. This serendipitous discovery suggests that synthetic replacement genes may be used to develop a genetic system for this geobiologically relevant model organism.

Retortamonad flagellates, an anaerobic protist group, have been shown to be closely related to diplomonads such as *Giardia.* (This may imply that all known living eukaryotes are descended from an ancestor that postdated the endosymbiotic event that gave rise to the energy−producing organelle, the mitochondrion. This view is not shared by members of other NAI teams who believe that *Giardia* and its close relatives predated the endosymbiotic event. Others are focusing on genes that have been imported by the endosymbiont and then lost to the host nucleus later on. Whether these genes are cryptic relics of the endosymbiont or were obtained by more recent lateral gene transfers will ultimately arbitrate this cross−team debate.

Looking back toward the RNA world, reorientation of transfer RNA molecules during protein synthesis may indicate how “proofreading” developed as life moved on from the RNA world. One of the goals of the UCLA team is to understand the origins of complexity in the evolution of life. Using genes involved in development, an antecedent of the pituitary gland has been identified in early−diverging metazoans (jellyfish and sponges). Because the pituitary is a relic of an external sense organ used for communication, this implies that the first step in the evolution of the complex sensory and neural organization that characterizes the animal condition predates the last common ancestor of all living animals.

Celestial Influences on Planetary Environments

Two dramatically different terrestrial impact records were investigated. Early Archean impact−produced spherule beds, thicker than that those at the K−T boundary, contain signature chromium isotope ratios indicative of an extraterrestrial source. These global−scale event beds provide direct evidence for the longevity of the late, heavy bombardment of the Earth−Moon system. At the other end of the geological timescale, significant quantities of unmelted meteoritic material have been recovered from the Eltanin impact into the Southern Ocean. Fragments of the impactor were found in seafloor cores on a *Polarstern* expedition.

Mathematicians have been using fast workstations to study the behavior of the Solar System over the past 250 million years An unexpected feature revealed by these months−long calculations was that the inner planets experienced some kind of dynamical transition about 65 million years ago. The coincidence between the time of this transition and that of the K−T impact that extinguished the dinosaurs suggested a possible causal relationship. Perhaps more asteroids were thrown into Earth−crossing orbits by this chaotic change in Solar System dynamics? This possibility is now being investigated by adding suites of asteroids to the Solar System models.

Rubey Colloquium, February 9-10, 2002, UCLA

Attendees at the Rubey Symposium on Impacts and the Origin, Evolution, and Extinction of Life held at UCLA in February, 2002. Undergraduate and graduate students enrolled in the Winter−long Rubey Colloqium are in the front row.