Abstracts from the Astrobiology Science Conference 2004

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Where Do We Come From?

Cosmology And Life

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I will examine recent findings in cosmology and their implications for the emergence of life in the universe and the ultimate fate of life. In particular, I will discuss:

- (i) The requirements for carbon-based life and their dependence on the values of physical constants.
- (ii) The inflationary model and its implications for the existence of a "multiverse."
- (iii) The nature of dark energy and its relation to anthropic considerations.
 - (iv) The possibility of time-varying constants of nature.
 - (v) The question of the potential rarity of intelligent life.

Organics In Space: Molecular Clouds And Comets

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Organic chemistry appears to be a nearly ubiquitous feature of our universe. The principal elements that are essential for terrestrial life (hydrogen, carbon, oxygen, nitrogen, sulfur, and phosphorus) take part in a complex chemistry in the dense interstellar clouds where new stars are forming. More than 100 molecular species, most of them organic and with molecular weights up to twice that of glycine, have been securely identified in these gas clouds. The low temperature kinetics in these regions leads to very large isotopic fractionation, particularly for hydrogen. There is strong evidence for significantly heavier organic molecules, particularly polycyclic aromatics, although precise identification of individual species has not yet been obtained. Moreover, observations suggest that a similar organic chemistry operates in other galaxies throughout the universe, and has done so back to times not long after the Big Bang. In our solar system cometary volatile compositions bear striking similarities to those of interstellar clouds, in both the relative abundances of molecular constituents and in the isotopic fractionation of hydrogen, raising the question of the extent to which comets may preserve interstellar organics. Comets, in turn have supplied the Earth with volatiles, including complex organics, which conceivably played a role in the origin of life.

Constraining Scenarios For The Origin Of Life. Working Backwards, Working Forwards, And Synthesizing Life In The Laboratory

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The origin of life is a puzzle that has long defied traditional hypothesis testing as a research paradigm. Instead, the box containing the historical events that surrounded the emergence of the first chemical systems capable of Darwinian evolution on Earth has been constrained by research that approaches the origins event(s) in four directions, from the big bang forward in time, from the present backwards in time, from missions to the planet, and in the laboratory to understand chemical constraints on molecules that support Darwinian evolution. This talk will cover recent work in the Benner laboratory that has:

(a) Moved forwards in time from small organic molecules known in the cosmos towards nucleic acids that may have been important when life emerged.

- (b) Moved backwards in time from modern microbial organisms to resurrect and analyze ancestral proteins from bacteria that lived perhaps as far back as 2 billion years ago (or more), where the sequences of ancient proteins from extinct bacteria are inferred from the sequences of modern proteins contained in genome sequence databases of modern bacteria.
- (c) Analyzed organic molecules that may be present today in planetary environments, including on Mars, in comets, and on Titan.
- (d) Developed a better understanding of the intimate connection between organic chemistry and Darwinian evolution based on artificial life forms constructed in the laboratory.

From this work, we can reinforce the RNA-first model for the origin of life on Earth, offering evidence that minerals can stabilize ribose formed under prebiotic-like conditions [1]. We also can support the hypothesis that very ancient bacteria were thermophilic, but not hyperthermophilic [2]. We also expect to find substantial amounts of organic molecules having particular structures on the surface of Mars [3]. Last, we have shown that the first artificial genetic alphabet can replicate and evolve just like natural RNA and DNA, but in the laboratory under controlled circumstances where we can understand the process of evolution of unnatural molecules within unnatural contexts [4]. This is a lead to quantitative analyses of a relationship between catalytic activity and nucleic acid structure within nucleic acid sequence space.

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Replicating Vesicles And The Origin Of Life

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Cellular life requires both a genetic polymer to encode heritable information, and compartment boundaries to enable Darwinian evolution by linking genotype to phenotype. However, the earliest genetic molecules and cell membranes must have been able to replicate solely in response to chemical and physical forces, because of the absence of any biochemical machinery. Darwinian evolution and life itself may be viewed as emergent properties of systems that combine self-replicating genetic polymers and compartment boundaries¹.

We have recently described a laboratory demonstration of the replication of membrane vesicles². Membrane growth was based upon the addition of alkaline fatty acid micelles to buffered vesicles, as originally described by Luisi and co-workers³. Extrusion through small pores resulted in vesicle division with minimal loss of contents. Repeated cycles of replication were carried out, with continuity of both membrane and contents from generation to generation. Our current work is aimed at finding more pre-biotically plausible scenarios for vesicle replication.

During the course of the above experiments, we observed that many mineral surfaces catalyze the assembly of micelles into membrane vesicles.

We were able to show that RNA bound to the surface of particles of the clay mineral montmorillonite could become encapsulated within fatty acid vesicles assembled by the clay. Thus, the same mineral surface that has been shown to catalyze the synthesis of RNA can also act to bring together nucleic acids and vesicles, suggesting a possible role for this process in the assembly of early cell-like structures.

More recently we have shown that mixed vesicles consisting of fatty acids and fatty acid-glycerol esters are sufficiently stable in the presence of Mg²+ to allow encapsulated ribozymes to exhibit catalytic activity, suggesting that RNA replication inside such primitive vesicles may be possible. We have also demonstrated that vesicles containing high concentrations of RNA become osmotically swollen, and that this phenomenon provides a driving force for the uptake of additional membrane components. This observation suggests the possibility of a direct coupling, based on physical principles, between RNA replication and vesicle growth. Finally, we have observed that fatty acid vesicles have surprising permeability properties, including greater permeability to ribose than to other aldopentoses. We suggest that primitive membranes may have contributed, along with other mechanisms such as specific catalysis and product stabilization, to simplifying the chemical environment in which early metabolism arose.

In summary, simple pre-biotic membranes are likely to have contributed in many distinct ways to the organization of cellular life from simpler chemical systems.

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Interpreting The Molecular Tree Of Life: Beyond The Textbooks

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Phylogenetic trees based on gene sequences of ribosomal RNAs, and other elements of the nucleic acids 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 so far. The eucaryotic nuclear line of descent clearly is as old as the archaeal line, and evolved in a more complex way. One of the early radiating lines of descent incorporated a cyanobacterium that became the chloroplast, and an -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 Fe2O3 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.

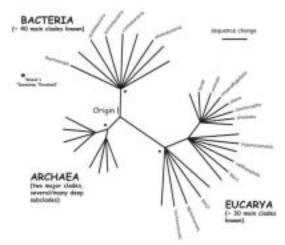


Figure. Diagram of universal phylogenetic tree based on rRNA sequences. (For further information, see Pace, N.R., A molecular view of microbial diversity and the biosphere, Science 276:734-740, 1997.)

The Origin Of Adaptability And Human Beings

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Earth's environments can be characterized in terms of two parameters. First, the consistent (sometimes relatively constant) properties of environments make specific habitats recognizable and measurable, and create a predictable set of adaptive conditions. Second, the dynamic or unstable properties are expressed as significant environmental change and create uncertainty for organisms. Life's history has been shaped by processes that reflect these two parameters – adaptation to specific local habitats, each defined by a particular range of temperature, water, and resource conditions; and evolution of the ability to accommodate to environmental instability. The latter result, or adaptability, can be assessed in three ways: the ability of an organism to persist through substantial environmental change, to spread to new habitats, or to respond in novel ways to its surroundings. Although adaptability pervades biological systems – from the simplest replicating molecules to the most complex forms of life – the processes by which adaptability originates in organisms are not well understood.

The evolution of human beings can be considered an odd and unrepeatable phenomenon, making it difficult to draw general principles of evolution, applicable broadly to life's origin and evolution, from our own evolutionary history. One possible exception is the evolution of adaptability. Dramatic expansion in the hominin ability to interact with environments was expressed as a small population of tropical African apelike creatures eventually gave rise (after a 6-million-year history rife with diversification and extinction) to a single species, Homo sapiens, spread worldwide and capable of unprecedented alteration of Earth's biota and habitats. The idea examined here is that the major features of human evolution – from bipedal behavior to complex cognition and symbolic expression – arose not from the challenges of the African savanna, ice-age Europe, and any other single array of habitat conditions, but rather from the dynamic and unstable qualities of environments.

According to new data from oceans and paleoanthropological sites, the evolution of humans was associated with rising variability in the environments of natural selection, an overall drop in large mammal species diversity, and the persistence of organisms either able to disperse and track a narrow range of habitat conditions or able to expand their means of adaptability. The findings show that (1) adaptability is not well described by the traditional specialist vs. generalist dichotomy, (2) human evolution was characterized by both versatile and specific habitat adaptation, and (3) the traits that define Homo sapiens reflect the "ratcheting up" of adaptability as genetic selection responded to rising environmental variation — a phenomenon described as "variability selection".

One hypothesis to emerge from this case study is that adaptable responses to changing environments require complex interactions in genomal, developmental, and/or behavioral systems, as indicated by the evolution of gene interaction, phenotypic plasticity, and cognition. One implication relevant to astrobiology is that once a genetic lineage originates, even in the simplest form, exposure to environmental variability will create conditions for rapidly evolving a critical degree of genetic and phenotypic complexity if the lineage is to buffer the unstable and unpredictable qualities of its surroundings.

Are We Alone?

Taking the Galactic Planetary Census

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Within the past decade, a new branch of Astronomy—the study of alien planetary systems—has been created essentially from scratch. At last count, over one hundred and twenty extrasolar planets have been detected, and more are being announced each month. The sudden wealth of information from these discoveries has opened up fascinating research areas: Can we increase the efficiency with which planetary systems are detected? Why are the planetary systems discovered thus far so different from our own? Are planetary configurations resembling our own Solar System (with gas giant planets on wide, nearly circular orbits) common within the galaxy? Can terrestrial planets form and survive in orbit around a large fraction of Solar-type stars? This talk will delve into the observational and theoretical basis for our understanding of planetary systems, and I will draw on current trends of thinking among astronomers studying extrasolar planets in order to provide current "best guess" answers to the above questions.

Specific topics to be addressed include, (1) an overview of the current state of the radial velocity and transit searches for planets. I will describe the overall statistics that these searches are achieving, and will project their performance into the next 5-10 years. (2) a discussion of the current exoplanetary "zoo", which includes hot jupiters, eccentric giants, true jovian analogs, and pulsar planets. I will try to emphasize how this apparently disparate collection of planets can be understood within the context of current theoretical ideas regarding planet formation, migration, and orbital evolution. (3) an examination of the known multiple planet systems. When more than one planet can be detected orbiting a particular star, the amount of information that can be leveraged from the data is vastly increased. Multiple-planet systems such as GJ 876 and Upsilon Andromedae are telling us a tremendous amount about the planet formation process.

Sympathy For The Devil: The Case For Life On Venus

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Venus has not traditionally been considered a promising target for Astrobiological exploration. I propose that Venus should be central to such an exploration program for several reasons.

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. Many geological and meteorological processes otherwise active only on Earth at present are currently active on Venus. For example, active volcanism is most likely responsible for maintaining the global cloud cover.

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 Venus presents us with a unique opportunity for putting the bulk properties, evolution and ongoing geochemical processes of Earth in a wider context.

- 2) The possibility of extant life: Venus almost surely once had warm oceans. The evaporation of these oceans, and subsequent escape of hydrogen, most likely resulted in an oxygenated atmosphere. The duration of this phase is poorly understood, but during this time the terrestrial planets were not isolated. Rather, due to frequent impact transport, they represented a continuous environment for early microbial life. Life, once established in the early oceans of Venus, may have migrated to the clouds which, on present day Venus, may represent a habitable niche. Though highly acidic, this aqueous environment enjoys moderate temperatures, surroundings far from chemical equilibrium, and potentially useful radiation fluxes. Observations of unusual chemistry in the clouds, and particle populations that are not well characterized, suggest that this environment must be explored much more fully before biology can be ruled out. A sulphur-based metabolism for cloud-based life on Venus has recently been proposed. While speculative, these arguments, along with the discovery of terrestrial extremophile organisms that might survive in the Venusian clouds, establish the credibility of astrobiological exploration of Venus. Arguments for the possible existence of life on Mars or Europa are, by convention and repetition, seen as more mainstream than arguments for life elsewhere, but their logical status is no different from the plausibility arguments for life on Venus.
- 3) Rare 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. Our planetary exploration, with an increasing focus on Astrobiology, is designed to "follow the water". This is a reasonable strategy but it is based, at best, on an educated guess about life's universals. 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 might include an atmosphere with signs of chemical disequilibrium and active, internally driven cycling of volatile elements between the surface, atmosphere and interior. At present, the two planets we know of which possess these characteristics are Earth and Venus.

Hyperthermophilic Microorganisms - A Possibility For Extraterrestrial Life?

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Hyperthermophilic microorganisms exhibit optimal growth temperatures above 80 °C and represent the upper temperature border of life on our planet. They thrive in continental solfataric areas and submarine hydrothermal systems, where they form complex communities. Hyperthermophiles are highly divers in their morphology (ranging from tiny long rods, to highly irregular cocci, discs or networks) and metabolic properties (1). Most of these organisms are anaerobes which use inorganic redox reactions of molecular hydrogen, carbon dioxide, iron-, nitrogen-, or sulfur compounds as energy sources. These properties enable them to grow in the absence of sunlight and oxygen even on other planets or moons that harbour thermal activity and liquid water.

As a common feature hyperthermophilic Archaea and Bacteria occupy all the short deep lineages close to the root of small subunit ribosomal RNA based phylogenetic trees. By this feature, they appear as the most primitive organisms known so far. Within the Archaea, representatives are found in all orders and families of the Crenarchaeota kingdom (phylum) and within the deep-branching groups of the Euryarchaeota kingdom. A nano-sized symbiont/parasite, obtained from a submarine hydrothermal system, represents a novel kingdom of Archaea, the "Nanoarchaeota" (1). Cells of "Nanoarchaeum equitans" are only 400 nm in diameter (which is in the range of large viruses) and grow attached to the surface of a new hyperthermophilic Archaeum (Ignicoccus). Besides its unique small subunit ribosomal RNA primary structure, "N. equitans" exhibits a genome size of only 490 kb, one of the smallest genomes known so far. Therefore, it can provide extraordinary insights into the evolution of thermophily, of minimal genetic equipment of cells, and of inter-species communications.

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Magnetofossils And ALH84001: Was The Requiem For Life On Mars Premature?

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A good biomarker is difficult to make inorganically. Ideally, it reflects the fingerprints of Darwinian Evolution through Natural Selection. Because iron is an essential trace element in virtually all living organisms, a wide variety of acquisition and storage mechanisms have evolved to meet iron demand. Many of the mechanisms involve precipitation of iron in the form of well-ordered biominerals, including magnetite, greigite, goethite, and lepidocrocite; these provide a set of potential mineral biomarkers that are sometimes preserved in the fossil record.

Because their biological function in magnetotaxis is clearly understood, the small magnetite crystals formed within the magnetosomes of the magnetotactic bacteria show some of the clearest fingerprints of natural selection of any bioinorganic material. Bacteria control the size, shape, composition, crystallinity, and intracellular organization of these particles to optimize their role as 'biological bar magnets'. Indeed, the physical constraints for producing uniformly magnetized and energetically stable magnetic particles (termed "single-domain", SD) are extremely well known; the agreement between this rock magnetic theory and actual HRTEM observations of magnetosomes is stunning. Magnetofossils, the fossil remains of these bacterial magnetosomes, have been studied extensively for the past 25 years, primarily because of their importance to the field of paleomagnetism1; prior to the ALH84001 debate, their biological origin has not been in question. These particles are extremely difficult to produce inorganically. While magnetite was the first 'ferrite' to be discovered over 60 years ago and launched the entire Ferrite Industry (now worth over \$35 billion/year), extensive industrial research on ferrite synthesis failed to produce magnetosome-like magnetite crystals. Because of its cubic crystal symmetry, it is difficult to make elongate magnetite particles in the 30-100 nm size range necessary for SD stability. We do not

So are magnetofossils really present in the ALH84001 carbonate blebs? Some of the individual crystals imaged with HRTEM certainly pass the double-blind 'duck' test (if it quacks like a duck, walks like a duck, and looks like a duck, it just might be a duck ...); the overall population of particles could easily have been extracted from a deep-sea sediment. Particularly impressive are the occasional SD crystals with nearly a 2/1 length/width ratio reported by Thomas-Keprta et al.2 – as of this writing, we have not seen them made in any natural, inorganic process, despite widely publicized claims to the contrary. Unfortunately, many of the arguments have devolved to an unproductive level. Diatribes about crystal nomenclature obscure the fundamental mineralogical problem of producing elongate, nm-scale, defect-free particles of a mineral with cubic symmetry. Additionally, the meteorite has had a complex history; some of the carbonates have been flash heated, and some have not, consistent with the well known localheating effects of shock waves passing through granular materials. The heterogeneity of the sample and importance of the questions demand open, honest sharing of samples and results, as well as caution in blindly applying results from one speck to the entire rock.

Ultimately, the origin of the magnetite can be resolved. Advances in high-resolution electron tomography coupled with non-destructive sample preparation techniques like focused ion beam (FIB) milling offer the promise of elucidating the structure of these objects in situ. Such studies could confirm or refute claims for the presence of intact chains³, which even the most severe critics admit would be definitive evidence for life. In the process, insights into new techniques and crystal growth can benefit both basic research and an important industry.

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- 2 Thomas- Keprta et al., GCA 64 (23), 4049-4081, 2002.
- 3 Friedmann et al., PNAS 98, 2176-2181, 2001.

Life And Death On Icy Worlds

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Life and Death are important on icy worlds. Life-on icy worlds occur in the Solar System and probably throughout the Universe. Among them are Earth (Antarctica, Snowball Earth) and probably one or more of the Icy Moons of Jupiter (JIMs). These worlds provide the three things life requires—the chemicals of life, energy to drive it, and habitats to support it. Death also occurs on icy worlds resulting in potential preservation of life forms and products as fossils that may have a story of the origin and evolution of life on the icy world.

On Earth's current and past icy worlds, life abounded. It lives in close association with ice-shelves and sea ice in Antarctica and the Arctic icy worlds. There life lives easily in a wide variety of sub-ice, inter-ice, and surficial ice habitats (Table). Earth's fossil record shows that life endured the Neoproterozoic Snowball Earth, covered entirely or substantially by ice; life was not eliminated and opportunities continued over tens of millions of years for its existence. Life has no problem with ice.

The icy worlds of Earth provide analogues for others in the Solar System. (Table). While evidence for life on JIMs is lacking, the inferred sub-ice oceans suggest that habitats for life may be abundant and diverse. Life present there may not resemble any on Earth, but all life requires resources that are heterogeneously distributed in habitats. These resources may include energy, substrates, primary production, prey, shelter, among others. Thus, a search strategy for JIMs, Europa in particular, is to define probable habitats by analogy with Earth's ice habitats (Table). At least 13 habitats may exist on JIMs, but most are not accessible at the surface. A search strategy therefore must identify sites where the habitats have been transported to and incorporated into the icy crust and exposed at the surface.

Death and the fate of the bodies or biochemicals, processes encapsulated in the term taphonomy, then become important. Death, as ancient and modern fossils of individuals, assemblages and biomarkers, is also likely to be preserved on icy worlds through various taphonomic processes well known on Earth in both icy and non-icy environments. These processes include transportation of sub-ice habitats to the icy crust, extrusion of water into or onto the icy crust, and freezing of ice habitats into the crust. The last taphonomic stage is then the exposure of these preserved habitats at the surface or near-surface of a moon or planet. Various geologic and glaciologic processes, such as cracking, fissuring, melting, tilting, folding, and faulting may expose the habitats where exploration is possible.

Taphonomic and biogeographic inferences based on current images of icy world surfaces provide a search strategy for proposed future exploration of JIMs. The exploration sites need to be identified through geologic study with respect to habitat taphonomy, and then detailed imaging and analyses need to be acquired of those sites from spacecraft carrying high resolution

instruments. A later exploration stage will be to contact the surface sites with probes, impactors, penetrators, "ice clippers", and or rovers that can search for both life and death on icy worlds

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Astrobiology And The Jupiter Icy Moons Orbiter (JIMO): Results Of The NASA Science Definition Team

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The Jupiter Icy Moons Orbiter (JIMO) is planned as the first in a series of missions in the NASA Prometheus project. JIMO would use nuclear-electric propulsion and nuclear power systems to enable unprecedented exploration in the outer solar system. A NASA Science Definition Team for JIMO, cochaired by T, Johnson and R. Greeley, consisted of 38 scientists and was appointed to formulate the science objectives for the mission. The SDT drew on previous studies by NASA, various National Academy of Sciences reports, and results from a community-wide "Forum" held in the summer of 2003 and attended by 130 scientists.

SDT recommendations include a mission statement for JIMO to: Explore the icy moons of Jupiter and determine their habitability in the context of the Jupiter system, which includes three crosscutting themes: Oceans (finding their locations, studying the structure of their icy crusts, and assessing active internal processes), Astrobiology (determining the types of volatiles and organics on and near the surfaces, and the processes involved in their formation and modification), and Jovian System Interactions (studying the atmospheres of Jupiter and the satellites and the interactions among Jupiter, its magnetosphere, and the surfaces and interiors of the satellites, including Io).

The SDT has formulated four equally important goals for the JIMO mission. Within each goal, the objectives, investigations and measurements were identified and prioritized. The goals and the means to meet them are summarized as follow:

•Surface Geology and Geochemistry Goal: to determine the evolution and present state of the Galilean satellite surfaces and subsurfaces, and the processes affecting them.

•Interior science Goal: to determine the interior structures of the icy satellites in relation to the formation and history of the Jupiter system, and the potential "habitability" of the moons.

•Astrobiology Goal: to search for signs of past and present life and to characterize the habitability of the Jovian moons with emphasis on Europa.

•Jupiter System Science Goal: to determine how the components of the Jovian system operate and interact, leading to the diverse and possibly habitable environments of the icy moons. The SDT recommended that JIMO include a small surface package for Europa, termed the Europa Surface Science Package (ESSP), because many high-priority measurements can be made only from the surface. These measurements are grouped into three science areas: 1) Astrobiology, in which measurements of organic materials and searches for patterns indicative of biology must be made in situ, 2) Geophysics, in which acoustic/seismic measurements made from the surface enable constraints to be placed on the interpretations of data taken from orbit regarding the presence of liquid water and the structure of the icy crust, and 3) Geology-geochemistry in which in situ measurements of the surface provide ground truth for remote sensing data and insight into the structure of the surface at sub-meter scales. Astrobiology and geophysical measurements are of highest priority; while geology-chemistry measurements are of lower priority.

In summary, the Jupiter Icy Moons Orbiter will afford an unparalleled opportunity to carry the exploration of the Jupiter System and Astrobiology to an unprecedented level. The large investment in resources (including funds, time, and intellect) for JIMO demand that there be a commensurately high scientific return as recommended by the SDT. Such a scientific program could be achieved by JIMO's large mass-delivery, high data rates, and extraordinary power for instruments, previously unavailable for deep space missions.

Uncovering Extraterrestrial Intelligence: When Will it Happen, and What Will We Find?

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It's been four decades since the first modern SETI experiment, and researchers have still not recorded a confirmed peep from the cosmos. But new telescopes, improved backend hardware, and novel ways of looking for signals are all accelerating our scrutiny of the sky. While Project Phoenix has carefully examined ~500 nearby, Sun-like star systems over the course of 8 years, the Allen Telescope Array, now under construction, will be able to exceed this number of "targets" in its first year of full operation. Thereafter, its reconnaissance of star systems can be expected to speed up in accordance with Moore's Law, an empirically observed, exponential growth in the capabilities of digital electronics. Within two dozen years, the number of targets examined by the Allen Telescope Array will tally in the millions.

In this presentation, we'll discuss what implications this, and other, new instruments and developments in astronomy have on the timeline for detecting a signal. In addition, we will provoke the audience with some speculative ideas about what we might learn from such a discovery.

Klein Lecture

Science Results From The MER Athena Science Investigation At Gusev Crater And Meridiani Planum

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The Mars Exploration Rover Spirit landed in Gusev Crater on January 4 (UTC), 2004. It was followed 21 days later by the rover Opportunity, which landed on Meridiani Planum.

The landing site at Gusev crater lies on a flat, rock-strewn plain. The rocks at the site are mostly angular, and some clearly appear to contain vesicles. The rock at Gusev that has been studied best to date has been named "Adirondack". In its surface texture, Adirondack appears to be dense, fine-grained and sand-blasted. Pancam images of Adirondack show evidence for a surface coating of some sort, perhaps dominated by dust. Three sets of measurements have been made on Adirondack with the full set of payload instruments: one of the natural rock surface, one of the same location after being brushed by the RAT, and one of the same location after removal of 2-3 mm of rock by the RAT. The concentration of presumably dust-borne elements like sulfur and chlorine diminished significantly with brushing, and diminished dramatically with grinding. All of the observations of Adirondack are consistent with it being an essentially unweathered olivine and magnetite-bearing, low-silica basalt.

The only soil at Gusev that has been investigated in detail so far is one dominated by fairly coarse (100-300 micron) grains that have the appearance and behavior of well-cemented agglomerates. APXS spectra of this soil are similar to those of soils found at the Viking and Pathfinder sites. Mössbauer spectra show two ferrous doublets and a ferric doublet, with the stronger ferrous doublet assigned to olivine. Mini-TES spectra have been acquired for soils surrounding the Spirit landing site, and show spectra nearly identical to globally averaged soil viewed by the TES instrument on Mars Global Surveyor. This includes identification of a small amount (a few percent) of carbonate.

The landing site at Meridiani Planum lies inside an impact crater that

is roughly 20 meters in diameter. The lander came to rest on soil that fills most of the crater. An outcrop of layered bedrock is exposed on the crater wall. The landing site was selected partly because coarse gray hematite was expected to be present on the basis of orbital data. Mini-TES data have confirmed the presence of this hematite in the soil.

The soil within the crater has several components. Microscopic images of undisturbed surface soil show that one component is fine (~100 micron) sand. Mössbauer spectra of the sand show two ferrous doublets (one of them due to olivine), a ferric doublet, and a weak magnetic sextet. APXS and Mini-TES data on this sand are consistent with a composition dominated by basalt.

Another component of the soil consists of coarse (several mm) granules. These range in shape from subangular to rounded to remarkably spherical. In some locations, granules have been pressed down into the soil by the impact of the lander's airbags. At those locations the concentration of hematite as determined by Mini-TES is sharply reduced, suggesting that at least some of the granules are hematite-bearing.

The bedrock outcrop is roughly 12 meters long and up to half a meter in height. It is finely laminated, with typical layer thicknesses of only a few mm. The texture of the outcrop as viewed in microscopic images suggests that it is fine-grained, with well-expressed structure that is revealed by varying degrees of mechanical abrasion of layers of varying induration. Initial APXS results on this fine-grained matrix suggest an unusual composition, including sulfur concentrations significantly higher than any observed elsewhere on Mars.

Embedded within the outcrop and weathering out of it are highly spherical granules with diameters of several mm. The visible to near-IR spectral properties of these embedded spherical granules, as determined by Pancam, are distinctly different from those of the matrix in which they are embedded.

The highest Mini-TES-derived concentrations of hematite are found in soil and possible rock units above the bedrock outcrop that have not been visited by the rover as of this writing. Future activities include climbing out of the crater and investigating this hematite-rich material.

Where Are We Going? The Earth

The Dynamics Of Global Biodiversity Gradients: Insights From The Fossil Record

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The most striking biodiversity pattern on planet Earth is the latitudinal diversity gradient (LDG), with maximum richness of species, higher taxa, and body plans near the equator and a stepwise decline in all three metrics towards the poles¹. Correlations across latitude between diversity and mean annual temperature (or other covariates with solar energy input) occur in a wide variety of marine and land-based taxa, suggesting that energy or a closely related variable shapes these pervasive trends on a global scale². However, this static picture tells us little of the dynamics underlying the origin and maintenance of this gradient. In the absence of a dynamical, deep-time perspective, most analyses make the simplifying assumption that taxa originated in the climate zones where they currently occur (e.g. tropical, temperate or polar), and the LDG is commonly viewed as the net result of in-situ origination and extinction ^{3,4}: the tropics might be a generator of biodiversity (the tropics-as-cradle hypothesis) or an accumulator of biodiversity (the tropics-as-museum hypothesis). In a preliminary analysis that begins to integrate the fossil record of marine bivalves - chosen for their high diversity, excellent fossil record and increasingly standardized taxonomy5 -- with the group's present-day biogeography, we show that the cradle vs museum debate hinges on a false dichotomy: the tropics are both the primary diversity source and accumulator. Taxa first appear in the tropics and then expand outwards without losing tropical occupancy, while the high latitudes are primarily a diversity sink. We thus present a dynamic model for the LDG, in which the tropics are so rich today not only because they are the source of young taxa, but because the geographic ranges of old, mostly widespread taxa overlap there with young and spatially restricted taxa. Under this model, the greater median geologic age of high-latitude assemblages reflects a lack of origination rather than a simple, strong latitudinal difference in extinction rates.

This dynamic model for the deployment of biodiversity provides a new framework for spatially explicit analyses of the evolutionary effects of mass extinctions and recoveries. Some mass extinctions are arguably focused on the tropics (e.g. end-Ordovician⁶), and these should reduce the

amplitude of the LDG; the constituents of recovery faunas will likely be derived preferentially from high latitudes (as seen for the post-Ordovician recovery), or be random with respect to the LDG. Other extinction events show no latitudinal trend in intensity (e.g. the end-Cretaceous event⁷), so that the LDG will be reset at a lower level but tends to retain its amplitude; probabilistically, the constituents of recovery faunas should mainly be derived from low latitudes (as seen for important molluscan lineages during the post-Cretaceous recovery). The jury is still out on whether the different extinction patterns, and corresponding spatial dynamics of recovery, are related to impact vs earthbound forcing mechanisms. In any case, analyses of diversity gradients in the dynamical context provided by the fossil record permits a deeper understanding of the general principles underlying the dynamics shaping global diversity patterns, and will provide a vehicle for modeling biotic responses to future climate changes.

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The Meaning Of Life: Astrobiology And Society

The Meaning Of Life: Astrobiology And Society

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The National Aeronautics and Space Act of 1958 charges NASA with eight objectives, including "the establishment of long-range studies of the potential benefits to be gained from, the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes." The new space exploration vision distributed after President Bush's January 14, 2004 announcement also noted that "exploration of the solar system will be guided by compelling questions of scientific and societal importance." In line with these pronouncements, the NASA History Office has recently placed the societal implications of space exploration under its purview.

Space exploration has societal implications at many levels, ranging from commercial spinoffs to applications satellites, and humanity's self-image based on the view of Earth from the Moon, Voyager's pale blue dot image from the edge of the solar system, and our place in the universe based on our newfound knowledge of cosmic evolution. But perhaps no area of space exploration has more potential for societal implications than astrobiology. This was recognized by astrobiology's founders when they stated in the third of 4 operating principles of the Astrobiology Roadmap that "Astrobiology recognizes a broad societal interest in our subject, especially in areas such as the search for extraterrestrial life and the potential to engineer new life forms adapted to live on other worlds."

Indeed, astrobiology's three overarching questions, the origins and evolution of life, the distribution of life in the universe, and the future of life on Earth and beyond, are among the most profound that a society can ask (Dick, 2000). Answers to those questions would reveal our place in the history of life, whether life is a cosmic imperative or a fluke, and (in the case of discovery of extraterrestrial intelligence) whether our systems of science, philosophy, epistemology and theology are parochial or universal. Questions of planetary protection, terraforming, bioengineering, artificial life, artificial intelligence and space colonization are all astrobiological questions of great importance to society. The possible implications of all these questions should be systematically studied, no less than the societal and ethical implications of the Human Genome Project have been substantially studied.

The reaction to the claimed detection of fossil life in Mars rock ALH84001, which brought serious discussions at the highest levels of government, is one example of a historical case study of the societal implications of astrobiology. If putative fossil life caused such a reaction, the discovery of microbial life, much less intelligent life, would have an even greater effect. In general the humanities and social sciences can inform discussion of societal implications of astrobiology as part of the need to improve dialogue between science and society. In a broader sense, it is well to remember that cosmic evolution includes not only astronomical and biological evolution, but also cultural evolution, astrobiology's third great

question of the future of life on Earth and beyond (Dick, 2003).

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Ethics and Exploration

Ethics Of Exploration – Engaging Public Interest And Concern

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Astrobiology is an ambitious endeavor to address fundamental scientific questions concerning life's origin, extent and future. From its inception the Astrobiology community has recognized "a broad societal interest in our subject, especially in areas such as the search for extraterrestrial life and the potential to engineer new life forms adapted to live on other worlds" (NASA Astrobiology Roadmap, 1999). This societal interest is a reflection in part of the philosophical, theological, and ethical questions that the research and discoveries of the Astrobiology program may raise. Addressing these questions will require the scientific community to engage with a broader academic and public community.

Continued public interest in and support of space exploration will demand a serious and responsible consideration of ethical issues by a community that extends beyond scientists. The participation of scientists in this effort is crucial, however, so that the discussion of ethical issues is grounded in a clear understanding of the science involved. The scientific community recognizes that successful space exploration programs involve long term research efforts and missions for which advanced preparation is necessary. Exploring the ethical implications of space exploration with a broader academic and public community is equally deserving of advanced preparation. Convening an "Ethics of Exploration" session at ABSciCon is another step in addressing this need.

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History and the Ethics of Exploration

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The concepts of "discovery" and "exploration" are frequently found throughout space literature, most recently in NASA's new "Vision for Space Exploration," billed as "A new spirit of discovery" published in February, 2004. The issue of the ethics of space exploration is seldom raised in the context of such programs, though to some extent it is inherent in the very decision to explore. Whether considered as a general question or more specifically focused on any particular target such as Mars, the space ethics question can profit greatly by analogy from the history of terrestrial exploration. Such issues fall into at least two broad categories: primary questions such as should we explore, why we explore, and how we explore, and secondary questions bearing on the consequences of exploration once undertaken

The primary questions of exploration are among the most important any society can ask. Whether or not a society chooses to explore - to what extent, with what resources, and toward what goals – is a reflection of the society's priorities. It is a decision many societies have made in the affirmative in cases such as Columbus, Captain Cook, Lewis and Clark, Darwin and the Beagle, the U. S. Exploring Expedition, and by those countries involved in the Space Age to a greater or lesser extent. The motivations have been varied: curiosity and the search for knowledge, the promise of riches, population expansion, and nationalism. These motivations have always had to be balanced against issues that might have had a more immediate benefit to society, an ethical choice. In other cases, such as 15th century China, societies have pulled back from exploration, with consequences well known to history. Questions such as funding priorities, risk aversion and self-image enter into exploration decisions. In my view, exploration is justified based on the search for knowledge alone; as a policy issue with many competing interests, the decision must rest with the society and its leadership.

A variety of consequences, both intended and unintended, inevitably flow from exploration. Columbus discovered a new world, but has sometimes been seen as initiating the decimation of the native population. Cortez and the Aztecs is another well-known episode with fatal cultural consequences. Culture clashes are common in exploration, no matter what the intent. In space exploration, culture clash will not be an issue, at least in the short term until we make contact with extraterrestrial intelligence or begin to explore other star systems. Solar system exploration raises important questions at a different level: to what extent should space be militarized; how do we dead with low life forms on Mars; what are the consequences of terraforming a planet, especially one with life; how do we avoid back contamination of Earth, and so on. These questions also have their earthly analogs in fields such as environmental ethics.

Should humans cease exploration for fear of the consequences? In my view humans should explore, but should learn the lessons of history, anticipate the consequences to the extent possible, and prepare to meet them as predicted or in real time as they arise. In accordance with the 1958 National Aeronautics and Space Act, NASA should engage a variety of experts in the humanities, philosophy and the social sciences to contribute to this effort.

Planetary Protection – The Ethics Of Sample Return

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The first extraterrestrial samples returned by a space mission were the rocks and soils collected on the Moon by the Apollo astronauts and the Soviet Luna missions from 1969 – 1976. No extraterrestrial material has been brought to Earth by spacecraft since then. However, three sample return missions are currently in space. The Genesis mission will return to Earth in September, 2004 carrying a two-year collection of atoms from the solar wind. The Stardust spacecraft recently flew past the head of comet, and will bring samples of comet and interstellar dust to Earth in January 2006. The Japanese Hayabusa mission is scheduled to sample an asteroid and return to Earth in 2007. Detailed proposals have been prepared for missions to sample the lunar farside, the surface of a comet, and multiple asteroids, as well as the satellites and atmospheric dust of Mars. The next decade may also witness one or more missions to sample the surface of Mars, possibly in areas with strong biological potential.

This is an appropriate time to address the scientific, political and ethical implications of sample return. Simply stated, how do we ethically embark on a series of missions to bring samples of "elsewhere" into Earth's biosphere?

The Philosophers Are Coming!

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When philosophers become involved in a scientific discipline, one of the first questions they confront is, "Why?" I want to take a brief look at two of the most basic skills philosophers can bring to astrobiology, and then show how they can have practical consequences. First, philosophers deal with questions which are not empirically tractable and have thereby developed a "persistence in the face of perplexity". This is extremely useful in an emerging discipline like astrobiology where one can not ignore basic philosophical questions like "What is life?" Second, philosophers are quite good at clarifying murky concepts. When venturing beyond empirical data, scientists often bring in unnecessary and unnoticed conceptual baggage which can obstruct constructive consensus.

For example, astrobiology raises a number of ethical questions. Many empirically oriented scientists despair of ever finding a single universal answer to ethical questions. This can lead to a kind of ethical relativism where ethical views are thought to be nothing more than social convention or personal opinion. However, a little reflection reveals that this position is not consistent - if ethics were mere personal opinion, then it could not possibly have the character we all think it does. At the other extreme, scientists sometimes develop the idea that being ethical means rejecting any suggestion that ethical values ultimately derive from human interests. This is certainly not necessary, as it's entirely possible to defend a robust environmental ethic without arguing that, say, Martian microbes have intrinsic moral value.

A Christian Ethical Perspective On Space Exploration

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The recent missions to Mars – and the resulting photographs of the Martian surface – have renewed popular interest and excitement concerning space

exploration. As we continue to learn more about Mars, this renewed popular interest will continue to build. Inevitably, public discourse will begin to emerge concerning the space program itself, including the ethics of space exploration. Within the context of American pluralism, this public discourse concerning space exploration will be informed by a rich diversity of viewpoints, including a variety of religious perspectives.

In this presentation, I will explore the ethics of space exploration from a Christian perspective. I will begin with a brief explanation of the resources that a Christian ethicist has to draw from when thinking about space exploration. In addition to scientific information, these resources include scripture, tradition, and experience. Following this introduction, I will outline the possibilities for a Christian ethic of space exploration. Two core claims shape this Christian ethic. First, all extraterrestrial life must be highly valued as a part of God's good creation. Second, the search for and transportation of extraterrestrial life must be informed by a caring concern for the well-being and flourishing of the new life-forms. In addition to ethical implications concerning the search for and transportation of extraterrestrial life, my presentation will conclude by examining the ethical implications of terraforming Mars.

Where Are We Going? The Future Of Space Exploration

Strep, Lies, and 16mm Film: Did S. mitis Survive on the Moon? Should Humans be Allowed on Mars?

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In late 1969, Apollo 12 astronauts landed on the Moon near the site of the Surveyor III spacecraft, which had landed there, near the eastern shore of Oceanus Procellarum, in April 1967. When they returned to Earth, the mission also returned the entire Surveyor TV camera, as well as other selected parts. Subsequently, the camera was partially disassembled, and portions (Mitchell & Ellis 1971; Knittel et al. 1971) were subjected to microbial sampling and analysis. The results of this sampling was reported to the Second Lunar Science Conference, and one of the groups (Mitchell & Ellis 1971) claimed that a live microbe—Streptococcus mitis— was found in the foam between printed circuit boards within the camera body, and that it most-likely had made the round trip to the lunar surface and back, and survived. Beyond the conference proceedings, this result was first reported widely by Taylor (1974) in the Annual Review of Microbiology, and since that time it has occasionally been cited by other scientists (cf., Nicholson et al. 2000 citing the contractor-report-version of the same paper, Mitchell & Ellis 1972), and by vast hordes of print and broadcast reporters, as proof that Earth microbes can survive the harsh lunar environment.

But did S. mitis really make the trip? And if so, did it make the trip on Surveyor, or on Apollo? What evidence can be brought to bear, and what are the chances, in retrospect?

This paper will examine the strange case of 'Streptococcus mitis on the Moon,' and discuss what it may mean in terms of a return-to-the-Moon and on-to-Mars program that is being envisioned by NASA. The implications of microbial survival in hostile environments will be discussed, and potential methods to ameliorate the influence of human-associated microbes on the astrobiological exploration of Mars (Race et al. 2003) will be put forward.

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Biology And The Future Of Mars

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It is possible that at some time in the future we might recreate a habitable climate on Mars, returning it to the life-bearing state it may have enjoyed early in its history. Our studies of Mars are still in a preliminary state but everything we have learned suggests that it may be possible to restore Mars to a habitable climate. Long part of the intersection of science and fiction (eg. Clarke, 1995), serious studies of planetary ecosynthesis on Mars began after the results of the Viking mission indicated that all the compounds needed for life were present on the surface of Mars is some accessible form (Averner and MacElroy, 1976; McKay et al., 1991; Fogg, 1995). Recent work has focused on the use of climate models to compute the timescales to warm Mars (McKay et al., 1991; McKay and Marinova, 2001).

Planetary ecosynthesis on Mars has implications for the objectives and conduct of robotic and human exploration. In particular the question of forward contamination must be considered in a new way if we wish to control the introduction of life to Mars in advance of planetary ecosynthesis.

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Planetary Exploration and Exobiology in Europe's Aurora Programme

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In November 2001, the European Space Agency's Aurora (Ref 1) programme for planetary exploration was approved. This programme aims at formulating and implementing a European long-term strategy for the robotic and human exploration of the solar system bodies that hold promise for finding traces of life. For the foreseeable future, Mars naturally becomes the main object of attention, and as a frame for the long-term planning the time around 2030 has been assumed as start for a crewed mission towards Mars.

To gather knowledge and experience on important topics and to develop required technologies robotic missions are foreseen. The first major mission, ExoMars, will focus on the search for past and present life on the Martian surface/subsurface, using a dedicated instrument package called "Pasteur". Additionally some experiments looking specifically at hazards for future manned missions will be included. For the final definition of this integrated instrument package a call for ideas managed to mobilise more than 500 researchers from all around the world.

The second 'flagship' mission will be a Mars Sample Return mission, for which concept studies are also running at the moment.

Next to the robotic missions, the longer-term planning and system studies for the crewed mission are ongoing. In the ambitious timeline, technology rehearsal missions are foreseen as well as a crewed mission to the moon, which in addition to technology demonstration (e.g., of the transfer habitat) also will provide insight on operational and crew performance aspects.

Finally ground-based activities form an important element of the Aurora programme activities, most importantly for human related topics, like isolation and confinement effects and countermeasures, improved microgravity countermeasures etc.. Also, with respect to exobiology,

work will be performed on aspects of planetary protection, including the development of a sample curation facility for the Mars Sample Return mission, support of exobiological fieldwork and general experience relevant to the exploration of Mars.

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1) http://www.esa.int/aurora

Astrobiología en Español

Adaptación Divergente de Escherichia coli a Exposiciones Cíclicas de Luz Ultravioleta

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Como consecuencia de la evolución adaptativa, las poblaciones de un organismo bajo presión selectiva cambian genética y fenotípicamente después de varias generaciones con objeto de sobrevivir en ese medio particular. Cuando la luz ultravioleta (UV) o los rayos X actúan como agentes selectivos sobre microorganismos como las bacterias, su resistencia natural a esos agentes se incrementa a través de un proceso de mutación y selección (Wright y Hill, 1968; Mouton et al., 1970; Rames, et al., 1997; Ewing, 1995; Ewing, 1997). Puesto que las mutaciones inducidas por esos agentes ocurren al azar y aparentemente sin ninguna direccionalidad, es muy probable que los mecanismos de resistencia divergirán en diferentes poblaciones después de exposiciones prolongadas a radiación. Sin embargo, la convergencia no puede ser descartada completamente si es que las lesiones más abundantes o más letales producidas en el ADN deben ser reparadas preferentemente por una vía particular de reparación o incluso por una enzima específica de reparación.

Para ver cuál de esas dos alternativas ocurre realmente, cinco poblaciones geneticamente idénticas de Escherichia coli PQ30 fueron establecidas a partir de un cultivo inicial e iradiadas paralela e independientemente con 80 ciclos de luz ultravioleta. Al final, se obtuvieron cinco cepas con diferentes niveles de resistencia a UV y a partir del mapeo genético de las mutaciones responsables de la resistencia, se puede concluir que la adaptación fue consecuencia de eventos de mutación y selección al azar que siguieron diferentes cursos en las distintas poblaciones bacterianas. Aunque esos experimentos están limitados a condiciones de laboratorio, muestran que la selección puede dar lugar a divergencia genética aún en poblaciones que viven en ambientes idénticos, si dichas poblaciones encuentran soluciones adaptativas alternativas. Esto muestra la gran capacidad adaptativa de los organismos y podría reflejar la naturaleza aleatoria del proceso evolutivo.

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Diversidad microbiana en el Río Tinto (España): Una aproximación a los tres dominios

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Situado en el suroeste de España, el Río Tinto es un ecosistema natural con pH de 1,7-2,5 y concentraciones de hierro tan altas como 20 g/L. El río es un modelo excelente de un mundo antiguo anóxico y rico en hierro (Arcaico), así como también de concentraciones de oxígeno crecientes (Proteozoico y Fanerozoico). Las investigaciones microbiológicas en el Río Tinto podrían ser clave para descubrir rutas antiguas y metabolismos que ya no son utilizados por microorganismos en otras condiciones menos extremas.

Un aspecto interesante del Río Tinto es la contrastada diversidad filogenética entre las comunidades procariota y eucariota. Aunque el río no soporta formas de vida metazoica compleja (excepto que se han observado ocasionalmente rotíferos y larvas), los eucariotas unicelulares son abundantes y más diversos que los procariotas. Junto con procariotas quimiolitotroficos, los protistas fotosintéticos constituyen los productores primarios del río. Estudios morfológicos revelan la presencia de diversos eucariotas heterotróficos y fotosintéticos, incluyendo hongos, varias algas verdes, protistas ameboides, flagelados y ciliados. Estudios basados en el gene del 16S rRNA demuestran incluso una mayor diversidad eucariótica que la observada con el microscopio. Estos estudios han sido restringidos a investigaciones de solamente procariotas (Bacteria y Archaea) o eucariotas (Eukarya), pero estudios combinados no se han llevados a cabo. En este proyecto emplearemos una técnica nueva llamada SAGT (see Palacios et al. poster) en combinación con la tradicional secuenciación del gen completo del rRNA en taxones nuevos para explorar la diversidad de la vida a nivel de los tres dominos. Nuestro muestreo tiene en cuenta una escala espacial y temporal así como concomitantes medidas físico-químicas.

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Teledetección, Arqueología e Historia de la Vegetación: El Proyecto Kargaly

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Desde 1993 un equipo del Instituto de Arqueología de Moscú (Academia Rusa de Ciencias) dirigido por E. N. Chernyj y otro dirigido por MªI. Martinez Navarrete del Instituto de Historia del C.S.I.C. de Madrid con participación de otras instituciones (España) colaboran en la investigación arqueológica del complejo minero-metalúrgico de Kargaly región de Orenburg (Rusia). Se trata de uno de los más importantes y antiguos centros de producción de mineral de cobre en la región de la Gran Estepa Euroasiática. Su explotación se inicia durante la Edad del Bronce, en un periodo fijado por 16 fechas de carbono 14 entre los siglos XVII al XIV

A.C. Kargaly desempeñó un relevante papel en el desarrollo de la temprana Edad de los Metales en esa parte del mundo.

La comprensión histórica del fenómeno arqueológico representado por este complejo minero-metalúrgico plantea importantes cuestiones relativas a la composición y evolución del paisaje vegetal durante la Prehistoria, particularmente dos:

- 1) establecer la distribución y composición de los recursos forestales en la región durante el período de apogeo de la minería prehistórica para evaluar la base energética de la misma.
- 2) determinar la naturaleza de las prácticas subsistenciales (agricultura y ganadería) de las poblaciones de la Edad del Bronce y su impacto en los procesos de transformación del medio.

Los métodos convencionales de la Arqueología paleoambiental, y particularmente la Palinología arqueológica, presentan serias limitaciones a la hora de abordar estas cuestiones. Dichos métodos pueden fijar las líneas generales de la evolución bioclimática a escala regional. Sin embargo las secuencias paleopalinológicas obtenidas en depósitos arqueológicos y naturales son, en general, poco informativas en lo que se refiere a la morfología local del paisaje vegetal, como consecuencia de los sesgos tafonómicos inducidos por los procesos de formación de los depósitos.

Con objeto de superar estas limitaciones el proyecto Kargaly ha desarrollado una metodología orientada a la calibración de dichos sesgos a partir de la modelización de los factores que determinan la formación del registro polínico en el paisaje actual. El objetivo principal es obtener criterios que permitan ensayar una interpretación de los espectros polínicos en términos de distribución local de la vegetación. Esta metodología se basa en las propuestas de D'Antoni y Spanner (1993), y consiste en el uso combinado de índices de vegetación (NDVI obtenido de imágenes Landsat 5 TM), muestras de la lluvia polínica actual e inventarios florísticos detallados para establecer un modelo predictivo de valores locales del NDVI a partir de la composición de los espectros polínicos. Este modelo se puede aplicar a los espectros paleopolínicos a fin de aproximar la distribución local hipotética del NDVI en momentos del pasado.

Los resultados preliminares obtenidos sugieren la posibilidad de generalizar este enfoque metodológico a problemas de historia de la vegetación en los que resulte relevante establecer indicaciones sobre la distribución local de la vegetación.

Relevancia Del Ciclo Del Hierro En La Búsqueda De Vida En Marte

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La caracterización geomicrobiológica de un ambiente extremadamente ácido, el Río Tinto, ha probado recientemente la importancia del ciclo del hierro, no sólo en la generación de las condiciones extremas del habitat sino también en el mantenimiento de un nivel inesperado de biodiversidad microbiana, principalmente eucariótica. Considerando las importantes concentraciones de hierro presentes en Marte y las propiedades fisicoquímicas de este elemento que puede ser usado como donante o receptor de electrones en la respiración, como tampón para el mantenimiento de un pH constante y como protector de la radiación y de la oxidación, se discutirá la posible existencia en Marte de un sistema geomicrobiano basado en el hierro y se presentarán las investigaciones actualmente en curso que utilizan al Río Tinto como un análogo terrestre del planeta rojo.

Diversidad Ecológica Microbiana Del Río Tinto (Huelva, España), Un Ecosistema Extremadamente Ácido Y Cargado De Metales Pesados

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El descubrimiento de comunidades microbianas activas en ambientes extremos extiende el rango de parámetros ambientales que podrían ser compatibles con la existencia de vida en otros planetas. Situado en el suroeste de España, el Río Tinto es un ecosistema de alta prioridad para los astrobiólogos por su analogía con un Marte más antiguo y húmedo [1]. La actividad de microorganismos quimiolitotróficos que habitan en el río da lugar a altas concentraciones de hierro (~20 mg/ml) y ácido sulfúrico (media pH 2.3) procedentes de metales de sulfuro. A través de la utilización de una nueva técnica molecular denominada ASEG (Análisis Seriado de Etiquetas Génicas), hemos podido determinar el número relativo de las distintas clases de microorganismos en lugares clave del Río Tinto (Origen, Jardín de Anabel y Berrocal, referirse al poster de Amaral-Zettler et al. para más detalles). En consistencia con datos de FISH [2], Acidithiobacillus sp. y Leptospirillum ferrooxidans, así como en menor medida, Acidiphillium sp. y Ferromicrobium sp., son las clases de microbios más abundantes del Río Tinto. Además, ASEG detectó especies que no han sido observadas antes en este ecosistema, incluyendo Sulfobacillus y la bacteria no cultivada AS6, que sí han sido asociados anteriormente con ambientes acídicos [3]. También encontramos otras poblaciones menores que no están representadas en las bases de datos moleculares y que suponen por tanto clases de microorganismos completamente nuevas. Los índices de diversidad ecológica Alpha y Beta muestran que el Jardín de Anabel y Berrocal tienen estructuras poblacionales similares, mientras que la comunidad bacteriana de Origen parece más particular y diversa.

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Prediciendo Ecosistemas Del Pasado En América Del Sur

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Con los grandes gradientes de temperatura media anual [260C-80C], precipitación anual [10.000 mm – 181 mm] y biodiversidad [106 especies por km-2 – 103 especies por km-2] que se observan en América del Sur desde la costa de Colombia sobre el Pacífico hasta la meseta central de Santa Cruz en la Patagonia Argentina, hemos construido una metáfora de un planeta que se está enfriando y secando (1). Tal planeta estaría acercándose al límite de la zona habitable alrededor de su estrella (2). En esta metáfora de biosfera estamos llevando a cabo una investigación de "retrodicción ecosistémica".

El objetivo central es producir un modelo ecosistémico que utilice el índice verde (NDVI), con datos estacionales, temperatura, insolación, temperatura superficial de los océanos Pacífico y Atlántico (SST) y otros datos que permitan hacer predicciones precisas usando algoritmos derivados de la teoría del caos. Al presente contamos con un estudio de las desviaciones del NDVI en América del Sur en los últimos 20 años(1), y reconstrucciones de la "paleo-SST(3)" para ambos océanos. Hemos realizado predicciones del "paleo-NDVI" con datos de polen de un perfil de 9.000 años (4), y establecimos 35 sitios de estudio en el continente que cuentan con estratigrafías polínicas Asimismo hemos obtenido extensas bases de datos de insolación y temperatura con las que alimentaremos el modelo que estamos construyendo.

<Al fin de este trabajo esperamos haber desarrollado un modelo eficaz para predecir la productividad primaria neta (NPP) y comparar nuestros resultados con los de otros modelos actuales sobre los 22 años de datos satelitales y de otras fuentes de que disponemos en la actualidad. Después de esta validación cruzada, intentaremos reconstruir la "paleo-NPP"de varios ecosistemas sudamericanos utilizando nuestro modelo con datos y simulaciones del pasado.</p>

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Depósitos De Óxidos De Hierro Dentro De Los Yacimientos Metálicos Del Análogo De Marte De Río Tinto Como Posibles Evidencias Of Criptobiosferas Quimiolitótrofas. Primeros Resultados De Geobiología Del Proyecto Marte.

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La búsqueda de vida reciente en Marte necesita el acceso de las sondas planetarias a aquellas áreas protegidas frente a la climatología extrema de su superficie. Se ha propuesto que algunas de estas regiones se encuentren en el subsuelo del planeta rojo. Sin embargo, la exploración astrobiológica del regolito y basamento de Marte requiere superar numerosos problemas científicos y técnicos relacionados con la definición conceptual de biomarcadores en dichos hábitats, así como el desarrollo de la tecnología complementaria capaz de sondear, muestrear y analizar los potenciales hábitats ocultos para detectar posible actividad biológica. El proyecto MARTE (Mars Analog Research and Technology Experiment) se ha definido para superar algunos de los problemas científicos y tecnológicos necesarios para abordar la prospección de vida subterránea en Marte, si esta existe en dicho planeta (Stoker et al., 2003).

Una de las primeras tareas de MARTE-ha sido sondear el basamento de un análogo de Marte por medio de técnicas estándar la cuenca de Río Tinto, para obtener información biológica y geobiológica del subsuelo. El basamento de la cuenca del Tinto está compuesto de apilamientos de sucesiones vulcanosedimentarias (Leistel et al., 1998) que han registrado una historia hidrotermal muy activa en forma de yacimientos metálicos. Si se consideran las propiedades geológicas y biológicas de la cuenca (López-Archilla et al., 2001; González-Toril et al., 2003), se presupone la existencia de un bioreactor quimiolitótrofo que mantiene las condiciones especiales químicas del río (Fernández-Remolar et al., 2003).

De acuerdo con los datos geológicos superficiales (Fernández-Remolar et al., 2003) y subterráneos obtenidos por técnicas geofísicas se eligieron cinco puntos para llevar a cabo el sondeo estándar del basamento de la Cuenca de Río Tinto. Durante 2003, fueron perforados dos de esas cinco áreas, puntos 1 y 4, recuperando 49 y 165,35 m de sondeos respectivamente. Las primeras interpretaciones de las muestras sugieren la existencia de diferentes hábitats microbianos desarrollado a partir de gradientes hídricos, disponibilidad de fuentes de energía quimiolitótrofa y contenido en oxígeno (Fernández-Remolar et al., 2004).

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51 Años de Química Prebiótica

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A pesar de la multiplicidad de teorías que se han propuesto sobre la aparición de la vida en la Tierra, éstas se pueden clasificar en tres grandes grupos: (a) las que sostienen que la vida llegó a nuestro planeta procedente de otro lugar del Universo; (b) que los primeros seres vivos eran autótrofos, es decir, capaces de sintetizar sus propios componentes a partir de la reducción de dióxido de carbono; y (c) las teorías heterótrofas, que sugieren que la vida surgió a partir de la evolución de compuestos orgánicos sintetizados abióticamente y que se habían acumulado en los mares primitivos formando la llamada sopa primitiva.

A pesar de los debates que existen sobre el surgimiento y la naturaleza de los primeros organismos, las evidencias observacionales y experimentales parecen apoyar fuertemente la propuesta de un origen heterótrofo a partir de caldo primitivo, sugerido por primera vez por A. I. Oparin en 1924 reelaborada por él mismo en 1936 (Lazcano, 1995). Estas ideas recibieron un fuerte apoyo empírico en 1953, cuando Stanley L. Miller, que en esa época era un estudiante de postgrado de Harold C. Urey, estudió en el laboratorio el efecto que las descargas eléctricas sobre una atmósfera de metano, amoniaco, hidrógeno y vapor de agua, tratando de simular el medio ambiente prebiótico. Aunque el trabajo de Miller no fue la primer síntesis de compuestos orgánicos en el laboratorio, sí representa el punto de partida el los estudios experimentales sobre el origen de la vida. En éste trabajo se discutirán las condiciones científicas y sociales en que el experimento de Miller se llevó a cabo, y las consecuencias que tuvo para las ciencias biológicas en general (Bada y Lazcano, 2003).

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Las Albarradas de la Costa del Ecuador: Rescatando El Conocimiento Ancestral sobre el Uso Sostenible de la Biodiversidad

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Las Albarradas (un antiguo sistema de control hídrico),es un proyecto arqueológico en concepto, pero interdisciplinario en ejecución, que ha servido para generar conocimientos que permiten y permitirán mantener la calidad de las fuentes de agua en el área de estudio.

Los pequeños embalses precolombinos llamados albarradas en Ecuador y/o jagüeyes en buena parte de la América hispana constituye un sistema tradicional de manejo sostenible del recurso agua y de la biodiversidad, que ayuda a minimizar la degradación del ecosistema Tumbésico de la costa central y sur del Ecuador y extremo norte del Perú. Este medioambiente único, combinación de bosque tropical deciduo, chaparral, y sabana seca, que en múltiples combinaciones es característico del área.

La flora asociada con las albarradas protege a este sistema contra la erosión del suelo. Las albarradas pueden también ser usadas en programas dirigidos a prevenir la degradación del suelo, ya que estas pequeñas represas de tierra – en forma de herradura – funcionan como un sistema de bajo costo para atrapar el agua de la escorrentía, enriquecer el acuífero,

Las albarradas como una bien probada forma ancestral de participación comunitaria pueden ayudar a minimizar las dificultades que a veces encuentran los programas de organización comunal. El reforzar el funcionamiento de las albarradas puede ayudar a renovar el viejo sistema de "tareas" que ha existido durante siglos entre las comunidades nativas de la Península de Santa Elena y Manabí. Como proyectos comunitarios e instrumentos de desarrollo sostenible las albarradas pueden reforzar las economías de las Comunas y de otros grupos de pequeños productores en el área de estudio.

Los avances del Proyecto:

Durante el primer año el proyecto ha logrado cumplir con las metas previstas. Aún más, se encontró un aumento del 400% entre las albarradas localizadas, y las que se habían estimado existían, lo que ha amentado el trabajo de investigación. Una evaluación de lo cumplido se describe a continuación:

Un sistema GIS para registrar y analizar la localización especial de las albarradas se ha creado y se mantiene al día mediante la confirmación en terreno. El sistema GIS ha usado las imágenes de satélites proveídas por la NASA. Se había predicho que a este estadio de avance del proyecto, se habrían registrado unas 100 albarradas, sin embargo, en la actualidad se han identificado y registrado más de 500 albarradas (254 entre Salinas y La Libertad y 264 en el área rural (territorios comunitarios).

Se llevaron adelante excavaciones en 5 albarradas. Se están preparando nuevos mapas hidrológicos para la Provincia del Guayas para ayudar en la identificación de la Formación Tablazo. Todas las 264 albarradas tradicionales del área rural, "albarradas" modernas, tapes han sido dibujadas en mapas topográficos del IGM (escala 1:50.000), solamente las mayores aparecen en el mosaico de imágenes de radar provistas por el Instituto de Astrobiología de la NASA. La observación directa en el campo ha permitido completar la definición de las albarradas del área de estudio. Las albarradas más antiguas datan de entre los 2000 y 1550 a.C., la mayoría se construyeron entre los 850 a los 300 a.C. Se las mantuvo durante todo el periodo prehispánico y una buena parte de ellas sigue funcionando hasta ahora.

En las Albarradas existe una elevada diversidad biológica, constituyéndose en verdaderas reservas de la vida silvestre. Por un lado el agua almacenada en su interior permite el desarrollo de la fauna y flora acuáticas, mientras que en sus alrededores, y gracias a la humedad que genera, se desarrolla una amplia gama de especies vegetales terrestres. Estas características hacen que las Albarradas sean visitadas por un sinnúmero de animales domésticos y silvestres -nativos y migratorios- que aprovechan el agua y la vegetación circundante como alimento o como lugar de refugio, para nidificar y reproducirse.

El impacto ambiental positivo que generan las Albarradas es muy evidente si consideramos que además de encontrar, en su área de impacto, una mayor diversidad y densidad de especies vegetales -nativas, endémicas o amenazadas-, en tiempo de seca, mientras la mayoría de la región sufre el fuerte efecto de la escasez de agua, en sus alrededores se puede encontrar una exuberante y verde vegetación.

Suelos Similares A Los Marcianos En El Desierto De Atacama, Chile

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Las naves Vikingo a Marte mostraron que la superficie marciana no contiene vida, esta desprovista de materia orgánica y contiene uno o más oxidantes presentes en el suelo marciano. Con el propósito de buscar análogos de Marte en la Tierra iniciamos un estudio en el desierto más árido y antiguo de la Tierra denominado el Desierto de Atacama, el cual esta ubicado al norte de Chile. En la zona más árida de este desierto, Yungay, hemos encontrado suelos con características similares a los estudiados por las misiones Vikingo (Navarro-González et al., 2003). Las muestras de esta región tienen

material orgánico solo a nivel de traza y niveles extremadamente bajos de bacterias heterotróficas cultivables. Dos muestras de suelo de la región más árida fueron analizadas para buscar ADN y esté no fue detectado. Experimentos de incubación diseñados después de las misiones Vikingo pero con mezclas de isómeros biológicos y no-biológicos mostraron alto grado de descomposición del material orgánico por procesos no-biológicos. El descubrimiento de esta zona en la Tierra con suelos similares a los marcianos es de gran importancia para la evaluación de instrumentos y experimentos diñados para la búsqueda de vida en futuras misiones a Marte.

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Acknowledgements

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Cambios en Condiciones Ambientales del Área del Río de la Plata, Argentina-Uruguay

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En el marco del Proyecto Binacional Argentino-Uruguayo FREPLATA (RLA/G31/99 PNUD-GEF) se está desarrollado una serie de estudios para comprender la dinámica del Río de la Plata y del Frente Marítimo.

El Río de la Plata es un cuerpo de agua extenso y poco profundo ubicado en la costa este de Sudamérica entre 34º00′- 36º20′ S y 55º00′-58º30′ W. Es uno de los sistemas estuariales más grandes del mundo e integra la Cuenca del Plata que resulta la más desarrollada de Sudamérica. Se extiende más de 280 km desde su cabecera, de 25 km de ancho, hasta su boca, de 230 km de ancho y ocupa una superficie de 35.000 Km². Es alimentado en su cabecera por las descargas del río Uruguay y del río Paraná, uno de los más largos del mundo, y drena hacia el Océano Atlántico. La confluencia de aguas de origen continental con las aguas del Océano Atlántico da lugar al Frente Marítimo, localizado entre 34º y 37ºS, que presenta una marcada variabilidad espacial.

Este escenario permite orientar la búsqueda de cambios antrópicos y naturales, mediante series históricas de información, que identifiquen patrones naturales, sus alteraciones y aquellas cualidades emergentes del sistema que sustente hipótesis predictivas de su futuro. La vinculación del Fenómeno del Niño con cambios en los principales forzantes de la circulación del Río de la Plata no está del todo establecida a pesar de que existen indicios importantes de esta relación. Aumentos extraordinarios del caudal medio del Río de la Plata y cambios en la salinidad han seguido a los grandes eventos El Niño.

El registro hidrológico de los ríos Paraná y Uruguay en el período 1931-2001 muestra que hubo un cambio fehaciente de tendencia en los regímenes hidrológicos de ambos ríos desde principios de la década del 70. desde entonces se desarrolla un ciclo de características húmedas. El caudal medio de ambos tributarios del Río de la Plata fue un 15% superior a la media histórica (31-01). Estas tendencias se manifiestan más arriba de la red de represas hídricas del Paraná con cambios consistentes en las características del ambiente.

Junto con el aumento de los caudales medios entre 1971-2001, se han observado otros cambios que incluyen una mayor amplitud de variación del caudal del Río Paraná, una mayor frecuencia de picos extremos de crecida y bajante en el río Paraná y de bajantes extremas en el Río Uruguay. Durante este período se incentivaron las componentes de alrededor de 8 años en el Río Paraná, lo cual coincide con la sucesión de crecidas extraordinarias observadas en ese intervalo de tiempo (82-83, 92 y 98), y se activaron las componentes de alrededor de 4 años en el Río Uruguay con períodos consistentes con los del Fenómeno El Niño.

En los últimos 50 años ha ocurrido un importante cambio en las velocidades del viento en verano e invierno, consistente con un desplazamiento de estas estaciones a meses más tempranos. Un cambio, relacionado con una mayor influencia de vientos del norte, se verifica asimismo en la dirección de los vientos en las estaciones de transición. El patrón de vientos presenta dos modos distintivos e importantes de variabilidad interanual. El primer modo con un período de dos años está altamente anticorrelacionada con cambios en la temperatura superficial del mar sobre el oeste del Pacífico tropical

occidental. El segundo modo con períodos entre 8 y 12 años está altamente correlacionado con cambios de temperatura en latitudes medias y altas del Hemisferio Sur y, particularmente, sobre el Océano Atlántico Sur.

Se modela la implicancia de estos patrones en los forzantes principales, vientos y caudal, actuando sinérgicamente en escenarios extremos, pero ya reales, sobre la alteración de las mareas en el ambiente del Río de la Plata y su impacto en el nivel medio del mar sobre las áreas costeras altamente urbanizadas y humedales de la región.

Tecnología para respaldar la Ciencia Astrobiológica

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La búsqueda de vida fuera de nuestro planeta requiere el desarrollo de nuevas tecnologías y para ello es necesario el desarrollo de nuevos tipos de sensores y herramientas, que operando de forma remota, realicen los análisis y actividades necesarios para poner de relieve la existencia de alguna forma de vida. El proyecto MARTE (desarrollado por la NASA en colaboración con el Centro de Astrobiología y varias universidades americanas) es un ejemplo de ello, se va a realizar una misión de simulación de la exploración del subsuelo de Marte y el CAB va a contribuir con un detector de moléculas orgánicas y una herramienta que permite hacer espectrometría Raman de las paredes de la perforación así como la toma de imagines.

Astrobiology And The Press

Astrobiology: A Publisher's Perspective Of The Opportunities For Outreach

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The public is strongly motivated by fundamental questions. Some of these have not changed in centuries: what is the origin and ultimate fate of the universe? What is the history of the solar system? Is there life on other worlds? Although the questions have scarcely altered, the answers have evolved greatly with increased knowledge. Professionals in astrobiology are well-placed to cover a wide spectrum of issues that interest the public. Their colleagues in astrophysics and cosmology have done so for decades. What is new and exciting about astrobiology is that it weaves biology, chemistry, and humanity into the adventure.

This presentation will highlight the opportunities for popularisation that can be realised through publication of full-length books, and through journal articles and reviews

Astrobiology And The Press

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Above the Executive Producer's desk at the CBS Evening News, there used to hang a placard with that famous quotation from Einstein: "Make everything as simple as possible, but not simpler." We will talk about the challenges of translating complicated science into simple stories. This reporter would argue that deadline pressure, more than the need for brevity or simplicity, is the most difficult issue when putting together a piece. We will discuss the ingredients of a successful story; the process by which stories are selected; and how they affect the relationship between science reporters and the researchers whose work they cover.

Astrobiology Drilling Session

Discovery of FeS2-Rich Marine Sediments In The ~2.76 Mt. Roe Basalt

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² Graduate School of Science, Kagoshima University, Kagoshima; nedachi@sci.kagoshima-u.ac.jp During summer of 2003, paleosol localities of the ~2.76 Ga Mt. Roe Basalt were drilled to ~300 m length. Drilled core samples exhibit significantly different lithology compared to surface rocks. We found pyrite-rich black shale units (a few meter in thickness) in lava flow units. Pyrite in Mt. Roe black shale occurs as fine-grained crystals, nodules and veins. Microanalyses of sulfur isotopes were performed using the EA-IRMS technique on these pyrite samples. The total range of sulfur isotope compositions is —4.8 to +0.9 per mil. Some pyrite nodules are isotopically zoned, suggesting microbial sulfate reduction in Mt.Roe black shale. Such microbial activity could not be detected on the weathered surface rocks. > < Some drilled core sections also exhibit unique textures. Fragmented black shales are, for example, often incorporated into lava flows, implying near-shore eruption of Mt.Roe lava flows. These new findings based on drilled core samples may postulate reexamination of the past depositional environments of Mt. Roe lava flows and published geochemical data.

Preliminary Report: The Bulk-rock Geochemistry Of The 3.45 Ga Marble Bar Chert (ABDP#1 site)

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Major, trace and rare earth element abundances were determined on 123 drill core samples of the Marble Bar Chert from the ABDP #1 site. Since Kato & Nakamura (2003) already reported geochemical data on outcrop samples of the Marble Bar Chert, we are able to evaluate the extents of modern weathering and three-dimensional variations in rock chemistry. The $Fe_2O_3^*$ contents of the core samples vary, but are generally low (0.02-10.2 wt%; average = 2.05 wt%). Their Eu anomaly values (Eu/Eu*) range from 0.84 to 2.72 (avg = 1.51), exhibiting weak positive Eu anomalies except for several samples. The Ce anomaly values (Ce/Ce*) narrowly range from 0.80 to 1.29, indicating most core samples lack Ce anomalies. However, some samples exhibit weak negative Ce anomalies. In contrast, the surface chert samples are characterized by: (1) much higher $Fe_2O_3^*$ contents (up to 39.6 wt%, avg = 10.7 wt%); (2) stronger positive Eu anomalies (Eu/Eu* = 1.31-6.61, avg = 2.61); and (3) distinct negative Ce anomalies (Ce/Ce* = 0.60-1.04, avg = 0.86).

The differences in bulk-rock geochemistry between the subsurface and surface samples probably reflect the primary differences in chert chemistry, rather than the effects of modern weathering. The ABDP#1 site is located several kilometres from the surface sample site. The surface chert samples with higher Fe₂O₃* contents and distinct positive Eu anomalies probably deposited from high temperature hydrothermal solutions emanating from a mid-oceanic ridge (MOR), while the cherts at the drilling site deposited from low temperature hydrothermal fluids. The observed relationships among (a) the magnitudes of positive Eu anomalies, (b) the magnitudes of negative Ce anomalies and (c) the Fe/Si ratios of Fe-rich sediments, and (d) the distance from the center of hydrothermal discharge zone for the 3.45 Ga Marble Bar cherts are essentially the same as those of modern MOR sediments.

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An Automated, Low Mass, Low Power Drill For Acquiring Subsurface Samples Of Ground Ice For Astrobiology Studies On Earth And On Mars.

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As a project that is part of NASA's Astrobiology Technology & Instrument

Development Program (ASTID), we are developing a low mass (~20kg) drill that will be operated without drilling fluids and at very low power levels (~60 watts electrical) to access and retrieve samples from permafrost regions of Earth and Mars. The drill, designed and built as a joint effort by NASA JSC and Baker-Hughes International, takes the form of a down-hole unit attached to a cable so that it can, in principle, be scaled easily to reach significant depths.

A parallel laboratory effort is being carried out at UC Berkeley to characterize the physics of dry drilling under martian conditions of pressure, temperature and atmospheric composition. Data from the UCB and JSC laboratory experiments are being used as input to a drill simulation program which is under development to provide autonomous control of the drill.

The first Arctic field test of the unit is planned for May 2004. A field expedition to Eureka on Ellesmere Island in Spring 2003 provided an introduction for several team members to the practical aspects of drilling under Arctic conditions. The field effort was organized by Wayne Pollard of McGill University and Christopher McKay of NASA ARC. A conventional science drill provided by New Zealand colleagues was used to recover ground ice cores for analysis of their microbial content and also to develop techniques using tracers to track the depth of penetration of contamination from the core surface into the interior of the samples.

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Acknowledgements

We wish to thank the Canadian Polar Continental Shelf Project for support in gaining access to sites in the Canadian Arctic.

An Initial Report Of ABDP Investigations: Evidence Of A High pO₂, High pCO₂ And Low pCH₄ Archean Atmosphere In The 3.45 Ga Marble Bar Chert

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According to the geologic information of the Pilbara district in Western Australia, the Marble Bar chert/jasper unit (50-100 m thick and extending a several km² area) was deposited ~3.45 Ga ago by submarine hydrothermal fluids that probably discharged on or near a mid-ocean ridge at a water depth >500 m. The jasper, which is characterized by alternating layers of red (hematite-rich)-, black (magnetite)-rich, green (siderite-rich)- and white (Fe-poor) cherts, has been an enigma for geochemists postulating an anoxic Archean atmosphere. They have interpreted the hematite (Fe₂O₂) was a modern oxidation product of siderite (FeCO₃). However, in the deep drill cores from the ABDP site #1 and also in many surface outcrop samples, fresh pyrite (FeS₂) crystals are ubiquitously found in numerous small (~mm thick) veinlets in the jasper unit and the interbedded hematitized pillow basalt. This suggests the hematite crystals are not oxidation products of siderite, because pyrite is easily altered to goethite under an oxygenated atmosphere. The textural and paragenetic relationships of the various ironbearing minerals suggest that the hematite and siderite crystals in the jasper and pillow layas formed 3.45 Ga on the seafloor as a result of mixing of Fe2+-, H₄SiO₄- and H₂S-rich submarine hydrothermal fluids with O₅- and ∑CO₃² (≈ CO₃ + HCO₃)-rich deep ocean water, while the pyrite crystals were forming from the simple cooling of hydrothermal fluids beneath the seafloor. From thermodynamic and kinetic evaluations of the formation conditions of iron-bearing minerals, together with an ocean-circulation model, we suggest the 3.45 Ga atmosphere contained pO₂ > 0.4 PAL, pCO₂ > 100 PAL, and pCH₄ $\approx 1 \text{ PAL}$.

The drill core samples from this site are also characterized by the abundance of organic carbon-rich layers (<1 to ~5 mm in thickness) in the chert/jasper unit. They probably represent remnants of microbial mats that developed on the seafloor during the quiescence periods of submarine hydrothermal activity.

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Archaean Park Project: The Fist Attempt To Drill Sub-vent Biosphere Of Hydrothermal System At Submarine Arc Volcano

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Seafloor hydrothermal system is often quoted as the birthplace of the terrestrial life. However, all the present information comes from the seawater/rock interface and we know virtually nothing about the biosphere that may develop beneath the vents. So we drilled ten shallow holes up to 12 meters deep at high-temperature hydrothermal site of Suiyo Seamount, an dacitic arc volcano of the Izu-Bonin Arc, Western Pacific. Fluids up to 308°C in temperature discharged from the cased holes that were bored with Benthic Multi-coring System (BMS) on R/V Hakurei-Maru #2.

The most striking structure of the hydrothermal system developed on the caldera floor (depth; 1390 meters) is the existence of ultra-shallow geothermal reservoir beneath impermeable "cap-rock" unit. The cap-rock was formed by self-sealing of anhydrite that cements the coarse-grained sediments on the caldera floor at depth between a few to ten meters subbottom depth.

The chemistry (20% more saline than seawater) and temperature (about 310 ° C) of the end-member fluid stay constant for >12 years (Umeki et al., 2001) and the chemistry is indicative of equilibrium with host volcanics at the temperature.

The sub-vent biosphere is characterized by proteobacteria which utilize sulfur compounds as their nutrient. Archaea such as Archaeoglobus are identified mainly from cased holes which suggests that we "made" Archaean Park by drilling.

The Archaean Park project is funded by MEXT Japan, through its Special Coordination Fund.

Scientific Objectives Of The Archean Biosphere Drilling Project (ABDP)

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In the summer of 2003, the Archean Biosphere Drilling Project (ABDP), an international scientific drilling project involving scientists from the USA, Australia and Japan, was initiated in the started at Pilbara Craton, Western Australia. The major goal of the ABDP is to increase our understanding of the co-evolution of life and environment during the Archean Era. During a two-month period, we completed drilling 150 - 300 m deep holes at locations to recover "fresh" (modern weathering-free) geologic formations that range from ~3.5 to ~2.7 Ga in age. The major drilling targets were: (1) one of the oldest (3.45 Ga) chert/jasper unit and submarine pillow lavas at Marble Bar; (2) one of the oldest black shale (3.45 Ga) during mafic volcanisms at Salgash; (3) black shale in the Archean lake at Stoney Creek (2.74 Ga), (4) explosive stromatolite formation and mafiv volcanisms at Meentheena Creek (2.76Ga), (5) black shale in the mid-Archean (2.8-3.2 Ga) Mosquito basin at Eastern Creek, and (6).one of the oldest (2.77 Ga) "paleosol (?)" on Mt Roe basalt at Whim Creek.

The initial investigations on the ABDP drill cores by the Japan-US members have already produced many exciting and interesting data and observations. For example, we have recognized the original textures and mineral assemblages, including hematite crystals of sub-micron size, in the 3.46 Ga Marble Bar chert, and drastic changes in sulfide/organic carbon ratios in black shales of Archean ages.

The focus of this presentation will be on the drill cores of the 2,77 Ga Mt Roe basalt. The drilling site is located ~1 km west of the outcrop areas where previous "paleosol" investigations were carried out by Macfarlane et al. (1994) and Nedachi et al. (2002). The 330 m-long core is mostly composed of basalt flows with various degrees of alteration and some beds of black shale. The abundance of black shale, the scarcity of sandstone, the absence of evaporite, the eruption of basalt on unsolidified black shale, and the weak alteration zone, all suggest that the sedimentation depth deepened toward west and that the alteration and volcanism occurred simultaneously in submarine environments. Although sulfides are poorly preserved in outcrop samples, pyrite and/or pyrrhotite nodules are abundant in the black shale. The _34S and _ 13C values range from -5 to +2, and from -56 to -45 permil, respectively. The three dimensional geochemical data suggest that the environment from oxic at shallow site to strongly euxinic due to the activities of sulfate reducers and methanogens at the deeper site.

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An Initial Report Of Abdp Investigations: Preliminary Observations Of Iron Oxides In The Marble Bar Chert, Pilbara Craton, Western Australia

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It has been been debated among researchers whether banded iron formations formed under oxic or anoxic environments. The Marble Bar Chert contains abundant hematite-rich bands, and many scientists have interpreted that the hematite was produced by modern weathering. On the other hand, other geologists emphasize the oxidation of aqueous Fe2+ by iron bacteria using photo energy without free oxygen. As some kinds of bacteria oxidize iron using free oxygen, however, the accurate description and identification of the texture of iron oxides became very important. We have examined the mineral assemblages and textures of iron oxides in fresh cores of the Marble bar Chert from the ABDP#1 hole using petrographical and electron

The Marble Bar chert is composed of organic-rich black chert, silicified white chert, and rhythmically banded chert composed of white, red and black bands, in order of sedimentation. Only the rhythmically banded chert has high magnetic susceptibility.

The iron minerals in the rhythmically banded chert are hematite, magnetite and small amount of syngenetic pyrite. The red bands contain numerous hematite grains of submicron size, which are accumulated in a botryoid cell with the size of 10-30 µm in diameter. The occurrence suggests that red band has maintained the original textures, and they were not affected by hydrothermal alteration, metamorphism or modern weathering. The black bands contain aggregates of magnetite grains that fill similar botryoid cells with hematite one. The alternation of red and black beds suggests that the magnetite is also a primary mineral. The magnetic properties well coincide with this observation. The mineralogical and textural difference of the two iron oxides might reflect differences in the environment of precipitation.

Acknowledgement

The ABDP cores used in this study, were collected by financial support from the Governmental authorities of Japan and USA, Westen Australia. We are indebted to Prof. Hiroshi Ohmoto, Dr Arthur Hickman, Dr Mark Berley, Prof. Bruce Runneger and other collaborators of ABDP. Thanks are also to Prof. Joseph L. Kirschvink for his encourage.

Missions To The Early Earth: Drilling And Other Projects On The Earth And Beyond

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Ongoing drilling activities of ancient sedimentary strata in Western Australia, under the auspices of the Astrobiology Drilling Program, promise to significantly advance understanding of life and environments on the early Earth. Such activities demonstrate that NASA's astrobiology research program in general, and the NAI in particular, facilitate largescale collaborative research projects focused on the early Earth that are of broad scientific interest. It is thus not too early to contemplate other such collaborative efforts.

Most obviously, the Western Australia drilling program could be a model for an expanded drilling program targeting multiple continents and geological epochs. A precedent is the highly successful Ocean Drilling Program which revolutionized understanding of the last ~ 100 Myr of Earth history. An early Earth equivalent, supported by NASA and other agencies,

could play a similar role for the preceding ~ 4000 Myr. This program might also provide a testbed for technologies and research paradigms eventually to be applied to the Moon and Mars.

More broadly, early Earth research could benefit greatly from geologic sampling beyond the Earth. In addition to the possibility of finding early Earth "meteorites" on the Moon (1), the lunar surface provides a unique record of the bombardment history of the Earth-Moon system. Fundamental questions persist about the intensity, duration and episodicity of this impact period — questions relevant to understanding sources of organic material to the prebiotic Earth and the "impact frustration" of life's origin and evolution. Early Earth research may thus provide a powerful scientific rational for future lunar exploration.

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Integrated Paleoecological And Paleoenvironmental Investigation Of A Late Archean Drill Core

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We plan integrated geological, paleobiological and geochemical examination of the Hamersley-Fortescue Archean sediment drill-core that will be obtained in the summer of 2004 by the Astrobiology Drilling Program. Funding for this analytical work is being sought from the National Science Foundation (Geology & Paleontology program). The general motivation of the proposed research is to characterize the nature of life and its environment in the late Archean, shortly before the rise of atmospheric oxygen. Many workers are examining the timing of this redox transition and its relationship to contemporaneous climatic oscillations that may include global ice ages. Our interest, somewhat different but complementary, is to understand how the Archean biosphere set the stage for this singular environmental transformation. Specifically, our major goal is to characterize the relative importance of different types of microbes in late Archean marine environments and, through lithofacies relationships, to study the environmental controls on their distributions. We will achieve this goal through integrated examination of hydrocarbon molecular biomarkers, redox indicators and biogeochemical cycling in kerogenous sediments. Additional goals are to characterize the status of major biogeochemical cycles in the late Archean and generate a robust baseline for future investigations by conducting sedimentological and biogeochemical reconnaissance of the entire core. Collectively, this work will test the hypothesis that oxygen-generating cyanobacteria and aerobic microorganisms were present in Archean ecosystems and that the environmental imprints of these metabolisms remained muted for hundreds of millions of years after their origins.

Multidisciplinary Study Of The Precambrian Biosphere And Surficial Oxygenation, Kaapvaal Craton, South Africa: The Agouron Cores

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The Campbellrand-Kuruman carbonate-iron formation stratigraphic succession, which drapes the Kaapvaal craton of South Africa, provides a unique opportunity to study the latest Archean/Earliest Proterozoic time interval in a multidisciplinary fashion, for four principal reasons: 1) The >1 km-thick succession of carbonates, cherts, shales, and associated iron formations is a storehouse of various geochemical and paleoclimatic proxy records, 2) the carbonate platform has never been significantly buried and contains abundant limestone, thus offering strong potential for preservation of organic biomarkers and fluid inclusions of ancient seawater, 3) the occurrence of early chert and abundant early sea-floor carbonate crusts provide good potential for the preservation of microfossils and magnetofossils, and 4) much of the stratigraphic succession has

not been significantly deformed and so it will be possible to establish a chronostratigraphic framework in which shallow water facies can be traced down the ancient paleoslope into facies deposited at water depths > 500 meters. The geologic framework provided by this sequence of rock offers an unparalleled opportunity to study the structure and composition of the Archean ocean and to merge this information with co-existing paleontological and geochemical records.

With support from the Agouron Institute, two separate cores, each ~ 1.5 km in length, were drilled through the margin of the carbonate platform, spaced so as to intercept the transitional facies at two paleodepths. The holes were deviated slightly from vertical so that a ball-mark system could be used to obtain absolute orientation. To enhance the utility for paleomagnetic investigations, core barrels and bits were demagnetized routinely with a portable mu-metal shielded coil assembly to reduce remagnetization problems, and all core slicing was done with non-magnetic blades. To minimize contamination problems for geochemical and isotopic analyses, we avoided the use of drilling lubricants containing organic materials. Almost complete core recovery was obtained. Studies are now in progress, but ultimately half of the core will be donated to the Smithsonian Institution, and the other will reside in Pretoria at the South African Geological Survey.

Drilling For Clues To Extant Life

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Subsurface organisms are subject to many of the most extreme conditions inhabited by life on Earth. High temperature and low access to energy are among the challenges to life in subsurface environments. Consequently, Earth's subsurface ecosystems serve as a test-bed for exploring life at its limits and as a model for possible life on other planets.

Recent studies have greatly advanced understanding of Earth's subsurface life. Prokaryotic cells have been reported from sediments throughout the world ocean, from the subseafloor basaltic aquifer, from deep aquifers of at least three continents, and from deep in Antarctic ice. Prokaryotic activities have been documented in sediments 0.8 km below the seafloor. Diverse metabolic processes are now known to occur in deeply buried sediments. Subseafloor communities include previously unknown prokaryotes. At least some subseafloor communities share common elements with other subseafloor communities thousands of km away.

Despite these advances, fundamental aspects of Earth's subsurface life remain unknown. We have probably not yet reached the greatest depth of subsurface life. We do not yet know the total living biomass of Earth's subsurface world, its rates of population turnover, the metabolic activities and ecological functions of most subsurface genotypes, the total genetic diversity of subsurface life, or the extent to which subsurface communities of one environment are connected to those of another. The minimum energy fluxes required to sustain subsurface organisms remain unknown. We do not yet know the extent to which subsurface life is independent of the surface world.

An Initial Report Of ABDP Investigations: Fluid Inclusions In Alteration Zones Of The 2.8 Ga Mount Roe Basalt, Pilbara, Western Australia

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The 2.77 Ga Mt. Roe basalt near Whim Creek, Pilbara, Western Australia, exhibits extensive developments of chlorite and sericite alteration zones. Because of strong depletions of Fe from the sericite zones, it was interpreted as a paleosol formed under an anoxic atmosphere (e.g., Rye and Holland, 2000). However, based on detailed mineralogical and geochemical investigations on a large number of outcrop samples, we (Nedachi et al., 2002) have suggested that the alteration zones are products of submarine hydrothermal activity at shallow water depths and that methanogenic microbes were actively producing methane in the hydrothermal system. The ABDP drilling was carried out at a location ~1 km from the outcrop sites in order to recover-fresh samples of the alteration zones of the Mt. Roe basalt for investigations aimed at resolving the controversy on the origin and significance of the alteration zones.

Alternating sequences of unaltered basalt, chloritized basalt, sericitized basalt, and thick black shale are observed in a 300 m drill core section.

The alteration zones in the drill core differ from those in the outcrops:) the thickness is thinner, 2) the intensity of alteration is weaker, and 3) no diaspore vein, but only black quartz veins are present. Some quartz veins contain fluid inclusions with filling temperature of 100°C–200°C, they contain high-salinity fluid and methane-rich gas phase. Organic carbons (kerogen) with δ13C values of -50% less were found from the shale and hydrothermal veins. Comparisons of mineralogical and geochemical data on the core samples with those on the outcrop samples suggest that a large-scale submarine hydrothermal activity took place at various water depths and that methanogens were highly active in the environment. The SHRIMP age of euhedral apatite minerals in hydrothermal veins is around 2.8 Ga; thus the hydrothermal alteration occurred essentially concurrent with the eruption of the Mt. Roe basalt.

Astrobiology Missions

Sensitive Amino Acid Composition And Chirality Analysis With The Mars Organic Analyzer (MOA)

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Detection of life on Mars requires identification of a suitable biomarker and development of sensitive yet compact instrumentation capable of performing in situ analyses. Our studies are focused on amino acid analysis because amino acids are more resistant to decomposition than other biomolecules, and because amino acid chirality is a well-defined biomarker. Previously, we developed a prototype microfabricated electrophoresis chip and analysis method where the amino acids were labeled with fluorescein and electrophoretically analyzed in under 3 minutes using -cyclodextrin as the chiral resolution agent [1]. Extracts of the Murchison meteorite were analyzed, and the D/L ratios determined by microchip CE agreed within error to those from HPLC and GCMS. Our microchip analyzer has now been improved by using fluorescamine, a fluorogenic dye with much faster labeling kinetics [2]. Fluorescamine-labeled amino acids are separated using similar conditions, resulting in similar separation times and identical elution orders. The next step in our project is development of the Mars Organic Analyzer (MOA), a portable analysis system that combines the previously developed amino acid sample extraction capabilities of the Mars Organic Detector (MOD) [3] with the composition and chiral analysis capabilities of microchip CE. Sample transfer between MOD and the CE microdevice is achieved through a capillary sipper driven by microfabricated valves and pumps. The complete integration of the CE system with MOD to form the MOA will soon be tested in remote Mars analog sites such as the Mojave Desert in California and the Atacama Desert in Chile.

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Astrobiology With ESA Space Missions

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Key Astrobiology questions can be addressed by several space missions from the ESA Science and Exploration Programmes, such as:

- 1) How do solar and stellar systems form? (using studies with ISO, FIRST-Herschel, SMART-1, Rosetta, Bepi-Colombo, Gaia);
- 2) Geological evolution of terrestrial planets (with Living planet, Mars-express, SMART-1, Venus-Express, Bepi-Colombo)
- 3) Interstellar Complex organic chemistry (with ISO, ISS/EXPOSE, FIRST-Herschel, Rosetta)
- 4) Co-evolution of Earth-Moon, impacts life frustration (with SMART-1, Bepi-Colombo)
- 5) How to detect other solar systems and habitable zones (with space photometry, COROT, Eddington, Gaia, Darwin)
- 6) Early Earth and alternative environments (Huygens/Cassini, Mars-express, Venus-Express)
- 7) Signature of biosphere and photosynthesis evolution (Earth explorer missions, Darwin)

- 8) Water on Mars (with orbiter instruments on Mars Express, and Exomars lander)
- 9) Search for organics and life on Mars, (with Mars Express, ExoMars lander and Mars sample return in the Aurora)
- 10) Astrobiology in low-Earth orbit (survival of organics in space, and human studies on ISS)
- 11) Terrestrial life beyond the Earth (life sciences and human missions on the Moon and Mars)

We shall review how the results from these ESA missions can be exploited for astrobiology, and the perspectives for the next phases of solar system exploration, and life expansion beyond Earth.

The AstroBiology Explorer (ABE) MIDEX Mission Concept – Exploring The Connections Between Chemistry In Space And Life On Planets

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Infrared spectroscopy in the 2.5-16 micron range provides an excellent means of detecting and identifying organics in space via their vibrational transitions. Ground-based, airborne, and spaceborne IR spectral studies demonstrate that a large fraction of the carbon in the interstellar medium (ISM) resides in complex organic molecular species [Sandford 1996]. The presence of D-enriched organics in meteorites suggests that some of these materials survived incorporation into the protosolar nebulae [Zinner 1997; Sandford et al., 2001]. Unfortunately, neither the distribution of these materials in space nor their genetic and evolutionary relationships with each other or their environments are understood. The Astrobiology Explorer (ABE) is a MIDEX mission concept that would conduct mid-IR spectroscopic observations to address outstanding important problems in astrobiology, astrochemistry, and astrophysics [Sandford et al. 2002; Ennico et al. 2003]. ABE's observational program would make fundamental scientific progress in understanding (1) the evolution of ices and organics in dense molecular clouds and young forming stellar systems, (2) the chemical evolution of organic molecules in the ISM as they transition from AGB outflows to planetary nebulae to the general diffuse ISM to HII regions and dense clouds, (3) the distribution of organics in the diffuse ISM, (4) the nature of organics in the Solar System, and (5) the nature and distribution of organics in galaxies of different types. In addition, ABE will attempt to detect and quantify deuterium enrichments in these materials to assist with understanding the chemical processes occurring in these environments and establishment of links between interstellar and meteoritic organics.

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Remote Mapping Of Earth's Earliest Biosphere: Hyperspectral Imagery Of The Pilbara Craton And Applications For Finding Niches For Life On Mars

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The North Pole Dome (NPD) region in the Pilbara Craton, Western Australia, is

The North Pole Dome (NPD) region in the Pilbara Craton, Western Australia, is a domical structure dominated by greenstone basalts of the early Archaean (3.3-3.5 Ga) Warrawoona Group. The rocks of the Dome are primarily volcanic, with minor volcaniclastic sedimentary successions. These minor volcaniclastic units have been postulated to provide evidence for Earth's earliest biosphere at three different stratigraphic levels (Walter et al., 1980; Groves et al., 1981; Schopf and Packer, 1987). Hydrothermal events have been implicated in mediation of these ecosystems (Van Kranendonk and Pirajno, in press). In order to obtain a

regional perspective on hydrothermal activity throughout the NPD, an airborne VNIR hyperspectral survey of the NPD region was undertaken by the Australian Centre for Astrobiology and the CSIRO. Fieldwork to ground truth initial maps was carried out in May-Jun 2003.

An innovative 3D movie of the terrain (DEM) draped by a map of hydrothermal activity has been prepared. Detailed maps of alteration minerals detected during the hyperspectral survey and their spatial relation to known stromatolite and putative microfossil horizons have also been prepared. Regional mineral maps of pyrophyllite, chlorite, sericite, serpentine and other hydrothermal alteration minerals have been developed and new areas of astrobiological interest within the Dome have been uncovered in the process. These include new information about the Strelley Pool Chert, Dresser and Apex Formations. Implications for the Earth's earliest biosphere are presented in graphical form, along with proposed models of hydrothermal activity that could support life on Mars and how such systems might be best detected and interpreted using orbiting hyperspectral remote sensing missions like OMEGA and CRISM.

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Subsurface Astrobiological And Geochemical Exploration Of Mars Using A Pulsed Neutron Generator Coupled With Neutron/gamma-ray Detectors

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The past decade has seen a fundamental shift in our understanding of Mars. The recognition of ancient, fluid-deposited carbonates in the Martian meteorite ALH 84001 [1], debate over ancient life in this meteorite [1], recognition of evolved rock types [2,3] and abundant ground ice [4] have transformed our view of the geologic, hydrologic and (potentially) biologic evolution of Mars. Current exploration on the surface of Mars promises to further our understanding, but current and past rover instruments measure to only ~100 microns in depth.

The '09 Mars Science Laboratory provides our first opportunity for rover-based exploration of the subsurface. Any landing site will likely be laterally and vertically heterogeneous, with a variety of igneous and sedimentary rocks, soils and ice. Neutron/gamma-ray spectroscopy provides subsurface geochemistry complementary to structural information provided by, e.g., ground-penetrating radar. Hydrogen is easily recognized from the combination of the neutron signature and 2.223 MeV gamma ray of hydrogen. Rock types and soils can be distinguished by ratios of major and minor elements (e.g., Fe/Si, Mg/K). Of particular importance are minerals conducive to or indicative of life, including carbonates, phosphates, phosphorites, sulfates, sulfides, and iron and manganese oxides.

Desired sensitivities and spatial scales require an active neutron source. A pulsed neutron generator (PNG) producing $\sim\!10^8 \rm n/sec$ at $\sim\!14$ MeV is preferable to the RTG or a radioactive source. A PNG allows determination of oxygen and carbon abundances, ability to conduct time-dependent measurements, and ability to perform traverse profiling for some elements (e.g., H). A system coupling a PNG with neutron/gamma-ray detectors, with a 5-7 kg mass, can aid in detecting environments conducive to ancient life and provide critical insights about the subsurface geologic environment in which they occur on Mars.

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Search For Microbiology In Cryogenically-collected Stratospheric Particles From Space

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Volumes of air from the upper stratosphere collected via balloon-carried cryogenic equipment have been found to trap interplanetary microparticles (1). Specimens are extracted under clean and sterile conditions. Collection from altitudes up to 41km avoids nearly all particles rising from the troposphere and allows a check on them, so that previously uncertain types of cosmic dust (2) may be identified. Fluffy smoke-like particles with delicate protuberances have been collected, demonstrating that the technique handles particle matter very gently. The samples contain types of interplanetary dust particles (IDPs) previously identified as cometary dust aggregates, asteroidal layer silicates and iron compounds. Particles of order 10µm in size are generally single spheres or conglomerates or lattice silicates. Some mineral composites are highly porous and composed of micron-sized crystals, but other fluffy composities have components down to the resolution limit (~ 0.05μm). The SEM/EDX analysis also shows carbonaceous material components within the composites. Organic composites are seen as clumps of evenly-sized spheres, shown in biochemical tests (anionic and cationic fluorescing dyes) to comprise dead and living cocci (1). Further work has succeeded in culturing particular organisms (3). A class of larger spheres (5-15µm) are spore-like, often with damage cracks and attached mineral particles. Rod-like particles come singly or attached to larger 'spores' and from µm's to over 10µm long. Further studies of the spore-like shells and and clumps containing viable microorganisms are underway, to determine mineralogical and isotopic associations with the chondritic IDPs.

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Earth's Atmospheric Oxygen Rise And Terrestrial Planet Finder

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TPF would detect the presence of life on an Earth-like planet by observing the spectral presence of oxygen or its surrogate ozone. Here we discuss the rise of oxygen on Earth to develop an understanding that can be applied to other planets of various sizes and thermal environments, sp as to understand the expectations of a TPF-type mission. We use the simplifications for volcanic materials described by Holland, but our analysis differs from his by explicitly putting in the biological carbon cycle. We determine that the current oxygen level is stabilized by the oxidation rate of organic matter, and that equilibrium is maintained with a time constant of less than 10⁴ years. We project this understanding back in time and explore the process of oxygenation of the atmosphere. The most likely explanation of earlier lower oxygen abundances is that the oxidation of organic material in earlier times

occurred at lower oxygen levels. The evolution of ecosystems to become less easily oxidized seem to have required environmental characteristics given by Punctuated Equilibrium. There would have been small ecosystems that adapted to higher oxygen levels and the overall population of life must have been strongly depressed. These characteristics are those expected from major snowball/slushball glaciation. Then on return to "normal" conditions, the higher oxygen levels would have been maintained. Following the glaciations, in times where cap carbonates show higher CO₂ levels, oxygenic photosynthesis would be favored over non oxygenic, because CO, would have stayed available, whereas reducing materials would have been deposited during the glaciation. This result is consistent with indications of major oxygen rise after both the 2.3Gya snowball event, and the late Proterozoic events. Application of Punctuated Equilibrium to procaryotes will be controversial, but is perhaps appropriate because of the severity of Snowball events, and perhaps also because of easy Lateral Gene Transfer within a phylum. An apparent problem arises because mass-independent sulfur isotopes (indicating a rise in oxygen) start to appear at 2.475Gya, whereas the first recognized major glaciation occurred at 2.3Gya, yet we require glaciations for the takeover of oxygenic photosynthesis. However, there is evidence of a major earlier glaciation from tillite-like diamictites in the Bruce Formation dating to ~2.7Gya, and scratching/polishing in the Witwatersrand Supergroup. The small capacity of the atmospheric reservoir and the stabilization of gas abundances in it result in the burial of organics and deposition of carbonates being controlled by the volcanic exhalation rates. Together these set the relative rates of deposition of carbonates and organics, and stabilize the C12/C13 ratios in "normal" times. It is concluded that earth's oxygen abundance was driven up by a combination of the albedo instability to glaciation and the tectonic driven CO, production. Thus the size of Earth and its associated tectonic activity seems to have been significant in causing the oxygen rise. TPF should focus on relatively large terrestrial planets ~ Earth size.

Mars Analog Rio Tinto Experiment (Marte): 2003 Drilling Campaign To Search For A Subsurface Biosphere At Rio Tinto Spain

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The Mars Astrobiology Research and Technology Experiment (MARTE) is a field experiment in the NASA ASTEP program designed to search for a subsurface biosphere in the region of the Tinto River in southwestern Spain while simulating a mission to search for subsurface life on Mars. MARTE has a dual focus on science and technology development: achieving new scientific results and demonstrating the technology for searching for a subsurface biosphere on Mars. The Tinto river is located in the Iberian Pyrite belt, one of the largest deposits of sulfide minerals in the world. The highly acidic (pH=2) river is colored red by the high concentration of ferric iron it carries. The extreme chemistry of the environment is produced by a microbial ecosystem that metabolizes sulfide minerals and produces sulfuric acid as a byproduct. Microorganisms found in the river live on chemical energy derived from sulfide and ferric iron minerals found in the region. We hypothesize that similar organisms could thrive in the underground aquifer that underlies the region. The system is of great interest for Astrobiology as an example of life sustained by inorganic compounds operating underground without oxygen and is an important analog to subsurface life on Mars. The first drilling campaign in the MARTE project took place in September 2003 and was focused on characterizing the microbiology of the subsurface at Rio Tinto using conventional drilling, sample handling and laboratory analysis techniques. This paper will describe results from the 2003 drilling campaign. .Lessons learned from our drilling campaign are being used to guide the development of robotic systems and instruments needed for searching for life underground on Mars.

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The Gulliver Mission: The Shortcut To Primitive Asteroid And Mars Sample Return

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The Martian moon Deimos has extraordinary potential as a repository of information about processes of organosynthesis in the early Solar System and the early history of Mars. Deimos is spectrally similar to D-type asteroids and is likely to be a captured primitive asteroid that originated in the outer asteroid belt. D-type asteroids are thought to contain abundant organic materials that may harbour clues to the origins of life. The capture of Deimos apparently took place in the earliest periods of Martian history over 4.4 Gyrs ago. While in Martian orbit Deimos has been accumulating material ejected from the Martian surface. Analysis suggests that Mars material may make up as much as 10% of the regolith on the body. Martian debris on Deimos would be dominated by ejecta delivered during the Noachian Period of basin-forming impacts and heavy bombardment on Mars. As a result, Deimos could be a repository of samples from ancient Mars, including the full range of crustal and upper mantle material from the periods of early differentiation and crustal-formation on the planet, as well as samples from the era of high volatile flux, thick atmosphere, and surface water.

The Gulliver Mission proposes to collect up to 10 kilograms of Deimos regolith and return it to Earth. This sample may contain up to 1000 grams of Martian material along with up to 9 kilograms of primitive D-type asteroidal material. In essence, Gulliver represents two shortcuts. One is to Mars sample return and the other to the outer asteroid belt.

Venus Astrobiology Investigation By Solar Airplane

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To look for life elsewhere in the solar system, one search strategy would be to study environments with pressure, temperature and solar energy conditions where life thrives on the Earth. The only other place where these conditions exist is the atmosphere of Venus, at an altitude of about fifty to sixty kilometers above the surface.

In the early solar system, isotopic composition suggests the amount of water present on Venus was comparable to that on Earth. The detailed process and timing of the loss of water are not known, leaving a blank area in understanding the history of the atmosphere. Did a Venus ocean exist, and if so, was it present for millions of years, or over a billion years?

Near the cloud layers, the present atmosphere of Venus is remarkably earthlike (though lacking free oxygen). While conditions are dry and acidic, extremophilic life has adapted to nearly as harsh conditions on Earth. As noted by Grinspoon and Schulze-Makuch, the atmosphere contains trace gasses outside chemical equilibrium, a possible signature of biological processes.

Finally, the chemistry and environment of Venus is significant to understanding the chemistry of atmospheres and the evolution of terrestrial planet atmospheric chemistry.

Exploration of the atmosphere could be done by drop probes, lighterthan-air probes, or aircraft. Each has advantages and disadvantages. Full access to a range of altitudes and locations requires an airplane, to allow all relevant regions to be sampled.

Figure: Rendered image of the proposed Venus aircraft in flight.

The challenge for a Venus aircraft will be the fierce winds and caustic atmosphere. To remain in sunlight, an exploration aircraft will have to be capable of sustained flight at or above the wind speed. For the astrobiology mission, an aircraft sized for a "Discovery"



class mission was designed. The baseline plan is for an aircraft to fit inside an aeroshell picked to be identical to the 2.65 meter diameter of the Pathfinder aeroshell, sized to fit into the fairing of Delta-II. For astrobiology

mission, the planned mission profile will be to glide down to low altitudes for periods of several hours, analyzing the in-situ location, and then climb back to higher altitudes and fly upwind to the original point, allowing both high and low altitudes to be probed..

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The Lunar Astrobiology Sample Return Mission: Searching For Planetary Material On The Moon

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Space flight missions to study Astrobiologically interesting objects including Comets, Mars, Europa and Titan are either currently in route (Cassini/Huygens bound for Titan) on site (Spirit and Opportunity on Mars), in the developmental phase (Comet Surface Sample Return, Mars Science Laboratory) or in the Early planning phases (Jupiter Icy Moons Orbiter for Europa and Post MSL Mars missions). One mission with potentially large Astrobiology relevance that is not currently under study is a lunar mission specifically to return astrobiologically interesting samples originating from other bodies that have collected there since the lunar crust solidified. We have begun to define and develop a sample return mission concept that will identify non-lunar material, cache it, and return it to Earth for further indepth study in terrestrial laboratories. This non-lunar material could consist of samples of early Venus and Mars released through impacts, meteoritic & comet material and, most promising, early Earth samples which could have retained the chemical signatures of ancient terrestrial environments (Armstrong et al. 2002). This material, removed from the geological and biological weathering processes of the host planet, could be sequestered and protected on the Moon. We will discuss viability of sample deposition on the surface, lunar site selection, and sample processing strategies for a future sample return mission.

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Iron Oxides Inside Metallic Ores Of The Río Tinto Mars Analog As Possible Traces Of Chemolithotrophic Cryptobiospheres. First Geobiology Results Of MARTE Project

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Searching for recent life on Mars requires accessing to areas that are protected against the extreme climatology of its surface. These mild regions are reasonably believed to be underground. However, subsurface exploration of Mars have to overcome serious challenges related to detecting subsurface life with planetary probes, and the development of technology for sounding, sampling and analyzing the hidden areas. MARTE project (Mars Analog Research and Technology Experiment) has been focused to face these challenges developing novel technology for sounding Mars and detecting subsurface life if exists (Stoker et al., 2003).

One of the previous tasks of MARTE has been to sound the basement of a Mars analog, the Río Tinto Basin, in order to extract the subsurface biology and geobiology information using solely standard technology. Río Tinto underground is made of successions of volcanosedimentary stacks (Leistel et al., 1998) having recorded an active hydrothermal history in the form of metallic ores. By considering the geological and biological properties of the basin (López-Archilla et al., 2001; González-Toril et al., 2003), it has been hypothesized the existence of a chemolithotrophic bioreactor that mediates

the chemical conditions of the river.

According to surface (Fernández-Remolar et al., 2003) and subsurface data obtained by geophysical techniques, five sites were selected for the standard sounding of the Río Tinto basement. During 2003, two of these five sites were drilled obtaining 165.35 and 49 meters. First interpretations of cores suggest the existence of different microbial habitats possibly depending on water availability, reduced minerals and oxygen content.

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Definitive Mineralogical Analysis Of Mars Analog Rocks Using The CheMin XRD/XRF

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Mineral identification is a critical component of Mars Astrobiological missions. Chemical or elemental data alone are not definitive because a single elemental or chemical composition or even a single bonding type can represent a range of substances or mineral assemblages. However, minerals can be fully characterized by structural analysis (X-ray Diffraction, XRD) without recourse to other data because XRD relies on the principles of atomic arrangement for its determinations. XRD is the primary means of identification and characterization of minerals on Earth. Using full-pattern fitting methods such as Rietveld refinement [1,2], it is now routinely possible to identify and quantify all minerals present in a complex mixture from diffraction data alone.

Over the last decade, the challenges facing remote deployment of a lowpower miniaturized XRD/XRF instrument have been overcome through the development of a low-power miniaturized X-ray tube [3], sample preparation and sample delivery systems [4-6] and improvement of Charge Coupled Device (CCD) imagers and electronics. CheMin is a fully capable spacecraft XRD/XRF instrument prototype that has no moving parts, can utilize sieved material directly from the JPL rock crusher (a facility instrument on the Mars '09 rover) without further processing, and can perform definitive mineralogic analysis of complex samples using only 5 watts of power. Quantitative results will be shown from a number of Mars analogs including hematite, olivine, basalt, and andesite.

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Wheel Science – Near-contact Surveys For Water, And Carbonates, And Possible Organic Fluorescence During Planetary Surface Exploration

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We propose two survey experiments for planetary surface exploration for seeking life-related species, water, and carbonate, particularly on the martian surface. The lack of direct evidence for organic carbon and the low amounts of water found in the soils at the Viking sites suggests that large amounts of surface material need to be sampled [1]. Recent results of the Odyssey GRS experiment indicate the presence of abundant water ice beneath the Mars surface. Mineralogical evidence for the presence of carbonate or clay minerals, products of weathering and aqueous deposition, have not been identified unambiguously on Mars [2, 3], however. Sulfur is present, but its mineral form not yet identified. Rocks such as shales and, more particularly, limestones, which we associate with moist and benign environments on Earth, are evidently not abundant. Presumably, then, neither were the photosynthetic organisms that might have produced them. In addition, the harsh present environment on Mars (e.g., dryness, low temperatures, large temperature cycles, high level of UV light on the surface, frequent dust storms, etc.) can hide or destroy carbon- and water-bearing materials, so that large amounts of material may have to be surveyed to determine whether they are present in small amounts. Therefore, we propose that "survey" type, near-contact instruments are essential components of the hunt for evidence of minerals that may require water for their formation and for organic substances. Such instruments examine small amounts of material at a time, and they will allow us to assess the spatial distribution of these substances along a rover traverse, should they be observed.

The WIR (Water-wheel IR) is an active near IR (2-6 µm) reflectance spectrometer system designed to detect water as free liquid, ice, or clathrates, H,O and OH bound structurally in minerals, and water adsorbed on the surfaces of fine particles. It can detect carbonates, and under favorable conditions, sulfates and C-H & N-H bonds in organic species. The WUF (Wheel UV-Fluorescence sensor) is designed to detect the short wavelength fluorescence from any source, including life-related species, that is stimulated by an active UV source, and in most cases to discriminate against radiation produced by REE and transition metals in minerals. Both sensors will be installed inside of wells set into the middle wheel of a planetary rover. During rover travel, the IR and UV sources will irradiate soil disturbed by the front and or rear wheel of the rover when the appropriate well is in wheel-nadir position. The reflected IR radiation in the 2-6 µm or stimulated fluorescence from the sample will be collected and recorded. The measurement will not interfere with the normal functions of the rover. Thousands small patches of disturbed soil will be examined in this way, and the statistically large sampling and good detection sensitivity enhances the probability of finding rare substances. In this manner, approximately 20 m² of surface can be examined per kilometer of rover travel.

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Taphonomy Of Europa: A Paleobiologic Search Strategy

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If life occurs on Europa (Chyba & Phillips, 2002), it likely is or was distributed in discrete habitats. These habitats, in benthic, water column, and ice environments (Lipps et al. 1977, 1979), would be distributed heterogeneously and preserved in near-surface ice. If they were preserved over geologic time, a record of past and present life may reside in the icy

Various processes—anchor ice flotation (Isham & Webb, 2003), freezing grounded ice, ice ploughing, cyrovolcanism, diapir formation, for example—may transport habitats to the crust where they are preserved. Ice dynamics and tectonics might expose them at the surface where detailed study and exploration will be possible. Likely exposures would be at ridges,

bands, blocks and matrix of chaotic terrains, and diapirs.

Modern organisms might be preserved too. Ice habitats like pores, channels, and the water-ice interface (Krebs et al., 1982), might be preserved in place. Floating or motile ones in the water column have a greater chance of being incorporated into the ice, if water from below fills openings. While radiation and chemistry preclude extant life on the surface, organisms or biosignatures may be found in ice sheltered by outcrops, ledges, or under ice blocks.

Exploration for life requires imaging likely sites with resolutions of 10cm/pixel or better; for example, with Lockheed Martin's MIDAS instrument (Pitman et al., 2004) to look for cracks, sediment, layering, and possible larger organisms.

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Anion Analysis For Evaluation Of Sample Quality And Potential Microbial Habitats In A Subsurface Fractured Rock Environment: Initial Results From The MARTE Project 2003 Field Season.

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The Mars Analog Research and Technology Experiment (MARTE) project is currently exploring the subsurface biosphere near the headwaters of the Rio Tinto, in southeastern Spain. Hypotheses to be tested include that potentially anoxic chemolithotrophic microbial respiration occurs within the volcanically-hosted massive sulfide bodies there, contributing to the acidic iron- and sulfate-rich springs that feed the Rio Tinto.

In the 2003 field season, two boreholes were drilled for microbiological research. Fractured rock aquifers present a special challenge for microbiological research because habitat is expected to be confined to fracture networks, which are also likely conduits for contaminating drilling fluids. Chemical, biological, and particulate tracers were used to differentiate contaminated and pristine samples. Samples were obtained from 156 1-m core sections using aseptic and anoxic techniques. Tracer data indicated that 75 of these were free from detectable contamination. For the remainder, quantitative analysis allowed determination of whether individual components of the sample could be explained by contamination. Analysis of anions leached from rock samples suggests that subsurface pyrite weathering is centered at two zones within the ore body. These coincide with localized occurrence of nitrate, which could provide an electron acceptor for microbial pyrite oxidation.

Preliminary conclusions are that high quality samples were obtained for microbiological analysis and that in situ resources are available to support anoxic chemolithotrophic microorganisms.

Astrobiology Technology

Development Of A Useful Mars Airplane Exploration At NASA Ames Research Center

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An airborne platform is well suited to exploration of planetary bodies with atmospheres, such as Mars, Venus, and possibly Titan. Unmanned Aerial Vehicles (UAV's) are a high growth terrestrial technology area applicable to planetary science missions. An airplane's range for exploration is greater than for surface platforms. Due to closer surface proximity, the resolution for airplane mounted instruments is greatly improved over orbiter mounted instruments. The variety of terrain accessible to an airplane is greater than for most surface platforms. An airplane is capable of correcting for atmospheric entry errors. The public outreach potential for an airplane mission is also very high. Airplane concepts have risks associated with deployment, flight conditions, and data return. These risks are being addressed through aggressive testing and technology development work, including flight tests in Mars-like conditions. The Mars airplane concept began in 1977 as a follow-on to the Viking project. Studies and tests were conducted at the Jet Propulsion Laboratory (JPL) and NASA / Ames Research Center's (ARC) Dryden Facility. During the last seven years, the pace of development has accelerated rapidly due to work by an ARC team including Cal Poly, San Luis Obispo (SLO), and the Naval Research Laboratory (NRL). These efforts have resulted in two Discovery Mission proposals from ARC and have spawned efforts from other teams, resulting in additional testing and mission proposals. The work has focused on four areas: 1) flight in severe and demanding aerodynamic conditions, 2) packaging the airplane for space travel, atmospheric entry, and deployment, 3) mission performance, and 4) data return. ARC has extensively studied the close interrelationship between these factors. Continued development of Mars airplanes at ARC and other locations, including more flight tests, will provide a useful tool for extraterrestrial robotic exploration and can provide capability augmentation for future human Mars exploration.

Acknowledgements

The KH3 project at ARC is a small group with members from four organizations.

The ARC portion of the team, consisting of Lawrence Lemke and co-authors Gonzales and Corpus, provided overall project management, component and system testing, and systems integration. Use of the Moffett Airfield was also arranged by ARC. R/C aircraft consultation and piloting assistance was provided by Robert Hogan, Division Chief of the Advanced Projects Division in which the KH3 team is located.

The SLO contingent, consisted of David W. Hall and Robert W. Parks, who have teamed for many years to develop unusual, special purpose aircraft for a variety of military and civilian customers. Hall and Parks were responsible for the overall definition, design, and analysis of airplane configurations and fabrication of test articles. Parks provided day-to-day consultation on a variety of issues including aerodynamic performance, test requirements, test hardware, and the simulation and integration efforts. Manual piloting of the low-level portion of test flights not under autopilot control was also performed by Parks.

The NRL group, consisted of Richard Foch, Gregory Page, Peter Chaplin, Steven Tayman, Michael Baur, and Nandy Pizzaro, who are part of a larger group that develops UAV's for use by the military. NRL has a large experience base in simulation and wing unfolding techniques and also consulted on the design of aircraft, provided expertise in the application of folding wing technology, performed mission simulations, and developed flight software. NRL also provided the autopilot, a control station and associated communications equipment, and personnel to support the launch efforts

GSSL was the contractor for the helium balloon flights and provided assistance with integration and communications activities. GSSL launches large high altitude tow balloons to support a variety of scientific and engineering investigations. GSSL also provided weather briefings and co-ordination with the FAA and the military for airspace use. Use of the Tillamook Airport for launch and recovery was arranged by GSSL who also assisted with post-flight tracking and recovery after HAFT1 and HAFT2. Timothy Lachenmeir and Robert Moody were the primary individuals who performed this work. Also participating from GSSL were Craig Brunson and Koh Murai.

Design And Operation Of A Quadruply Differentially Pumped Extreme Ultrahigh Vacuum Machine To Study The Formation Of Astro Biologically Relevant Molecules In Extraterrestrial Ices

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The physical and chemical processes leading to the formation of molecules in the interstellar medium fascinated scientists since the first detection of CH, CH+, and CN radicals in extraterrestrial environments 60 years ago. Although more than half a century passed by and 123 species from molecular hydrogen (H₂) to polyatomics like the sugar glycolaldehyde (HOCH₂CHO) and the amino acid glycine (H,NCH,COOH) have been identified so far, the enigma 'How are these molecules actually formed under the harsh conditions in the interstellar medium?' is still under debate. Classically, the majority of mechanistical information on potential synthetic routes are being derived from chemical reaction networks which actually model the formation of complex organic molecules in interstellar environments. However, in case of glycolaldehyde, models of pure gas phase chemistry focusing on ion-molecule reactions involving for instance methanol and formaldehyde yield a factor of 50-100 less than observed. Alternatively, astrobiologically important species have been proposed to be formed via grain-surface reactions in cold mo≠lecular clouds through radical-radical reactions on interstellar grains and then to be liberated into the gas phase via sublimation in hot cores when the surrounded matter is heated above 100 K by the embedded proto star. However, even those refined models could not fit observed abundances of complex molecules simultaneously and still underestimate their number densities strongly. This suggests that key production routes involving interstellar grains—such as charged particle and/or photon processing—are still missing.

In our lab, we designed a novel, quadruply differentially pumped extreme ultra high vacuum chamber to simulate the cosmic ray and photon induced formation of astrobiologically molecules in space. This contribution presents the key building principles of this new machine (contamination-free vacuum conditions, temperatures, ice compositions, detection of newly formed species in the solid state and in the gas phase via matrix interval algebra). Preliminary results on the chemical processing of neat carbon dioxide ices, carbon dioxide-ethylene mixtures, and of carbon monoxide-methane ices are also presented. These experiments provide the first data under-well defined physico-chemical conditions how, for example, distinct C₂H₄O isomers like acetaldehyde and ethylene oxide can be formed in cold molecular clouds, hot cores, and in cometary ices.

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A New Non-destructive Micro-analytical Method For Stable Carbon Isotope Analysis Of TEM-sections

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Stable carbon isotopes play an important role in the interpretation of biological activity, particularly when the fossil record is studied, and combined with morphological and chemical data, isotopic information may be a very useful tool in paleontological and astrobiological studies.

Here we present a new non-destructive micro-analytical ion beam system for measurement of stable carbon isotope ratios in TEM-samples with high spatial resolution and good statistics. The technique is based on elastic scattering of alpha particles with an energy of 2.75 MeV. At this energy the ¹³C cross-section is enhanced relative to the pure Rutherford cross-section while the ¹²C cross section is reduced. The method has advantages that will make it a valuable complement to other micro- or nano-analytical methods:

- (1) It is a non-destructive method for TEM analysis, and therefore particularly suited for micro/nano-analysis of extraterrestrial and other rare or irreplaceable material.
- (2) There are no matrix effects associated with the method. Thus, any type of solid material can be analyzed, including biological material.

The implications of this method are of particular interest in Martian exploration research, especially for the analysis of samples returned from Mars. Any material delivered from Mars would be considered extremely valuable, and this is particularly true in material containing possible microfossils. Destructive methods would harm or destroy valuable samples, while with the method presented here, carbon isotopes in microscopic samples could be analysed non-destructively.

Titan Ice And Dust Experiment (TIDE): Detection And Analysis Of Compounds Of Interest To Astrobiology In The Lower Atmosphere And Surface Of Titan

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The Titan Orbiter Aerorover Mission (TOAM) (Sittler, et al, 2001), is a proposed concept for the Solar System Exploration Visions Mission, Titan Explorer, a follow-on to the Cassini-Huygens mission. TOAM would use a Titan polar orbiter and a lighter-than-air aerorover to investigate the surface and atmosphere of Titan. Astrobiology issues will be addressed though TOAM investigations including, for example: Distribution and composition of organics (atmospheric, aerosol, surface); Organic chemical processes, their chemical context and energy sources; and Seasonal variations and interactions of the atmosphere and surface.

The TIDE instrument will perform in-situ analyses to obtain comprehensive and sensitive molecular and elemental assays of volatile organics in the atmosphere, oceans and surface. TIDE chemical analyses are conducted by a Gas Chromatograph - Ion Mobility Spectrometer (GC-IMS). This TIDE GC-IMS was a component of the mini-Cometary Ice and Dust Experiment (mini-CIDEX) developed for the chemical analysis of a cometary environment. Both the GC and helium IMS of mini-CIDEX have been further developed to better meet the analytical and operational requirements of the TOAM. application. A Micro-ElectroMechanical System (MEMS) GC (Kojiro et al 2002, Holland et al 2004) and Mini-Cell helium IMS (Stimac and Kaye, 2003) are under development to replace their respective mini-CIDEX components, providing similar or advanced analytical capabilities.

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Building Expertise And Infrastructure For Astrobiology Research In Nevada

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As part of NASA's EPSCoR national program our research group within the University and Community College System of Nevada (UCCSN) seeks to build expertise that fosters contributions to present and future Astrobiological research. In our efforts to stimulate competitive research, enhance education and develop technologies relevant to these Astrobiology, we are 1) developing facilities and techniques for establishing the limits and characteristics of microbial life- with emphasis on cold and icy environments, 2) developing geochemical models of aqueous solutions for studies of microhabitats on different planets within our solar system, and 3) establishing quantifiable links between spectroscopic signatures and habitable environments on earth as analogs for Martian and Europan conditions. We also are developing technologies capable of characterizing UV radiation fluxes on Mars. All of these research activities aid in the accomplishment of specific objectives that are derived from NASA's Astrobiology Institute's goals.

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Enzyme-cascade Analysis Of The Rio Tinto Subsurface Environment: A Biosensor Development Experiment

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The Personal Test System (PTS), designed & developed by Charles Rivers Laboratories and Dr. Norman Wainwright of the Marine Biological Laboratory, is a portable instrument that was designed to perform analysis of enzymatic assays related to rapid assessment of microbial contamination (Norman R. Wainwright 2003). Enzymatic assays are known to be one of the most sensitive techniques available for microbial detection; hence this instrument is being evaluated as a potential life detection technology for in situ Astrobiology missions. In the summer of 2003 the system was tested as a part of the Mars Astrobiology Research and Technology Experiment (MARTE) ground truth science campaign in the Rio Tinto Analogue environment near Nerva, Spain. The preliminary results show that the PTS analysis correlates well with the contamination control tests and the more traditional lab-based biological assays performed during the MARTE field mission.

Further work will be conducted on this research during a second field campaign in 2004 and a technology demonstration of a prototype instrument that includes autonomous sample preparation will occur in 2005.

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Remote Sensing Astrobiological Space Science Enabled by the Multiple Instrument Distributed Aperture Sensor (MIDAS) Concept

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The Multiple Instrument Distributed Aperture Sensor (MIDAS) concept provides a large-aperture, wide-field, diffraction-limited telescope at a fraction of the cost, mass and volume of conventional spacecraft telescopes. By integrating optical interferometry technologies into a mature multiple aperture array concept [1], MIDAS fulfils primary astrobiological science capabilities necessary for advancing future planetary science remote sensing [2]. MIDAS acts as a single front-end remote sensing science payload for multiple missions, reducing the cost, resources, complexity, and risks of a set of back-end science instruments (SI's) tailored to each specific mission. MIDAS enables either sequential or concurrent SI operations in all functional modes, such as passive imaging at diffraction-limited resolution sequentially by any one SI, or at somewhat lower resolution by all SI's concurrently. In its active remote sensing modes, using an integrated solid-state laser source, MIDAS enables LIDAR, vibrometry, surface illumination, ablation, and laser spectroscopy. MIDAS inherently provides nanometer-resolution hyperspectral passive imaging without the need for any moving parts in the SI's, enabling effective searches for key signs of life [3]. On a mission to the icy moons of Jupiter, MIDAS addresses most top level science requirements [4] by providing high-resolution imaging of the geology and geomorphology of the surface [5, 6], high spectral resolution to help determine the geochemistry of surface materials [7, 8], and active imaging to help conduct seismic and tidal studies [9]. The MIDAS optical design features high-resolution imaging at high-altitude with long dwell times, enabling real-time wide-area remote sensing of dynamic changes in planet surface characteristics. The powerful combination of MIDAS passive and active modes, each with sequential or concurrent SI operations, increases potential science return for astrobiological planetary science

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Development Of An Extremophile Microbial Digester For Astrobiology Relevant Biomass Production

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Large volume digester/chemostat studies are not normally associated with extremophile microbiology. This is particularly true for psychrophilic (low temperature), halophilic (high salt adapted) anaerobic communities. The low rate of culturing success and long culturing times required discourages the use of large volume culturing techniques for these communities. This is unfortunate for astrobiology, because low temperature brine environments are particularly attractive possibilities for extending water, and thus the potential for biologically viable habitats into otherwise unfavourable locations and conditions (like subsurface Europa and Mars).

The digester developed in this study provides two significant advantages over normal culturing techniques by developing:

An operational instrument test chamber (8.5 litre volume) with active, monitored and controlled psychrophilic and halophilic, anaerobic metabolism in situ.

A substantial quantity of biomass product, under astrobiology relevant conditions, for development of biosignature target material.

The initial proof of concept target culture habitat used was a high sulfate brine environment that was moderately halophilic ($\cong 2.5\%$ salt as NaCl) and psychrophilic (4°C). Robust sulphate reduction, substrate utilization, and target biomass production is currently being observed and reported. This

initial test environment most directly relates to development of a Europan relevant biosignature development target biomass production.

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Special thanks go to Dr. Christian Fritsen of the Desert Research Institute and Dr. James Taranik of the Nevada Space Grant Consortium for their support of this work.

Controlled Fluid-Inclusion Extraction

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Fluid inclusions in rocks and minerals act as sealed containers and may hold valuable information about the temperature and composition of the fluids in which the minerals precipitated. Hydrocarbons are occasionally trapped inside the inclusions, something that may provide important information about the ancient biosphere on Earth, and possible biotic and abiotic hydrocarbons on Mars. To perform (often needed) direct analysis of trapped hydrocarbons, it has been necessary either to crush the sample or to heat it, with subsequent decrepitation of the inclusions, in order to extract the fluids. However, a disadvantage with crushing or heating is that a mean composition of all fluid inclusions in the sample is analyzed, and no distinction is made between primary and secondary inclusions.

Here I present a novel concept to extract selected fluid inclusions with a minimized risk of contamination. The method is based on the illumination of selected fluid inclusions with a laser of a wavelength that is absorbed by water and organic material, but not the minerals encapsulating the fluid (as a contrast to laser ablation). Thus, when the inclusion is illuminated by the laser, the fluid expands and the inclusion decrepitates. Since the sample is placed in a vacuum chamber, the fluid evaporates, and may subsequently either be collected in a cooling trap, or transported by a carrier gas directly for analysis.

Minimized contamination risk and the potential ability to extract selected fluid inclusions could make the method a useful tool in the search for organic biomarkers in early-Earth material, and eventually, in samples returned from Mars.

Examination Of An Endolithic Community From A Mars-analog Location By Laser-induced Breakdown Spectroscopy (LIBS)

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Laser-induced breakdown spectroscopy uses a pulsed laser to ablate a target material, generating a short-lived plasma with each laser pulse. Emitted light from this plasma amounts to an elemental emission spectrum that is collected and used to identify the composition of the target material. The LIBS method is under active investigation for use in future planetary exploration². In the case of the search for life on Mars, this technique may be especially useful for identifying endolithic organisms since LIBS is capable of detecting a wide range of elements including C, N, O, P, and H to a depth of several millimetres in the target material^{2,3}. In order to provide a basis for future comparison, data will be presented on LIBS spectra collected from an endolithic organism-containing carbonate sample collected at the Marsanalog location of Svalbard in the Arctic Circle⁴.

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Carotenoid Pigments As Potential Biomarkers: UV-Resistant Bacteria Isolated From Rock Varnish

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Rock varnish is a dark, nanosedimentary coating composed of clay minerals cemented together by oxides and hydroxides of manganese and iron (Potter and Rossman, 1977; Perry and Adams, 1978). It has been suggested that varnish-like materials may exist on Mars (e.g. Guinness, et al., 1997). Bacteria have been frequently isolated from terrestrial varnish (e.g. Hungate, et al., 1987; Eppard, et al., 1996).

The microbial community in rock varnish from the Whipple Mtns. in the Sonoran Desert is quite diverse (Kuhlman, et al., 2004). In addition, large numbers of bacteria (10^7 - 10^8 per gram dry weight) are associated with this varnish (Kuhlman, et al. 2004b). Several bacterial colonies grew from varnish exposed to UV(C) irradiation at $52~\mu \text{W} \cdot \text{cm}^2$ for five minutes. These colonies were picked and restreaked until pure. Samples of the pure cultures were characterized using 16S rDNA sequencing techniques and the lethal dose of UV(C) was measured for each.

Meanwhile, Raman imaging and IR spectroscopy were performed on samples of these pure cultures. Peaks due to carotenoid pigments were found in the case of the culture found to be 99% related to Geodermatophilus obscura, raising the possibility of using the Raman and IR signatures of carotenoids and their derivatives as microbial biomarkers. Carotenoids are shared by many other life forms, including bacteria, but may provide features that are unique relative to minerals/rock, providing a recognizable signature of life. Raman and IR fingerprints have already been used to classify a number of bacteria and yeasts (Maquelin, et al., 2002).

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Robotic Autonomous Genetics Technology Demonstrations on Nanosatellites

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Advances in miniaturization of key technologies coupled with the emergence of a nascent secondary payloads market for small spacecraft (with associated launch opportunities) offer a new, low-cost approach to space biology research. One of the first biologically related missions of this sort is the recently initiated In-Situ Genetics Experiments on Nanosatellites (ISGEN) project. This project is chartered to design and develop miniature biological stasis, growth, and analysis systems along with the necessary

life support (culturing) capabilities to study gene expression in model small/micro organisms in a fully self-contained, autonomous system that telemeters results to Earth, requiring no specimen return. The main components of this project are technology demonstration modules including quantitative fluorescent imagers, liquid arrays for the replicate study of multiple genetic constructs, miniature environmental control systems, and microfluidic subsystems. These modules will enable small gene array analyzers, small spacecraft systems that can be carried as secondary payloads on planned missions, and specific reference-experiment protocols designed for the study of genetic changes arising from the unique space environment. This paper will describe these systems in detail and discuss future technologies under consideration for use on small spacecraft and related platforms, which could lead to the development and construction of in-situ genetic analysis tools and technologies for deployment in a number of Astrobiology missions.

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Development of an Extremophile Microbial Digester for Astrobiology Relevant Biomass Production

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Special thanks go to Dr. Christian Fritsen of the Desert Research Institute and Dr. James Taranik of the Nevada Space Grant Consortium for their support of this work.

In-Field Testing Of Life Detection Instruments And Protocols In A Mars Analogue Arctic Environment

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During August of 2003 an expedition including 19 scientists tested various equipment at a series of hotsprings sites on the island of Svalbard. This island is considered a Mars analogue environment due to the presence of hot springs, carbonate terraces and volcanic activity which have produced carbonate rosettes similar to those found in ALH84001. The goal was to test 4 portable instruments for their robustness as field instruments for lied detection (for future human missions to Mars), to assess the Mars analogue environments for signs of life, to refine protocols for contamination reduction and to understand the effects of transport on sample integrity by assessing bioloads immediately in the field and then comparing these with laboratory measurements made after transportation.

The instruments used in this investigation were; ATP luminometry which assays for ATP as a measure of metabolic activity; Scalar DG2 hand held digital microscope which enables digital microscopy images to be captured at magnifications of up to x200. Charles River Endosafe unit which uses the Limulus Aemebocyte Lysate assay (LAL) and Mobile PCR, which is manufactured by MJ research.

We were able to detect and quantify bacterial load from several sites including endolithic communities from travertine dry terraces at the site. We have been able to use functional gene analysis in the field to rapidly constrain the types of bacterial activity being undertaken within the hotsprings site. We refined one suite of techniques and protocols to enable primary life detection and characterisation in the field. These techniques could also be used in support of trials of flight hardware being developed to detect microbial life on Mars or elsewhere.

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The entire AMASE team and crew of M/S Polarsyssel especially Tori Hoehler who spotted the endoliths. NAI Wes Huntress, Mike Meyer and the ASTEP program.

The SSBRP Incubator: A Tool For Space Biological Research

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The International Space Station (ISS) offers a unique opportunity for scientists to investigate the characteristics of the biological response to the space environment over multiple generations. The NASA Space Station Biological Research Project (SSBRP) is developing an Incubator designed to accommodate the growth of a variety of specimens including plants [A. thaliana], small animals [C. elegans and D. melanogaster], and microbes. It is anticipated that the Incubator may be used to study physiological, developmental, and radiation biology effects on these organisms. Comparative gravitational biology studies using the Incubator are also possible by placing one Incubator on the 2.5-meter Centrifuge Rotor (CR) of the ISS Centrifuge Accommodation Module and maintaining another in the microgravity environment. The use of the CR provides researchers with on-orbit 1-g controls and the potential to conduct experiments that expose biological specimens to intermittent or reduced gravity, including simulated Lunar, Martian, and Earth gravity. Power and data communication ports inside the Incubator specimen chamber also provide the capability to support experiment unique equipment.

A Logging Instrument For Subsurface Planetary **Exploration**

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Mars subsurface exploration is an objective of the coming missions to the red planet in order to study the different layers that are piled up below the surface of any planet, collecting knowledge about geology processes, ancient and recent climate and data about the present and past biosphere.

On Earth, core drilling has been used in petroleum, gas and water market as well as in geological research for many years. Borehole logging is used, from the beginning of last century, to measure geophysics parameters from the wall materials as well as from the surrounding rocks, as a complement to core analysis. In fact, there are many logging tools in the market capable of performing these tasks.

In the frame of the MARTE project (Stoker, 2003) a complete system has been designed to accomplish logging activity during the Mars subsurface simulation campaign, since these techniques have been considered suitable for Mars exploration (Blacic et al. 2000). The Bore Hole Inspection System (BHIS) is built up by two subsystems: a deployment module and logging tools (Borehole Inspection Tool, BHIT). The deployment module will be placed on the "lander" platform and will hold the BHITs during drilling activities. This module will position the BHIT over the hole and will control its movements inside it by means of a special winch. Furthermore, it houses all the electronic and power modules.

As on earth logging, the aim of this system is to identify the geo-biologic characteristics of the subsurface. Several techniques have been identified to be implemented, but only a Raman spectrometer, a camera for microscopic images, and resistivity and magnetic susceptibility sensors have been selected. Based on that, both the Raman probe and the camera have been implemented in a special instrument, providing scanning capabilities. Resistivity and magnetic susceptibility will be measured with standard

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Field Testing As A First Step Towards An Automated Soil DNA Extraction Instrument For Use With PCR On Mars-Like Soils.

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We have proposed to develop an instrument to extract DNA from hyperarid soils which contain extremely low levels of biological material. The ability to conduct nucleic-acid based analyses on soil samples on Mars will be important both for planetary protection questions and as one of the first steps in any search for life on Mars. Automated DNA detection systems based on Polymerase Chain Reaction (PCR) are well established. However, for application to soil samples, the main difficulty is extracting the DNA from the soil matrix and removing compounds that might inhibit the PCR reaction. The former is particularly difficult for extremely arid soils with low levels of biological material which are highly desiccated and tightly bound to the soil. Our basic design leverages existing extraction technologies and chemistries, but automates the cumbersome process, paving the way toward automated and integrated life detection instruments for terrestrial and planetary explorations. In the approach proposed, soil samples are first added to a solution that lyses any cells, thus releasing their DNA. Reagents are then added that remove soil substances (e.g., humic acids) that interfere with the DNA amplification. The final step is the purification of the DNA by chemical treatment. The sample is then ready for delivery to a standard PCR amplification system (e.g., commercially available real-time PCR).

This approach and process was successfully tested in the Atacama Desert, Chile, in November, 2003. The results show that in-situ Soil DNA extraction and PCR amplification and detection can be accomplished in the field on Mars-like soils. The in-field results confirmed previously published bench-top laboratory results (Navarro-Gonzalez, et. al., 2003) reporting no recoverable DNA in some of the Mars-like soils of the Atacama Desert. The current sensitivity of the system using these protocols and procedures was determined to be about 500 CFU/gram of soil, with an eventual goal of 1-10 CFU/gram of soil. These positive results provide the baseline configuration of system specifications required for the successful development of an automated soil DNA extraction system that has the sensitivity required to detect extremely low levels of microbes in Mars-like soils. Here we will present the hardware and protocols used in the field, the results, and an overview of the proposed automated soil DNA extraction instrument for Mars-like soils.

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We wish to thank Cepheid, Inc., for providing training, probes, primer, enzymes, and a Smart Cycler, Real-Time PCR Instrument for use during preliminary process development and data collection in the Atacama Desert. We also acknowledge support from NASA's Astrobiology Science and Technology for Exploring Planets program.

Automating Protein Microarrays For Biomarker Detection

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Identification of molecules of biological origin from soil samples is of great astrobiological and environmental interest. Molecular biology techniques based on the specificity of biological recognition (bio-affinity) have been extensively developed for biomarker detection (nucleic acids, proteins, lipids, other metabolites). These techniques are the fundaments for the development of many biosensor devices. DNA and protein microarray technology allows covalent binding of thousands of probes in an small area (few square centimeters) on a solid support. That microarrays can be considered as a kind of bio-affinity biosensor. Antibodies are one of the most appropriate receptor elements in a protein detection microarray because they possess the specificity required to identify a target epitope. Antibodies are large molecules that can react with other substances, including fluorophores, other proteins or even other antibodies, without affecting the binding capacity and specificity to its antigen. Some advantages of antibody arrays are: Multiple probes at a time, including many positive and negative controls, as well as internal calibration curves; no special external calibration or standards are required for the assay; robustness; very little sample pre-processing; relatively easy automation; etc.

Based on protein microarray technology, we have design and built a prototype instrument called SOLID (for "Signs Of LIfe Detector") for the detection and identification of biochemical compounds. Our system include all the mechanisms, detectors and electronics needed to automatically operate and collect results. The prototype (patent pending) is now being tested in the laboratory using commercial and home made antibodies. Instrument and first laboratory results will be shown.

Autonomous robotic placement of contact instruments for planetary science

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Future Mars rovers, such as the planned 2009 MSL rover, require sufficient autonomy to robustly approach rock targets and place an instrument in contact with them. It took the 1997 Sojournerars rover between 3 and 5 communications cycles to accomplish this. The current 2003 MER rovers require the same level of operator intervention. This paper describes work at NASA Ames on a method to robustly accomplish single cycle instrument deployment using the K9 prototype Mars rover. An off-board 3D site model is used to select science targets for the rover. K9 navigates to targets using visual feedback, autonomously assesses the target area to determine where to safely place an arm mounted microscopic camera, then places the instrument to make the measurement. Onboard K9 is a resource cognizant executive, which extends the complexity and duration of operations that can be accomplished without intervention from mission control. We have demonstrated effective single cycle instrument placement that can provide future Mars rover missions with the capability of making one or more contact instrument measurements in a single Sol.

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Autonomous Small Robot for Use in Mars-Like Environments

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As Science Missions evolve, they are becoming more complicated. Not all science objectives and hardware can be accommodated with all-inclusive robots (those that have the full science package as an integrated component of a robot). There is a need for small autonomous exploratory robots which would work with a central Base Station containing the primary science hardware. These robots would be tasked to explore and catalog nearby regions (5-10 km range) and would have on-board sensors to collect preliminary science data sets as well as sample collection systems for transportation of samples back to the Base Station for more detailed analyses.

A small autonomous prototype robot, "Elias", has been developed to autonomously traverse the Mars-Like environment of the Peruvian Desert un-aided by a remote operator, while avoiding obstacles and locating a predetermined target as a first step towards satisfying this mission scenario. Elias has been developed using commercially available mechanical and electrical components. An on-board computer controls motion, collects and transmits sensor data, and provides communication with the Base Station via a Max Stream wireless modem (2.4 GHz). The obstacle avoidance system uses two ultrasonic range finders to sweep for objects in the predetermined path. Autonomous navigation is coordinated by the Base Station using Matlab, internal compass sensor data, and a time delay signal from the robot in order to determine position and distance. On-board rechargeable batteries provide about 5 hours of operation. Elias has a size of 27x27x10cm, weighs about 1kg, and can walk at a rate of about 3 meters per minute depending on the surface material.

Elias was tested in the Peruvian Desert in January, 2004. Basic communication and control in-between Elias and the Base Station were established for a 1.5 km distance and basic walking tasks were demonstrated in this Mars-Like environment. Forward work includes the installation of an upgraded obstacle avoidance system and a full-scale test for a 1 km distance to demonstrate the full capabilities of this autonomous robot. Here we will present an overview of the robot design, autonomous object avoidance and navigation systems, and the most recent results.

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Astrovirology

Bacteriophage Genomics: Evolution Of The Majority

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Tailed, dsDNA-containing bacteriophages probably constitute the majority of organisms on Earth. The recent availability of significant numbers of genome sequences for these viruses and comparative analyses of those sequences has led to an improved appreciation of the mechanisms by which they evolve, of their population structure and dynamics, and of the remarkable diversity of their genetic information. The hallmark of the phages' genome structure is genetic mosaicism, reflecting non-homologous recombination events in their ancestry. We have recently determined

the genome sequence of phage G, a Bacillus megaterium phage with a 497,513 bp genome and 684 genes, and other "jumbo" phages are in the works. G is remarkable for the facts that only 26% of its predicted protein sequences have detectable matches in the sequence databases and that many of those that do match look more like "bacterial" proteins than "phage" proteins (e.g., FtsZ, tRNA synthetase; also 17 tRNA's and one tmRNA). These findings emphasize the close interconnections between evolution of bacteriophages and evolution of their hosts.

"Astrovirology" The Nai Virology Focus Group.

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Archaea and other microorganisms that inhabit extreme environments are very common and a large body of literature has accumulated on their characteristics. Relatively little is known about the viruses that share this environment with them. Available data indicate that viruses of extreme environments can be very differnt from other viruses. Knowledge of their structure, replication processes, molecular biology, and gene function will add to our understanding of how viruses fit into these demanding environments and into the evolutionary scheme. There are several fascinating questions that can be addressed. What role, if any, did viruses have in the period when life began and shortly afterward. Did viruses develop on Mars, Europa, or elsewhere in space or were they transported there, and, if so, how could they be detected? Many of the genes that appear in Archaea have homologous couterparts in organisms from more temperate environments. Are the functions of archaea still retained in the homologous genes and, if so, what is the effect of phages of Archaea on function. Are any of these viruses pathogenic in humans or other organisms. There are exciting possibilities in a field of study that is just beginning.

Why is experimental evolution important for astrobiology?

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Astrobiology seeks to identify life elsewhere in the Universe, and to understand how these life forms evolve. Viruses are overwhelmingly successful on Earth, suggesting that virus-like elements are likely to evolve under favorable conditions elsewhere. How might these viruses differ from typical Earthly viruses? The study of viruses in extreme environments may yield some clues. Viruses isolated from extreme habitats tend to phenotypically differ from those found in more benign environments, but striking similarities exist as well. These findings yield hope that we can accurately identify virus-like elements off Earth. But we lack even a basic understanding of what drives the evolution of viruses at life's extremes, in environments that might be encountered elsewhere in the Universe. Experimental evolution (laboratory study of evolution-in-action) provides a powerful approach for examining the various possibilities.

Studies of experimental evolution in viruses can be highly informative for developing future space missions. Manned space missions would expose humans and other essential organisms (e.g., cultivated plants) to environmental forces different than those experienced within our atmosphere. How would the exposure affect associated microbes, such as the bacteria that aid in our digestion or that symbiotically interact with plant roots? Genome sequencing projects reveal a surprising amount of viral DNA incorporated within the chromosomes of host organisms. These stretches of genetic information are hallmarks of prior infections, but it is long known that environmental stimuli, such as exposure to UV light, can cause latent viruses to excise from bacterial chromosomes and become active again. Might similar phenomena impact the organisms taking part in long-term space missions? By simulating these novel conditions in the laboratory or on a space station, one can use experimental evolution to examine the effects and risks of virus re-activation. Once a manned mission has reached its destination, what is the possibility that the foreign virus-like elements might infect mission organisms or contaminate equipment? The likelihood deals largely with the ability for viruses to survive and adapt in conditions different from the extreme habitats they are suited to. Once again, one can use experimental evolution to look at the adaptive potential of extreme viruses in their own and in dissimilar environments. How broad or narrow are the abiotic conditions (heat, cold, pH, pressure) that support virus evolution at the extremes? These questions have not been thoroughly explored, but my lab group has been actively collecting viruses from extreme environments, and conducting experiments that address these issues.

Biogeochemistry

Context For The 3.46 Ga Old Apex Chert 'Microfossils' And An Early Hydrothermal Biosphere?

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The aim of our continuing studies of the Apex chert is to further test hypotheses put forward by Brasier et al. (2002) through a programme of integrated field mapping, petrography, paleobiology and geochemistry. Two field seasons have now been completed, generously assisted by the Geological Survey of Western Australia. The results are being prepared for full publication, and include geological maps of the Chinaman Creek region (areas 12km square), fabric maps plus a detailed atlas of the Apex 'microfossils', their context and origin.

We conclude that the carbonaceous, black chert dyke of Chinaman Creek (that contains the 'microfossils') accreted along one of several growth fault systems that had a strong influence on patterns of surface deposition, allowing the recognition of three separate fault blocks. Volcaniclastics appear to have been sourced from two large fractures - the Southern Boundary fault and the Chinaman Creek fault, both now preserved as black chert dykes. These, and smaller fracture arrays, are argued to have acted as major conduits for hydrothermal circulation during deposition of the stratiform Apex silica deposits, also supplying iron, barite and transition metals. These black chert dykes underplate and dilate the stratiform cherts but do not rise above them. We are currently exploring the contributions of deep biological and abiological sources for some or all of the isotopically light carbon within the Apex cherts.

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Turning Ferns Into Fossils: Biogeochemical Alchemy

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Understanding the processes of fossilization is vital to the interpretation of fossils themselves, especially of geochemical fossils. The search for past life on other planets will likely be the search for such biosignatures or, at best, morphologically intact fossil "microbes". However, the interpretation of ancient microfossils found even in terrestrial sediments has been hotly debated for years. It is for this reason that new techniques and approaches to organic chemical characterization of morphological fossils and geochemical biosignatures must be developed.

Laser-Raman spectroscopy, nuclear magnetic resonance spectroscopy, and pyrolysis-gas chromatography/mass spectrometry are three such techniques. This study involves the use of these three techniques to analyze the structural chemistry of a modern fern (Dennstaedtia cicutaria) and its Eocene-aged three dimensionally permineralized fossil analogue (Dennstaedtiopsis aerenchymata) as well as representative individual structural biochemicals of fern cell walls. Specimens of the modern fern and aliquots of the biochemicals have been anoxically thermally degraded to simulate the alteration that occurs during diagenesis and resultant fossilization.

Results thus far are promising. The analyses show that there is a wealth of chemical information preserved in the fossil organic matter that is of sufficient quality to be informative about its original composition. Moreover, the heating experiments show that the organic matter of the modern fern can be converted into carbonaceous matter that closely resembles that of the fossil fern, providing new insight into the processes and products of geochemical maturation. The three analytical techniques investigated, useful for analyzing fossil terrestrial organic matter, hold promise for studies of extraterrestrial materials as well.

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Nighttime Loss Of Fermentation-Derived Organic Acids As The Basis Of A Syntrophic Link Between Phototrophs And Heterotrophs In Microbial Mats

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Well-established, permanently submerged photosynthetic microbial mats dominated by Microcoleus chthonoplastes were found to lose significant quantities of low-molecular weight organic acids to the overlying water when incubated under dark, anoxic conditions. Thin pioneering mats on exposed mudflats dominated by Lyngbya sp. also lost acids under these conditions, but at even higher rates. These losses are presumably due to fermentation of storage polysaccharides by the cyanobacteria in the mats to gain energy for both maintenance and nitrogen fixation activities. Both types of mat followed a pattern in which lactate was lost at the highest rate immediately following the onset of anoxia, but this flux ceased within 3 hours. Fluxes of acetate, formate and propionate continued at constant rates while dark, anoxic conditions were maintained (~12 hours). This difference in behaviour between lactate and the other acids may reflect their origins in different pooled storage carbohydrates (e.g. glycogen v trehalose). In any case, their loss to the medium, along with any hydrogen also produced, provides an opportunity for direct coupling of phototrophs and heterotrophs living in the mat. Sulfate reducing bacteria probably use these substrates directly and may also use this energy source to fix nitrogen themselves aiding the mat's overall fixed nitrogen yield from this fermentation. Removal of these products will also aid the thermodynamic favourability of continued fermentation by the cyanobacteria. These links, beneficial to both partners, form the basis of a syntrophic relationship between the phototrophic and heterotrophic members of the mat community.

Synthesis Of And Calculations On The Inorganic Core Of The Photosynthetic Water Splitting Catalyst: Blueprint For Renewable Hydrogen Generation?

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We shall summarize experimental and computational progess that brings us closer to understanding the in vivo mechanism and in replicating this chemistry in abiotic water splitting catalysts inspired by the photosynthetic enzyme. Understanding photosynthesis is important for understanding life, the development of the atmosphere on earth and possibly renewable hydrogen generation in the future.

Data from EPR and XAS spectroscopies and new X-Ray diffraction of the photosynthetic water splitting enzyme concur that the active-site inorganic core appears to contain a "calcium capped manganese-oxo cubane core" containing the [Mn4O4]ⁿ⁺ cluster bridged by a corner oxo to Ca²⁺.

In anticipation of this outcome we previously synthesized the novel μ_3 -oxo core types: $Mn_4O_4^{\ 7^+},\ Mn_4O_4^{\ 6^+}$ and $Mn_4O_3(OH)^{6^+}$ and demonstrated both activated release of molecular O_2 and selective reduction to two water molecules and $Mn_4O_2^{\ 6^+}.$ This chemistry is unique to the cubane topology and does not occur in simpler μ_2 -oxo core types. Both experiments and dynamic density functional theory calculations confirm that O_2 forms via a homolytic intramolecular pathway involving a peroxo intermediate in this model system. An alternative mechanism involving the heterolytic attack of activated water on a manganyl $(Mn^V\!=\!O)$ is also possible under some circumstances.

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The Search For Extracellular Biological Tungsten Ligands

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Trace metals are typically required by microorganisms as micronutrients, commonly for catalytic roles in a variety of enzymes. However, under nutrient limiting conditions in the environment, microorganisms may secrete ligands, such as siderophores, to scavenge trace metal micronutrients. In the marine environment, hydrothermal fluids contain large amounts of trace metals compared to typical seawater: for example, one study reports tungsten concentrations 3x greater in hydrothermal fluids (Kletzin & Adams 1996) than is found in seawater. Nevertheless, even though research has demonstrated the existence of metal-specific ligands in seawater (Bruland 1992; Saito et al. 2002; Croot et al. 2003) the nature and source of these ligands have yet to be determined.

Tungsten is one trace metal which may be biologically important to hyperthermophilic microorganisms inhabiting deep marine hydrothermal settings. These microbes will transport metals from hydrothermal fluids into their cells but it is not known if they need to secrete ligands to preferentially leach metals, such as tungsten, from basalts and minerals.

Through supernatant growth experiments, we investigated whether the facultative aerobic hyperthermophile, Pyrobaculum calidifontis, would produce tungsten-specific ligands under tungsten limiting conditions but in the presence of basalt powder (USGS-BIR). Additionally, cell-lysing experiments were conducted with another hyperthermophile, Pyrococcus furiosus, to determine the tungsten content within hyperthermophilic cells and to investigate the cell's uptake of tungsten from the environment. The concentration of tungsten, as well as Ca, Mg, Mo, Sr, Ni, Cr, Fe, P, S & K were measured via ICP-MS. In the growth experiment, ligand production would be indicated by enhanced metal leaching in the biotic component as compared to the abiotic control. However, the same trends in metal concentration and behaviour were observed in both biotic and abiotic components, indicating metal-specific ligands were not produced. Furthermore, the concentration of tungsten measured in the lysed cells were below detection levels, indicating there was originally very little of the trace metal in the cells and also, that the organism's uptake of the element over the growth period, was negligible.

Initial results based on our experiments suggests hyperthermophilic microorganisms do not produce tungsten or any other metal-specific ligands to leach trace metals from basalts. In addition, the low levels of tungsten present within the cell indicates that further work to determine the presence or absence of tungsten ligands may require optimization of experimental conditions.

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Understanding The Rock-Water Interactions Of The Subsurface N Cycle

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One of the most exciting scientific advances of the past decade has been the discovery of microbial life existing in the deep subsurface and the subsequent speculation that it may further serve as a parallel to extraterrestrial life. By looking towards the most extreme reaches of life researchers have probed what defines the essence of "life" and although our definition remains unclear, there remain certain required elements. Thus, the terrestrial

subsurface biogeochemical cycling of C, H, P, S, and N should likely occur, but to what degree it differs from our known cycles remains unresolved. With a slower water turnover time and different suite of substrates in the subsurface, the processes, end products, and rates of such cycling could be completely different. This study begins to explore where the deep biosphere derives its N, how it cycles, and whether or not it is limiting.

A perfect locale to study such questions is the Archean igneous/ metamorphic bedrock and sedimentary strata of the Witswatersrand Basin, South Africa, which is accessible down to depths of 3.5 kmbls due to the Au mining. In order to study the subsurface N cycle, the various organic and inorganic N species of the N cycle within fissure water and rock samples of the Witswatersrand strata were characterized, quantified and their 15N/14N isotopic ratios measured. Fissure water NO3- concentrations ranged from below detection limit to 14 uM while NH4+ levels ranged from 0.58-175 uM and N2 concentrations were between 0 and 52 mM. In comparing fissure water C:N:P ratios, it appeared as though N may be the limiting nutrient since total P numbers are sufficient. However, PO43- may prove to be the ultimate limiting factor as it seems bound to organic ligands and thus not bioavailable. Noble Gas age estimates for the samples ranged from 50-365 Ma.1

Preliminary results showed $\delta 15N2$ of the mine gas samples ranging from -2o/oo to +5.76o/oo. The $\delta 15N$ of the NH4+ and the NO3- will be determined soon. Rock pore water chemistry is currently being characterized to establish the matrix/fracture chemical fluxes of C, N, and P.

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Hot Spring Microbial Mats: A Model For Precambrian Banded Iron Formations?

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Precambrian Banded Iron Formations (BIFs) contain substantial oxidized iron and are extremely low in manganese. Early photosynthetic organisms are assumed to have played a major role in the formation of these iron deposits by either oxidizing the iron directly or by producing oxygen during photosynthesis, which in turn oxidized the iron. Microbial mats at Chocolate Pots Hot Springs in Yellowstone National Park were studied to resolve their possible role in iron oxidation. The microbial mats were composed of oxygenic cyanobacteria and the anoxygenic phototroph Chloroflexus. Voltammetric microelectrodes were used in situ to measure oxygen, peroxide, manganese and iron concentrations simultaneously in the mat with 0.1mm resolution. 14C-bicarbonate uptake experiments were conducted with mat samples to test for iron-dependent photosynthesis. Our in situ measurements showed that photosynthesis produced enough oxygen to remove all iron (II) from solution. An infrared filter was used to determine if anoxygenic photosynthesis played an important role in oxidation of iron (II), but no significant oxidation was observed. This implies that the primary mechanism of iron oxidation in this microbial mat is oxygen production by cyanobacteria. We confirmed that rates of CO, fixation by cyanobacteria were enhanced in the presence of iron and were much higher than those of anoxygenic phototrophs. Photosynthesis in light intensities >270 W m⁻², produced enough oxygen to remove all iron (II) from solution. CO, fixation rates also increased with increasing light intensity, attaining maximal values between 200 and 300 W m⁻². Changing from darkness (<4 W m⁻²) to full sunlight (620 W m⁻²) decreased the iron (II) concentration from 80 micromolar to 0 micromolar in 60 seconds. A return to darkness from full sunlight replenished the iron (II) to the initial level within 90 seconds. In conclusion, cyanobacterial photosynthesis controls the amount of iron oxidation in these mats.

The Effect Of Sulfate Concentration On Rates And Sulfur Isotope Signatures Of Sulfate Reduction In A Phototrophic Microbial Mat.

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Sulfate-reducing bacteria substantially contribute to the community metabolism and affect the chemical environment of marine and hypersaline microbial mats. Early in Earth's history, when mat-like microbial communities dominated shallow waters, seawater sulfate concentrations were likely ~1% of present levels. As part of an investigation of how such different sulfate levels affect the ecophysiology of phototrophic microbial mats, we explored sulfate reduction kinetics and sulfur isotope fractionation in mats transferred from their natural sulfate-rich environment to low sulfate concentrations.

At natural sulfate concentrations, sulfate reduction was intense with rates comparable to total mat respiration, and hydrogen sulfide exceeded 1 mM inside the mat. As sulfate concentrations in the water overlying the mat were decreased from 60 to <0.1 mM, sulfate reduction was restricted to 0-1 cm depth, and hydrogen sulfide declined to <0.1 mM. The apparent half saturation concentration with respect to sulfate was about 0.5 mM in both low- and normal-sulfate mats. Sulfur isotope fractionation during sulfate reduction decreased in parallel to sulfate reduction rates from ~25‰ at normal sulfate levels to ~5% at 0.2 mM sulfate. Model calculations based on the observed kinetics and fractionation indicated that with, e.g., 1 mM sulfate in the seawater, depth-integrated sulfate reduction rates would be inhibited by 50% while the difference in $\delta^{34}S$ between seawater sulfate and the iron sulfide accumulating in the mat would be reduced to < 5‰. Thus, even with relatively low sulfate concentrations, sulfate reduction may be a significant process in the mats, though its activity may not be easily detected in the isotope record.

Extremely Small, Actively-metabolizing, Sulfate Reducing Bacteria Persist In Deep Subsurface Ouartzite.

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Discoveries of microorganisms in extreme environments on Earth has led to thoughts that life may exist in similar harsh conditions on other planetary bodies. Drawing parallels between these environments has led scientific research to probe the interior of our planet for signs of life.

Extremely small sulfate reducing bacteria (SRB) with cell volumes of ~1.4x10⁻³ µm³, were detected within deep terrestrial subsurface rock cores collected from two locations within a 2.9 Ga quartzite formation in the Evander Basin, South Africa (~1.8km below land surface).35SO₄2 -autoradiographic experiments (Krumholz et al 1997) were performed to determine the spatial distribution of SRB's in the cores as compared to a baked negative control core. Positive results yielded millimeter-scale 'hotspots' of trapped radioactive sulfide on Ag foils and subsequent scanning electron microscopy (SEM) further visualized colony morphology of SRB's present on the fracture face, correlating surface location to autoradiogram 'hotspot' location. It was seen that isolated microcolonies of ~40µm diameter of extremely small rod-shaped microorganisms and associated filamentous organic matter, as determined by X-ray dispersive spectral imaging (XDS), were associated with K-rich aluminosilicates. The sizes of the active cells are barely within the lower limits of what is normally considered to constitute life (Kieft 2000).

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A Lipid Biomarker Study Of Cyanobacterial Mats From Shark Bay, Western Australia

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Lipids are essential components of all living organisms. These molecules can be used as biomarkers because their degradation products persist in the environment for millions of years. The lipid profile of an environmental sample is thus a powerful way of comparing modern day populations with those from fossil sediments.

The subjects of this study were the modern microbial mats of hypersaline Hamelin Pool [Shark Bay, Western Australia], which are considered to be analogues of some Precambrian stromatolites. For the first time the lipid profiles of "pustular" and "smooth" mats, dominated by Entophysalis sp. and Microcoleus sp. respectively, have been documented.

Using gas chromatography/mass spectrometry, classes of lipids including fatty acids (analyzed as fatty acid methyl esters), ether-linked hydrocarbons and hopanoids were studied and specific molecules identified. This identifies the principal mat inhabitants as cyanobacteria, sulfate reducing bacteria and sulfur oxidising bacteria according to the biomarkers that were observed, with diatoms, green non-sulfur bacteria, and unspecified archaea not detected or at very low levels. The two different mats showed similar lipid profiles.

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Atmospheric Composition As An Indicator Of Life On Earth And Mars

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Biology is an important non-equilibrium chemical process that can significantly modify the chemical composition of a planetary atmosphere. Chemical thermodynamic equilibrium calculations for several trace atmospheric gases produced by biological processes, including methane, ammonia, nitrous oxide, and various reduced sulfur species were performed for the Earth's oxygen-deficient paleoatmosphere, the present-day atmosphere of Earth and the atmosphere of Mars (Levine et al., 1989). These calculations indicate, for example, that methane, ammonia, nitrous oxide, and various reduced sulfur species should not exist in measurable amounts in the Earth's present day atmosphere. The fact that they exist in quantities dozens of orders of magnitude in excess of their chemical thermodynamic equilibrium concentration is testament to role and importance of biology in modifying the chemical composition of an atmosphere. The stability and atmospheric lifetime of these gases of biogenic origin are primarily controlled by chemical destruction by reaction with the hydroxyl radical (OH) and by destruction by photolysis by solar ultraviolet radiation (Levine, 1985; Summers et al., 2002). The distribution and lifetime of biogenic gases in both the Earth's paleoatmosphere and present-day atmosphere will be summarized and a strategy to measure possible gases of biogenic origin in the atmosphere of Mars will be discussed.

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Voltage-Dependent Electrochemical Fractionation Of Iron Isotopes

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Charge transfer in iron (Fe) governs a variety of geological and biological processes, and anomalous isotopic signatures in Fe associated with biologic processes may be a potential indicator of chemical complexity. To examine the connection between electron charge transfer and Fe isotope fractionation, we measured the isotopic fractionation of Fe electroplated at several different plating potentials, using multiple-collector inductively coupled plasma mass spectroscopy (MC-ICP-MS). A series of potentiostatic electroplating experiments were performed, over a 1.1 V range. We find that Fe isotope fractionation shows a strong dependence on applied, with measured δ^{56} Fe values of electroplated iron ranging from -0.106(10) to -2.290(6) (relative to the IRMM-14 Fe standard) and corresponding δ^{57} Fe values of -0.145(11) and -3.354(19). The slope of the three-isotope plot is equal to 0.6723(32), consistent with a kinetic process involving unsolvated iron atoms. The results show that the extent of Fe isotope fractionation indicates the driving force for the non-equilibrium redox reaction. The ability to control isotope fractionation in a simple redox system is an important new tool for understanding the significance of Fe isotope fractionations in nature.

Isotopic Fingerprints Of Sulfur Metabolisms.

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Here we report sulfur multiple-isotope measurements of the hydrogen sulfide and sulfate associated with dissimilatory sulfate reducing bacteria, sulfite disproportionating bacteria, and sulfur disproportionating bacteria. Our results confirm our prior findings and are consistent with our prior interpretations of sulfate reduction by A. fulgidus (see Farquhar et al., 2003). We suggest that it will be possible use this approach to identify and differentiate between sulfur metabolisms in the geological and planetary records.

Two types of information are provided by our sulfur multiple-isotope analyses. The traditional approach to sulfur isotopes involves measuring fractionations between sulfide and sulfate using $\delta^{34}S$. Because we also report $\delta^{33}S$, our data allow us to quantify a second characteristic that describes the relationship between $\delta^{34}S$ and $\delta^{33}S$, referred to as λ .

Eleven experiments with three different sulfate reducers yielded an average λ of 0.5114 and a range between 0.5084 and 0.5124. Six experiments with two sulfite disproportionating bacteria and one elemental sulfur disproportionating bacteria yielded an average λ of 0.5164 and a range between 0.5145 and 0.5187. The different λ _values allow us to distinguish between metabolisms even when $\delta^{34}S$ are similar. These differences are also consistent model predictions of sulfur isotope fractionations produced by biosynthetic networks.

On the basis of these results and their consistency with the predictions of our model, we suggest that it should be possible to use sulfur multiple-isotope measurements to identify the signature of, and in some cases evidence for evolution of, specific sulfur metabolisms in the geologic and extraterrestrial records.

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Abiotic Versus Biotic Cycling Of Sulfur In South-Central Oregon

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Water-rock interactions in basaltic terrains on Earth are important analogues for geochemical processes in groundwater, seeps and springs on Mars. For this reason, andesitic basalts and associated spring waters were collected from Warner Valley, a closed-drainage graben located within the Oregon-Nevada Great Basin. Warner Valley is surrounded by extensionally faulted continental flood basalts (CFB's) genetically related to the Tertiary Columbia River Group. Outcropping rock and spring water samples were analyzed for S isotopic compositions (34S) in order to identify biotic and abiotic geochemical processes driving the S cycle in this semi-arid setting.

Whole-rock S contents for Warner Valley CFB's range from 10 to 2870 ppm. Sulfur species in basalt samples were isolated and purified using sequential chemical extraction. Values of $\delta^{34}S$ for basalt-disulfide minerals (chrome-reducible) range from 3.9 to $13.5^{\circ}/_{00}$ (n=8; avg.= $4.2^{\circ}/_{00}$), and values of δ^{34} S for basalt-sulfate minerals range from 0.7 to 9.5 $\frac{0}{00}$ (n=18; avg.= $7.3^{\circ}/_{00}$). Values of δ^{34} S for dissolved sulfate is 7.9 to 10.8 ${}^{\circ}/_{00}$ (n=10; avg.= $9.6^{\circ}/_{00}$) in cool springs and 7.8 to 9.4 ${}^{\circ}/_{00}$ (n=9; avg.= $10.3^{\circ}/_{00}$) in hot springs. Spring waters and basalts have similar δ^{34} S for sulfate species, suggesting a genetic relationship. It remains enigmatic, however, if the source of sulfate is dissolution of primary basalt minerals or introduction of hydrothermal fluids. It is notable that thiosulfate was detected at low concentrations in some hydrothermal springs in Warner Valley. Previous studies suggest thiosulfate as an important catalyst for sulfate-sulfide isotope exchange reactions. Laboratory experiments are in progress to monitor the influence of thiosulfate on isotope exchange between sulfide minerals and dissolved sulfate at temperatures ranging from 90 to 200°C. Results from this study will provide a more comprehensive understanding of hydrothermal processes influencing the sulfur cycle in terrestrial and extra-terrestrial settings.

Quantitative Relationships Between Photosynthetic, Nitrogen Fixing, And Fermentative H₂ Metabolism In A Photosynthetic Microbial Mat

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The ultimate potential of any microbial ecosystem to contribute chemically to its environment – and therefore, to impact planetary biogeochemistry or to generate recognizable biosignatures – depends not only on the individual metabolic capabilities of constituent organisms, but also on how those capabilities are expressed through interactions with neighboring organisms. This is particularly important for microbial mats, which compress an extremely broad range of metabolic potential into a small and dynamic system. H, participates in many of these metabolic processes, including

the major elemental cycling processes of photosynthesis, nitrogen fixation, sulfate reduction, and fermentation, and may therefore serve as a mediator of microbial interactions within the mat system.

Collectively, the requirements of energy, electron transfer, and biomass element stoichiometry suggest quantitative relationships among the major element cycling processes, as regards H, metabolism. We determined experimentally the major contributions to H2 cycling in hypersaline microbial mats from Baja California, Mexico, and compared them to predicted relationships. Fermentation under dark, anoxic conditions is quantitatively the most important mechanism of H, production, consistent with expectations for non-heterocystous mats such as those under study. Up to 16% of reducing equivalents fixed by photosynthesis during the day may be released by this mechanism. The direct contribution of nitrogen fixation to H2 production is small in comparison, but this process may indirectly stimulate substantial H, generation, by requiring higher rates of fermentation. Sulfate reduction, aerobic consumption, diffusive and ebulitive loss, and possibly H2-based photoreduction of CO2 serve as the principal H₂ sinks. Collectively, these processes interact to create an ordersof-magnitude daily variation in H, concentrations and fluxes, and thereby in the oxidation-reduction potential that is imposed on microbial processes occuring within the mat matrix.

Chemical Signatures In Thermal Springs: Atomic-Level Structure Of Silicon And Aluminum In Natural And Synthetic Minerals

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In this study, we focus on changes in the concentrations and forms of aluminum and silicon in thermal springs of different compositions. An unnamed geyser in Shoshone Geyser Basin (Yellowstone National Park, Wyoming) and Trinoi Geyser (Krontoskii Reserve, Kamchatka, Russia) are used to represent different spring chemistries that might result from changes over a long time period or may result from original differences in host rock composition. Nuclear magnetic resonance (NMR) spectra illustrate differences in the atomic environment of Al between the unnamed and Trinoi Geyser. Trinoi Geyser shows significant quantities of both tetrahedrally coordinated aluminum and octahedrally coordinated aluminum. The unnamed geyser has no octahedrally coordinate aluminum. The differences in silicon environment between Trinoi and Pork Chop geysers are not as pronounced. Solid state Si-NMR shows two distinct silicon environments. Results from cross-polarization experiments show silicon bridging to two other silicon atoms via oxygen (Q2) and to three other silicon atoms via oxygen (Q3). Sinters from both Yellowstone and Kamchatka are a mix of these two silicon types. Such differences in Al atomic environment may be attributed to effects of solution chemistry on the speciation of dissolved forms of Al. Speciation affects the rate and properties of solid deposition and therefore is the likely explanation in the observed differences in NMR spectra. Spring chemistry, therefore, affects the properties of solids formed there and may yield evidence of spring changes in the past.

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Influence Of Methanogens On Mineral Weathering

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Methanogens are microorganisms in the domain Archaea that produce methane from carbon dioxide and hydrogen, acetate, or one-carbon compounds. They have played an important role in the carbon cycle and global climate throughout Earth's history through the production of methane, which is a potent greenhouse gas. Additionally, it has been proposed that life in the subsurface of Mars and Europa might consist mainly of methanogens (Boston et al., 1992; McCollom, 1999), similar to communities which have been found on Earth in deep, subsurface environments which lack organic carbon (Chapelle et al., 2002).

We have conducted experiments to determine whether methanogens enhance the dissolution of mineral analogs in batch experiments in the laboratory, or form characteristic biomarkers on mineral analog surfaces. This information could contribute to the interpretation of paleosols from early Earth, or potential biomarkers from Mars or Europa. We have determined that methanogens do enhance dissolution of mineral analogs in

the laboratory, which may be due to pH changes, production of cell lysates or exudates. Experiments are currently ongoing to distinguish between these mechanisms. We have not observed any characteristic biomarkers formed by methanogens.

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Mathematical Simulation Of The Diel O, S, And C Biogeochemistry Of A Hypersaline Microbial Mat

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The creation of a mathematical simulation model of photosynthetic microbial mats is an important step in our understanding of key biogeochemical cycles that may have altered the atmospheres of early Earth and of other terrestrial planets. A modeling investigation is presented here as a tool to utilize and integrate empirical results from research on hypersaline mats from Baja California, Mexico into a computational system that can be used to simulate biospheric inputs of trace gases to the atmosphere. An early version of our model calculates fluxes and cycling of oxygen, sulfide, and dissolved inorganic carbon (DIC) via abiotic components and via the major bacterial guilds: cyanobacteria (CYA), sulfur reducing bacteria (SRB), purple sulfur bacteria (PSB) and colorless sulfur bacteria (CSB). We used generalized monod-type equations that incorporate substrate and energy limits upon maximum rates of metabolic processes such as photosynthesis and sulfate reduction. We ran a simulation using temperature and irradiance inputs from data collected from a microbial mat in Guerrero Negro in Baja Mexico. Model oxygen, sulfide, and DIC results compared well with data collected in the field mats. A divergence from the field data was an initial large negative DIC flux early in the morning and little flux into the mat thereafter in the simulation. We hypothesize that this divergence will be reduced or eliminated if the salinity of the water surrounding the mat were used as an environmental input and as a limit to photosynthesis rates. Salinity levels, organic carbon, methane, methanogens and green nonsulfur bacteria will be added to this model before it is incorporated into a global model to simulate geological time scales.

Δ^{17} O In The Troposphere: Implications For Understanding Global Biospheric Productivity

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 $\Delta^{17}{\rm O}$ is the deviation from the Terrestrial Fractionation Line (TFL) defined by the relationship between $\delta^{17}{\rm O}$ and $\delta^{18}{\rm O}$ for all terrestrial rocks and ocean water. The slope (β) of this line is 0.525 (Miller, 2002) and is a result of equilibrium mass-dependent fractionation laws. Isotope ratios for tropospheric O₂ lie below the TFL, purportedly due to mass-independent fractionation of O₂ in the stratosphere (Luz et al., 1999). Measured kinetic mass-dependent fractionation from respiration reactions (Angert, 2003) yield β values close to the predicted 0.508 (Young, et al., 2002). A steady state between production of O₂ by photosynthesis and consumption of O₂ by respiration is then capable of producing a $\Delta^{17}{\rm O}$ of -0.400‰, without invoking a stratospheric contribution. However, tropospheric $\Delta^{17}{\rm O}$ has not been measured directly at high precision.

We obtained two direct, high-precision measurements of tropospheric $\Delta^{17}O$ relative to terrestrial rocks by separating analyte O_2 from N_2 using molecular sieves and analyzing the resulting O/Ar mixtures by IRMS. We applied an experimentally derived Ar correction factor to the measured isotope ratios, which is on the order of 0.05% for $\delta^{17}O$. Results yield a $\Delta^{17}O$ of -0.330 \pm 0.003 ($\delta^{18}O$ =23.520 \pm 0.005%, $\delta^{17}O$ =11.950 \pm 0.005%), and -0.370 \pm 0.008 ($\delta^{18}O$ =23.507 \pm 0.004%, $\delta^{17}O$ =11.903 \pm 0.008%) respectively for tropospheric O2 relative to the TFL. These results imply

kinetic fractionation with β =0.508 can account for the total observed tropospheric $\Delta^{17}O$ (Young et al., 2002), suggesting that $\Delta^{17}O$ in tropospheric O, is a product of respiration.

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Searching For Life On Other Worlds: Follow The Water (Or Ammonia, Or Hydrocyanic Acid, Or Some Other Solvent)?

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The guideline provided by the NASA Astrobiology Roadmap for finding extraterrestrial life is to follow the water with the reasoning that water is the life-sustaining and essential solvent (e.g. Des Marais et al 2003). This may be a true assumption for the terrestrial inner planets such as Venus and Mars, and certainly for Earth, where water is an ideal solvent for the complex chemical systems that constitute life on Earth, because of its (1) broad thermal range of liquidity corresponding to Earth's average temperature and atmospheric pressure, (2) buffer properties against environmental fluctuations, (3) density sufficient to maintain critical concentrations of reactants and constrain their dispersal, and (4) ability to dissolve many solutes allowing frequent chemical interchange and energy transformations from one molecular state to another, while enabling some macromolecules to resist dissolution, thereby providing boundaries, surfaces, interfaces, and stereochemical stability. However, caution should be used when applying this strategy elsewhere. On other worlds where temperatures and pressures are different, other solvents are more likely to be found in the liquid state and may be available in appreciable abundance. Titan, Io, and Triton represent possible examples. Many of the alternative solvents have properties that make them adequate, if not advantageous, as solvents for complex chemical systems (Schulze-Makuch & Irwin 2004). This includes, in particular, polar solvents like ammonia, hydrocyanic acid, and methanol, and possibly non-polar compounds such as methane and ethane. While each of these could in principle host complex biochemical interactions, the nature of the molecules that would thrive in a given solvent would be dependent on the nature of that solvent. On worlds where the physicochemical conditions have mandated that a solvent other than water exists in liquid form, the conditions for the origin of biomolecules and the assemblage of their variations and transformations would be different, and likely would result in the evolution of a biochemical system different from that known to us from the example of life on Earth.

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Laboratory Modelling Of The 3.40ga Strelley Pool Chert Stromatoloids

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The stromatoloids of the 3.40 Ga Strelley Pool Chert (SPC) are of great astrobiological interest as perhaps the world's oldest microbial macrostructures (Hofmann et al. 1999). An alternative hypothesis is that they are unusual inorganic precipitates (cf. Pope et al. 2000). We combine a

novel experimental approach with field observations to investigate their biogenicity.

The majority of stromatoloids are simple unbranched cones with continuous isopacheous laminae (i.e. of uniform thickness) preserved in silicified carbonate. They show current elongation and often co-occur or intergrade with current ripples. Primary crystal fans form <30% of the sequence and often template stromatoloid accretion. Rare, radial fibrous crystal fabrics in well-preserved laminae suggest a strong chemical component to stromatoloid growth. We advance the hypothesis for laboratory testing, that the SPC stromatoloids are complex undulose bedforms, created by the crystallisation of carbonate pavements (and subordinate gels) subject to multidirectional currents.

Initial flume experiments to study aqueous flow across stromatoloids casts are described. The fluid dynamics of stromatoloid distribution, inclination and peripheral troughs are discussed. Further experiments are in progress to investigate 1) the upward propagation of the stromatoloids by crystal precipitation; 2) the interaction of the stromatoloids with gelatinous and detrital sediment; 3) the affects of rare flank structures.

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Biogeochemistry Of Cyanobacterial Microbial Mats, Guerrero Negro, BCS, Mexico

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The hierarchical organization of microbial ecosystems determines the rates of processes that shape Earth's environment and define the stage upon which major evolutionary events occurred. Cyanobacterial mats, like those we studied from hypersaline ponds at Guerrero Negro, BCS, Mexico, have existed for billions of years. Oxygenic photosynthesis provides organic substrates and $\rm O_2$ to the mat ecosystem, and it fuels flows of energy and electrons that shape interactions between groups of microorganisms. These interactions have influenced those biosignatures that we will seek in ancient rocks from Earth and Mars, and in atmospheres of planets beyond our Solar System.

We measured the exchange of O_2 , dissolved inorganic C (DIC) and volatile fatty acids (VFA) between mats and the overlying water, during 24-hour cycles. We observed the effects of O_2 and sulfate levels and temperature. Gross rates of photosynthesis did not vary substantially between the manipulations. Under anoxic conditions at night, DIC effluxes declined and VFA effluxes increased, consistent with expected C stoichiometry. Mats incubated under low sulfate levels (<1 mmolar) exhibited lower DIC fluxes and higher VFA fluxes than did mats under normal, hypersaline sulfate (ca. 70 mmolar). The increased VFA effluxes are consistent with the lower rates of microbial sulfate reduction. These patterns slowly changed in mats incubated under low sulfate levels for more than a year, potentially indicating that microbial populations changed over the long-term. A greater understanding of microbial mat communities will emerge from coordinated studies of C and O_2 biogeochemistry and genomic studies of microbial populations.

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Detection and Characterization of Extrasolar Planets

Stability of Test Particles in Extrasolar Planetary Systems

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We present results on the stability of massless particles in the planetary systems orbiting the stars GJ 876, u Andromedae, 55 Cancri, and 47 Uma. The results of our study may be used to address questions concerning the stability of terrestrial planets in these systems and also the trapping of particles in resonances with the planets. The possibility of the existence of islands of stability and/or instability at different regions in multi-body systems and their probable correspondence to certain resonances are also discussed.

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Hydrodynamic Escape from Hydrogen Rich Atmospheres

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Atmospheric loss processes have played a major role in the evolution and habitability of the terrestrial planet atmospheres in our solar system. The hydrogen escape rate to space is the key parameter that controls the composition of the primitive terrestrial atmosphere, including its possible methane concentration. Most models of the early atmosphere assume that hydrogen escapes at the diffusion-limited rate (Walker, 1977), but this need not necessarily have been true. A CO2- or CH4-rich primitive atmosphere may have been relatively cool in its upper regions, and the escape may therefore have been limited by energy considerations rather than by diffusion. Resolving questions of hydrogen escape for these cases requires solving a set of hydrodynamic equations for conservation of mass, momentum, and energy. Hydrodynamic escape may also be important for Close-in Extrasolar Gas Giants (CEGPs) such as HD209458b, which has recently been observed to be losing hydrogen by the Hubble Space Telescope (Vidal-Madjar et al., 2003; 2004). Although planetary hydrodynamic escape models have been created in the past (Watson et al., 1981; Kasting and Pollack, 1983; Chassefiere, 1996), the problems were solved by integrating the coupled, time independent mass, momentum, and energy equations for the escaping gas from the homopause out to infinity. Solving the one-dimensional, steady state approximation becomes problematic at the distance where the outflow becomes supersonic. A new technique has been developed for the treatment of hydrodynamic loss processes from planetary atmospheres by Parkinson et al. (in preparation). This method overcomes the instabilities inherent in modelling transonic conditions by solving the coupled, time dependent mass, momentum, and energy equations, instead of integrating time independent equations. We validate a preliminary model of hydrodynamic escape against simple, idealized cases (viz., steady state and isothermal conditions) showing that a robust solution obtains and then compare to existing cases in the literature as cited above. The general tools developed here are applied to the problems of hydrodynamic escape on the early Earth and close-in extrasolar gas giant planets and results from these analyses are shown.

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Klio: A 5 micron camera for the detection of giant exoplanets

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We are in the process of building a thermal infrared (3-5 microns wavelength) coronograph, Klio, to image giant exoplanets around nearby, Sun-like stars. We have targeted the 3-5 micron region to take advantage of the unprecedented combination of low thermal background and high resolution provided by the 6.5m MMT's adaptive secondary mirror. Results from simulations modelling the coronographic performance and exoplanet detection probability will be presented.

The coronographic simulations model the amount of suppression of the primary star's light over the field of view of the instrument. This information translates into the detectable exoplanet mass versus separation. Atmospheric turbulence and adaptive optics correction typical of the MMT site and adaptive optics performance are included.

We have also undertaken a series of Monte Carlo simulations to calculate the number of expected exoplanet detections, given a set of assumed separation and mass distribution functions. Starting with distribution functions extrapolated from radial velocity results, we expect to detect 14 ± 3 companions with 5-15 $M_{\rm Jupiter}$ at 13-50 AU for a sample of 80 M0-F0 stars within 20 parsecs and less than 1 Gyr old. Our sample has also been constructed so that a non-detection will allow us to put valuable constraints on the actual distribution functions for giant exoplanets.

With knowledge of the prevalence and distribution of giant exoplanets, we can begin to understand to what extent such planets may disrupt or provide a hospitable environment for terrestrial planets in the habitable zone of the systems.

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Polarization of Planet Earth, Model Earth-Like Planets and Close-in Extrasolar Giant Planets

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Very remote sensing will play a key role in the characterization of extrasolar planets once techniques for separating the light of a planet and its parent star are fully developed. Besides the potential of photometric and spectroscopic data, polarimetric data may also play an important role in the characterization. In the case of Earth, polarimetry of the Earthshine versus phase angle by Dollfuss (1957) indicated that Planet Earth reaches a peak polarization of about 35% in the visible. From extensive observations of the POLDER satellite (see eg Breon & Goloub,1998) the dependence of polarization on the nature of the surface (ocean, desert, vegetation, snow) and the atmosphere (clear,cloud) as well as on wavelength and phase angle are known in detail. We have used POLDER data to model the brightness and polarization of a Pale Blue Dot Earth from 400 to 900nm versus viewing angle and orbital phase, as well as cloud cover and present results here. We also use POLDER data to construct simple models of Earth-like planets

with different areas of oceans, forests, deserts etc and will discuss specimen results. Some applications of the above to the polarization of Close-in Extrasolar Giant Planets will also be briefly discussed.

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Detectability of surface and atmospheric properties of Earth-like and Mars-like planets from disk averaged synthetic spectra

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The NAI Virtual Planetary Laboratory is using computer models to explore the observational sensitivity to atmospheric and surface properties in the disk-averaged spectra of terrestrial planets. We present here our results for Mars (a good example of a likely abiotic planet) and Earth (the only example of life supporting planet known, so far...). At the core of our model is a spectrum-resolving (line-by-line) atmospheric/surface radiative transfer model (SMART) developed by David Crisp. We have used Martian surface albedos and General Circulation Model interpolations of Mars atmospheric properties as input for Mars, and AIRS (Atmospheric Infrared Sounder) data as input for Earth. SMART has been run to generate a database of synthetic spectra for a variety of viewing angles, illuminations, surface type and cloud coverage. The user specifies spatial resolution and observing position, and our model selects the appropriate synthetic spectra generated by SMART and creates the final view, which can then be averaged on the disk.

These results have been processed with an instrument simulator to improve our understanding of the detectable characteristics as viewed by the first (and probably second) generation extrasolar terrestrial planet detection and characterization missions.

We have validated our Earth-model against observations of the Earth by the Mars Global Surveyor Thermal Emission Spectrometer (MGS TES) and the Mars-model has been validated against spectra recorded by Mariner 9 Interferometer Spectrometer (IRIS).

The results presented here include globally averaged synthetic spectra, light-curves and the spectral variability at visible and MIR wavelengths as a function of viewing angle, simulations of an increasingly frozen Mars, an increasingly cloudy/forested/oceanic Earth and detectability of biosignatures on an Earth-like planet.

Detection and implication of a jovian circumbinary planet in the old globular cluster Messier 4

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The pulsar B1620-26 has two companions, one of stellar mass and one of planetary mass. We detected the stellar companion with the use of Hubble Space Telescope observations. The color and magnitude of the stellar companion indicate that it is an undermassive white dwarf (0.34 +/- 0.04 solar mass) of age 480 \times 106 +/- 140 \times 106 years. This places a constraint on the recent history of this triple system and supports a scenario in which the current configuration arose through a dynamical exchange interaction in the cluster core. This implies that planets may be relatively common in low-metallicity globular clusters and that planet formation is more widespread and has happened earlier than previously believed

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Evidence for Comet-Like Bodies Around the 12 Myr Old Star Beta Pictoris

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Most nearby young stars are now known to be surrounded by disks of dust and gas, which may be the sites of current or recent planet formation. One class of disks are debris disks, which are believed to be young, dense analogues of our Kuiper and asteroid belts. These disks provide a window onto the early evolution of planetary systems, since it is likely that most of the volatile content of the Earth's surface was delivered during the debris phase by the impact of water-rich planetesimals.

We discuss far-UV spectroscopy of molecular gas in the 12 million year old debris disk system Beta Pictoris. Detection of carbon monoxide using the Hubble Space Telescope (Roberge et al. 2000) contrasted with limits on molecular hydrogen using the Far Ultraviolet Spectroscopic Explorer (Lecavelier des Etangs et al. 2001) provides some of the first evidence for the presence of icy bodies similar to Solar System comets in this disk.

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Forming Gas Giant Planets using the Core Accretion Model

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There are over 100 extrasolar planets that have been discovered and new ones are continually added to this list. These planets are massive: about the size of Jupiter to several times greater. It is widely accepted by planetary scientists that these gas giant planets are formed by the core accretion model which states that a solid core is formed from the accretion of planetesimals in the solar nebular followed by the capture of a massive envelope from the solar nebula gas.

Derived core masses and observed short lifetimes of protoplanetary disks strongly constrain conditions for forming gas giant planets. We have computed evolutionary models based on the core accretion model for Jupiter, Saturn, and Uranus, and some extrasolar planets. Our simulations have been successful in explaining many features of the giant planets and the results demonstrate that the formation time of gas giant planets is within the observational constraints.

Two parameters that were found to effect the formation time and the size of the solid cores of the growing protoplanet are the grain opacity and the planetesimal surface density of the solar nebula. Our results demonstrate that decreasing the grain opacity significantly reduces the evolution time. Decreasing the surface density of the planetesimals lowers the final core mass of the protoplanet but increases the formation timescale.

We also explore the implications of halting the solid accretion at selected core mass values during the protoplanet's growth, thus simulating the presence of a competing embryo. This core mass cutoff results in the reduction of the time needed for a protoplanet to evolve provided the cutoff mass is not too small.

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Using Artificial Neural Networks for Analysis and Discrimination of TPF Planetary Spectra.

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The Terrestrial Planet Finder (TPF) mission will use low-resolution spectra to characterize extrasolar terrestrial planets, with the ultimate goal of finding global signs of life in their atmospheres or surfaces. A decision has not yet been made whether the TPF architecture will be an optical coronagraph or an infrared interferometer. Similarly, the exact wavelength range, spectral resolution or likely sensitivity of the spectrometer for either configuration has not been determined. To help understand the trade-offs for spectral characterization of terrestrial planets inherent in choosing the optical or infrared approach, we are using Artificial Neural Networks to discern the degree to which planetary spectra can be reliably classified as a function of wavelength coverage, spectral resolution and signal-to-noise. To do this, we have generated synthetic spectra in both the optical and mid-infrared for a range of plausible terrestrial planets, from frozen to more Earth-like worlds. These spectra are produced for a range of spectral resolutions and S/N levels. Our results indicate that Artificial Neural Networks can make important distinctions between atmospheric types at the modest resolutions and signal-to-noise likely to be characteristic of TPF planetary spectra.

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Digging in the Stellar Graveyard: The Search For Planets around White Dwarfs

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White Dwarfs are the post main-sequence remnants of stars that had masses between 1-8 solarmasses. These objects are orders of magnitude dimmer than stars like the Sun and presenta unique chance to probe these systems for low mass companions such as Brown Dwarfs andextrasolar Jovian planets. Planets at separations ~5 AU and larger should survive post main-sequence evolution. We present the initial results of our survey using the Hubble Space Telescope (HST) with the Near-Infrared and Multi-Object Spectrograph (NICMOS). We find that for WD ages between 1-3 Gyr, our survey is sensitive to sub-Brown Dwarf masses at separations greater than 10 AU from the host star. We present the results of a common proper motion test for some of our candidate faint companions.

A comprehensive Climate Model for Extrasolar Terrestrial Planets

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In support of the NAI Virtual Planetary Laboratory (PI V. S. Meadows) we are developing a climate model to simulate the environments of extrasolar terrestrial planets. As the first step in our efforts, a simple 1-dimensional radiative convective equilibrium (RCE) model (c.f. Crisp,1989) will be used to study the globally averaged, thermal structures of terrestrial planets' atmospheres and surfaces. An existing RCE model has been upgraded to simulate a broad range of plausible environments. In particular the mixing length scheme used to simulate convection has been upgraded by adopting the vertical transport scheme from the University of Helsinki 1-D planetary boundary layer model (Savijarvi 1999). The new scheme includes the transport of volatiles as well as heat. A simple, non-precipitating cloud model was also added, so that clouds could form and dissipate as the atmospheric thermal structure evolved toward equilibrium.

The soil temperature prediction was improved with a 20-layer soil thermal diffusion scheme in order to include daily and annual variations. The Spectral Mapping Atmospheric Radiative Transfer (SMART) algorithm (Meadows, Crisp 1997) has been installed in place of the simpler band modeling and 2-stream methods. The cloud model is being further upgraded to include precipitation as well as condensation and evaporation of clouds

(Imamura, Hashimoto 2001). In addition, a horizontal energy balance (EB) model is being developed to integrate the planetary temperature distribution with the specific atmospheric structure. To test the robustness of this efficient yet comprehensive climate model we compare the results with general circulation models and observational (e.g. Thermal Emission Spectrometer) data for Mars. However, as a generic planetary climate model, the ultimate goal is to extend these results to Venus, Earth, and other novel climate systems.

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Effects of rotation on temperature, variability, and spectral signatures of extrasolar terrestrial planets

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The major goal of the Terrestrial Planet Finder and Darwin missions is to directly detect Earth-sized extrasolar planets and ascertain their habitability. While the preferred spectral bands for atmospheric characterization -- based on Earth's atmospheric signatures -- are known, knowledge of atmospheric circulation patterns and how they change extrasolar planets' temperature and spectral signatures have yet to be explored. Using a general circulation model, we study the effects of planetary rotation rate -- one of the most important of the atmospheric dynamical parameters -- on the large-scale atmospheric structure, flow, and variability. We find that the circulation, cloud, and temperature patterns all change significantly with rotation rate. This work, together with analysis of other circulation-controlling parameters, will augment the definition of the habitable zone and help redefine the strength and depth of spectral signatures to be characterized.

Infrared lightcurves of Earth-like exoplanets with extreme seasonality.

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Planet formation theory suggests that rocky exoplanets may have more eccentric orbits and larger obliquities than that of the Earth. Such planets will experience extreme seasonal variation in incident stellar radiation along their orbits (Williams and Kasting 1997; Williams and Pollard 2002). We propose that future space-based observatories may not only detect extremely seasonal planets but that monitoring of these objects along their orbits may prove informative about their surface properties and potential habitability. We calculate rotationally-averaged infrared light curves for planets with different obliquities, orbital eccentricities, and viewing geometries using an analytic energy-balance model. This model assumes globally uniform values of the thermal inertia and meridional heat transport coefficient, and a linear relationship between surface temperature and emitted IR flux. We investigate the effects of thermal inertia and meridional heat transport of any atmosphere or ocean on the IR light curve of an Earth-like planet and compare these calculations with the output of a 3-dimensional climate model (Williams and Pollard 2003). The infrared emission of lunar-like bodies with high obliquities can vary by an order of magnitude along the orbit, depending on the viewing geometry. We show that the thermal inertia and meridional heat transport of an ocean and/or atmosphere significantly reduces the amplitude of the light curves. Thermal inertia also introduces a phase lag of the emitted infrared light curve relative to the incident stellar flux. Our analytic model currently over-predicts the phase lag relative to the 3-D numerical climate model, possibly a result of the assumptions of uniform albedo and a fixed cloud cover fraction.

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Finding Planetary Moons in the Spectra of Distant lupiters

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More than one hundred nearby stars are known to have at least one Jupitersized planet. Whether any of these giant gaseous planets have moons akin to the satellites of Jupiter and Saturn or larger is unknown, but here we suggest a possible way of detecting them with future technology. In particular, the planned Darwin/Terrestrial Planet Finder1 (TPF) observatory will be able to detect and analyze the light from distant Earth-sized worlds. Such objects might orbit their stars either as isolated planets or moons to giant planets. The jovian planets, themselves, will appear naturally dark in the near-infrared between 2-4 µm because of the high abundance of methane in their atmospheres2. Some of the newly discovered planets should be even darker than Jupiter at these wavelengths because their warmer atmospheres will allow starlight to be absorbed at greater depth by water and water vapor. Here we show that if such a planet had a moon the size of the Earth3, the combined starlight reflected by the planet-moon pair would be up to a hundred thousand times greater than for a moon-less planet. By taking advantage of this contrast in the near-infrared, the Darwin/TPF observatory should be able to discern which of the new jovian planets have moons capable of supporting life.

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Earth History

Broadband Photolysis Of SO₂: Implications For The Mechanism Of Sulfur Mass-independent Fractionation

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Mass-independent fractionation (MIF) in sulfides and sulfates older than 2 Ga (Farquhar et al. 2000) promises to be a valuable proxy for atmospheric oxygen. However, the photochemical mechanism of sulfur MIF remains uncertain. Atmospheric chemistry models have yielded useful upper limits to O_2 partial pressure (Pavlov and Kasting 2002), but have been hampered by a lack of sulfur-related laboratory data. Here we report initial results from a collaborative effort between the University of Maryland and UCLA to understand S isotope fractionation during SO, photodissociation.

Key to the new experiments is the use of a broadband UV source. SO₂ is photolyzed over a 'full spectrum' as well as over 20 nm wide windows. Previous experiments (Farquhar et al. 2001) employed narrow-band (~ 1 nm) excimer lasers at several wavelengths. Because the Archean-Paleoproterozoic atmosphere is believed to have been a broadband transmitter of UV radiation, we felt that the new experiments would better

simulate atmospheric processes. Results thus far show that at wavelengths shortward of the SO_2 dissociation limit (< 220 nm), elemental sulfur produced during SO_2 photodissociation over a 20 nm window has large positive $\Delta^{33}S$ and a $\delta^{33}S - \delta^{34}S$ slope > 0.52 relative to initial SO_2 . The latter result differs from the negative slopes obtained with the excimer laser at 193 and 184.9 nm (Farquhar et al. 2001), but are in agreement with the stratigraphic interpretation of Ono et al. (2003) of Archean sulfides.

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Mo Isotopes As Indicators Of Global Paleoredox

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The molybdenum isotope system is emerging as an indicator of global redox conditions. The foundation of this application is the relatively straightforward marine chemistry of Mo isotopes. We have constructed a simple mass-balance model to quantify the relationship between changes in $\delta^{97.95} \text{Mo}$ in the oceans and the extent of global ocean anoxia, including euxinic and suboxic sedimentary sinks. This model incorporates a fractionation of ~2% between seawater and oxic sediments (1-2), an effective ~2.5 % fractionation in suboxic sediments (3, 4), and little-or-no fractionation during removal to euxinic sediments (1). Adopting literature estimates that 50 –90 % of ocean Mo is removed to oxic sediments today, removal to suboxic sediments accounts for < 28% of Mo cycling., The remainder is removed to euxinic sediments.

In the past, the model demonstrates that shifts towards lighter $\delta^{97,95}$ Mo in seawater result from decreases in Mo removal to the fractionating sinks, oxic or suboxic, and consequent increases in euxinic removal.

Combined with $\delta^{97,95} Mo$ data from ancient sediments, this model indicates expanded euxinic conditions in mid-Proterozoic oceans compared to the present day. Specifically, euxinic sediments from the mid-Proterozoic have an average $\delta^{97,95} Mo = +0.54$ % (vs. ~ 1.3 % in modern equivalents). Given these data, removal of Mo to the sum of oxic and suboxic sediments was smaller than today. In contrast, Mo removal to euxinic sediments was three to four times larger. These results tighten the limits set by our prior findings that oxygenation of the deep oceans may have lagged the atmosphere by over a billion years (5).

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Deciphering The Depositional Environment Of The Chengjiang Fossil Beds.

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The Cambrian explosion of life is considered one of the most important periods in the history of evolution. Most organisms from this time are soft-bodied making their preservation in the geologic record highly unlikely. In the mid-1980s, a fossil bed was discovered in China bearing the Chengjiang biota. Chengjiang biota, largely an assemblage of soft-bodied organisms, are three-dimensional. The conditions leading to preservation of these fossils are undoubtedly rare but not entirely unique. Understanding the mechanisms responsible for this type of preservation could lead to

identification of other fossil beds on Earth (and Mars?). Deposition in common marine sedimentary environments cannot explain the unique threedimensional preservation and excellent fossil fidelity. Preservation likely occurred in fine-grained volcaniclastic sediments deposited in a shallow marine embayment. Such an environment would provide the observed uniform grain size, rapid burial, and three-dimensional preservation. To test this hypothesis, a combination of geochemical, petrographic, mineralogical, and electron microscopy techniques were employed. Petrographic analysis revealed a few large, subangular to angular grains in a dominantly finegrained matrix, consistent with a water-laid tuff. The matrix is andesitic in composition with high concentrations of potassium, aluminium and iron. Electron microscopy analysis identified high concentrations of silicon and iron, low concentrations of aluminum and potassium, and trace amounts of chromium in the fossil body. Quartz and layered-silicate minerals dominate with smaller amounts of goethite in both matrix and fossil materials. These observations are consistent with volcaniclastic sediments deposited in a shallow marine environment, which could have been common on a volcanically active, wet early Mars.

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Carbon Dioxide, Methane, Climate And A Little Bit Of

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The Earth has maintained a more or less temperate climate—with some notable exceptions-over the span of geological time, yet the Sun has brightened by some 30% since the mid-Archean. This "faint young Sun" paradox calls for an effective albeit sometimes balky thermostat. The leading hypothesis has been a CO₂ greenhouse governed by a geological cycle that balances temperature-dependent weathering against volcanic emissions. The CO, cycle can be given a Gaian flavor if life as it evolves progressively acts as a better catalyst for weathering reactions. But temperate climates in the Archean require rather a lot of atmospheric CO2. Recent observational and theoretical arguments cast some doubts on whether the atmosphere could have built up enough CO, to keep the surface warm. Methane is an alternative greenhouse gas that can provide substantial additional warming at modest levels in the atmosphere. An effective methane greenhouse would require a biogenic methane source. Thus methane admits overtly Gaian climate-controlling feedbacks. If the biosphere emits more methane when cooler, the feedback would be stabilizing. But if there is more methane than CO₂, photochemistry will generate a high-altitude hydrocarbon haze. The haze would have a global cooling effect. It is possible that the cooling effect can exceed the additional greenhouse effect of more methane and its vaprous hydocarbon derivatives. If the biosphere emits less methane when cooler, the feedback would be stabilizing. If so, then a methane-driven climate must inevitably be governed by a blind Gaia

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This work has been done with David Catling, Mark Claire, Norman Sleep, and others, but I didn't have a chance to ask them whether they were fine with Coin

Evidence In Carbon Isotope Ratios Of Siderites For A CO₂-Rich And CH₄-Poor Archean Atmosphere And Oceans

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Siderite is a minor constituent of Phanerozoic sedimentary rocks. It typically formed disseminated crystals, nodules, and small lenses during the early diagenetic stage of sediments. Siderites that formed in sulfate-poor environments (e.g., swamps) typically possess positive and variable $\delta^{13}\mathrm{C}$ values (+6.0 \pm 5.7(1 σ) ‰), indicating most of the $\Sigma\mathrm{CO_3}^2$ (= $\mathrm{CO_2}$ + $\mathrm{HCO_3}^2$ + $\mathrm{CO_3}^2$) used for the siderites was generated by methanogens; those formed in marine sediments typically possess negative and variable $\delta^{13}\mathrm{C}$ values (-4.7 \pm 7.2 ‰), indicating the Σ $\mathrm{CO_3}^2$ - was mostly generated by sulfate-reducers and fermentaters (Mozley & Wersin, 1992). In contrast, siderite directly precipitated from the overlying seawater and formed thick

(>10 m) and extensive (>100,000 km²) massive beds in many pre-1.8 Ga sedimentary sequences (e.g., Beukes et al., 1990). We have analyzed the chemical and isotopic compositions of ~400 samples of siderite from major siderite-rich formations in Canada and Australia. The δ^{13} C values of the pre-1.8 Ga siderites from this and other studies (e.g., Shields & Veizer, 2002) mostly fall between –10 and 0‰, indicating that most of the \sum CO₃²⁻ for the siderites came from normal seawater and less than ~30 percent of the \sum CO₃²⁻ from the decay of organic matter (δ^{13} C = -35 – -20‰) by non-methanogenic microbes; methanogens were not major organisms in the pre-1.8 Ga oceans.

Thermodynamic calculations for the formational conditions of siderite at T = 10-50 °C, SiO $_{2(aq)}$ = 20-100 ppm, and Σ Fe = 1-100 ppm suggest the Σ CO $_3$ ² content of the pre-1.8 Ga oceans was \sim 10^{-2.5}m (compared to \sim 10⁻³m today) and the pH was between \sim 5.5 and \sim 7.5 (compared to \sim 8 today). These data, together with the carbon isotope mass balance from the siderite data, suggest the minimum pCO $_2$ of the pre-1.8 Ga atmosphere was10^{-1.440,2}atm (i.e., \sim 100 PAL). This pCO $_2$ alone, without CH $_4$, could have provided sufficient greenhouse effect to compensate the lower solar flux and maintain liquid oceans on the early Earth.

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Reliability Of Black Shales As Recorders Of Marine Molybdenum Isotopes And Paleoredox

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Molybdenum isotopes in ancient euxinic sediments show promise as a proxy of ocean paleoredox (1). Many proxies record the oxidation state of local depositional environments, but Mo isotopes may uniquely provide information about regional or global ocean paleoredox (2). Here, we examine the limits of robustness and reliability of Mo isotope paleorecords in ancient black shales.

Examination of a weathering profile in the Devonian New Albany shale near Clay City, Kentucky, shows a nearly +0.4% shift in $\delta^{97/95}$ Mo approaching the weathering horizon. This is accompanied by an increase in Mo and Mn concentrations and a nearly total loss of Re. Although the coincident position of the changes in elemental concentrations and isotopic composition suggests that Mo is adsorbed by diagenetic Mn oxides, the direction of the isotopic shift is opposite to that expected from such a process (3).

In addition, $\delta^{97/95}$ Mo of relatively unweathered samples of this shale is $\sim 0.3\%$, considerably lighter than modern euxinic sediments ($\sim 1.5\%$) and another Devonian shale (1.0%). However, examination of local redox proxies such as DOP and Mo/Al indicates that the depositional environment in this location, while dysoxic, was not intensely euxinic. Molybdenum isotope fractionation in such systems is possible (4,5) and hence $\delta^{97/95}$ Mo in this pyritic black shale may not represent contemporaneous seawater.

These findings demonstrate that diagenetic oxidation can alter $\delta^{97,95}$ Mo paleorecords and highlight the importance of combining $\delta^{97,95}$ Mo data with local redox proxies when reconstructing ancient ocean $\delta^{97,95}$ Mo.

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Neodymium Isotopic Evolution Of The Kalkkloof Paleosol, South Africa

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The Kalkkloof paleosol is a weathering profile developed on Archean (~3.4 Ga) ultramafic cumulates of the Barberton greenstone belt, Eastern Transvaal, South Africa. Based on stratigraphic relations, the paleosol is thought to have formed between 2.7 and 2.4 Ga, a critical period for understanding the history of oxygen in the Earth's atmosphere. It is one of a series of paleosols in the region that show evidence of terrestrial microbial mats (Martini, 1994; Watanabe et al., 2000) and distinct negative Ce anomalies, indicating soil formation under an oxygenated atmosphere (Watanabe et al., 2003). To better understand the processes and timing of syn- and post-pedogenic mobility of rare earth elements (REE), we have undertaken a neodymium isotope investigation of the paleosol.

Initial results from four samples from the top and bottom of the profile suggest a systematic Sm-Nd behavior. All samples show light rare earth element enrichment relative to the parent material, which is consistent with pedogenic fractionation. The two samples with the lowest REE concentrations ([Nd]<3 ppm) yield identical $\epsilon_{\rm Nd}(T)$ values of +6.1 at 2.46 Ga; these values fall along the upper limit of reasonable depleted mantle curves (Goldstein et al., 1984). The two most REE-enriched samples from the profile ([Nd]>7 ppm) yield $\epsilon_{\rm Nd}(2.5)$ values of +9.5 to +12.5, which suggests that they were enriched in radiogenic Nd prior to pedogenesis. Ongoing Sm-Nd work on additional low-REE samples will help better define pedogenic REE redistribution and the timing of oxidative weathering in the Kalkkloof profile.

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"Detrital" Pyrites In The Archean Witwatersrand Basin (South Africa) Are Not Detrital

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Rounded grains and "pebbles" of pyrite (FeS₂) in gold- and uranium-rich conglomerates of Archean ages have been interpreted by many previous investigators as detrital minerals representing remnants of pyrite crystals from igneous rocks and ore deposits, which were transported and deposited

in fluvial systems. They serve as important evidence for an anoxic Archean atmosphere, because pyrite is unstable under an oxygenated atmosphere (e.g., Holland, 1994). We have investigated the distributions of 30 elements (Fe, S, Si, Al, Ti, K, Na, Ni, Co, Au, Th, U, La, etc.) in and around ~100 "grains" and "pebbles" of pyrite in quartz-rich conglomerate samples from several ore horizons in the Witwatersrand Basin. A recently-developed X-ray chemical microscope (Horiba XGT-5000) allows chemical mapping of a large sample (up to $10x10~{\rm cm}$ size) with the spatial resolution of $10~{\rm cm}$

Our investigation has revealed that: (1) pyrite "grains" and "pebbles" larger than ~ 100µm in size are almost always comprised of aggregates of euhedral, micro (<10 µm) pyrite crystals; (2) the "grains" and "pebbles" contain appreciable amounts of Si (~0.1 - ~10 wt%), Al (~0.1 - ~5 wt%), and other rock-forming elements; and their elemental ratios (e.g., Fe/S, Fe/Si) ratios are highly variable; and (3) remnants of Si-rich micro layers, similar to the silica-rich laminae in banded iron formations and in cherts, are recognizable in many large (>5 mm size) pyrite "pebbles". These characteristics indicate that the so-called "detrital pyrite grains and pebbles" in Archean conglomerates were created by reactions between H₂S-rich hydrothermal fluids and detrital grains and pebbles of Fe-rich rock fragments (e.g., banded iron ores, ferruginous cherts, and Fe-rich pisolites) after the deposition of host rock sediments. Therefore, these pyrite grains and pebbles cannot be used as evidence for an anoxic atmosphere. However, the Fe-rich pisolites, which were possible precursors of some pyrite-rich pebbles, may be used as a strong argument for an oxygenated Archean atmosphere.

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Microbial Ecology In An Early Archean Stratified Ocean

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Recent re-evaluation of the geologic record of the earliest life on Earth has suggested that some of the oldest putative microfossils and carbonaceous matter formed through abiotic hydrothermal processes. Similarly, many early Archean cherts have been re-interpreted as hydrothermal exhalites rather than products of normal marine sedimentary processes. Here we show that the 3,416 Myr old Buck Reef Chert, South Africa, accumulated as normal open shallow- to deep-marine deposits in a stratified ocean and that the carbonaceous matter it contains was produced biologically.

The distribution, morphology, structuring, and isotopic composition of included carbonaceous matter varies with depositional setting. From shallow- to deep-water settings, $\delta^{13}C_{org}$ increases from -35% to -20% vs. PDB. Mat-like laminations most likely structured by filamentous bacteria were restricted to shallow-water environments above storm wave base. In the modern ocean, this generally corresponds to depths of < 200 m. Restriction of these communities to shallow water probably reflects confinement to the euphotic zone, which generally corresponds to depths of < 150 m. Environmental setting and isotopic composition are consistent with these communities deriving their fixed carbon by photosynthesis. Shallow-water mats were ripped up and distributed as detrital matter by waves and currents to surrounding environments. In deep-water settings characterized by very slow sedimentation, this carbonaceous matter was degraded by consortia of fermenters and methanogens leaving relatively ¹³C-enriched residuum. There is no evidence that hydrothermal processes played any direct role in the deposition of either the carbonaceous matter or the enclosing sediments.

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Paleomagnetism Of Marble Bar Chert, Pilbara Craton, Western Australia

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We conducted preliminary Paleomagnetic study on the early Archean rocks in Pilbara Craton, Western Australia. A continuous 250 m thick section had been drilled by Archean Biosphere Drilling Project from the Towers Formation with U-Pb ages 3460 Ma (Kranendonk et al. 2001). Lithofacies of the drilled core are divided into Basalt/Dolerite Zone and various colored Chert Zone named Marble Bar Chert Member. Initial magnetic measurements of whole core by the pass-through cryogenic magnetometer and rock magnetic experiments of selected specimens by Vibrating Sample Magnetometer (VSM) indicated that black or red layers in the various colored Chert Zone are containing ferrimagnetic mineral (magnetite or titanomagnetite) and having strong Natural Remanence Magnetization (NRM). Through Alternative Field Demagnetization (AFD) and Thermal Demagnetization (ThD) treatments of a suite of discrete samples, we found that the remanent magnetization of the black or red layers apparently define two to three components: (1) a low coercivity (<10 mT) Viscous Remanent Magnetization (VRM) may caused by drilling process; (2) a mid-temperature (<450°C) component (only happens on one sample); (3) a high-temperature component (450 to 575°C). We interpret that the stable component isolated at high-temperature stage is primary magnetization. Directions of the primary magnetization are put on nearly opposite side of the hemisphere. This result suggests that the black/red colored Chert may preserve the geomagnetic reversal record at early Archean age. Furthermore, these rocks may have potential of suggesting the existence of the dynamo activity which is comparable to the present day.

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H₂ Consumers And The Redox State Of The Archean Ocean.

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The recent discovery of hematite in unweathered, 3.5 b.y.-old Archean sediments by H. Ohmoto and his NAI-sponsored drilling crew in Australia suggests to some that oxygenic photosynthesis evolved very early. The presence of this oxidized iron stands in apparent contrast to constraints on atmospheric O_2 prior to 2.3 Ga imposed by the presence of mass-independent sulfur isotope fractionation, which requires $pO_2 < 10^{-5}$ times present (Farquhar et. al., 2000; Pavlov & Kasting 200). pO_2 might have been higher than this in the water column if cyanobacteria were present; however, we are led to look for alternative solutions.

We suggest that Fe-oxide stability was driven by consumption of reduced species instead of by production of O_2 . Zinder (1993) has shown that some hydrogen consumers can draw pH_2 down to 10^{-8} atm. If bacteria were able to keep dissolved H_2 and O_2 in thermodynamic equilibrium, pH_2 values this low could have allowed hematite to be stable without any free O_2 being present. The ferric iron could have been precipitated either by direct photooxidation of Fe⁺⁺ or by phototrophic Fe-oxidizing bacteria. Hydrogen concentrations in the water column could have been suppressed by a combination of methanogens and Fe-reducing bacteria that used H_2 as the reductant. This model is consistent with the concept of an upside-down Archean biosphere proposed originally by Walker (1987).

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Astrobiology Drilling Program Of The NASA Astrobiology Institute

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Access to unweathered and uncontaminated samples of the least altered, oldest, sedimentary rocks is essential for understanding the early history of life on Earth and the environments in which it may have existed. For this reason, the NASA Astrobiology Institute (NAI) has embarked on two international programs, a series of Field Workshops aimed at making the most important surface samples available to investigators, and the Astrobiology Drilling Program (ADP), which serves to provide access to fresh subsurface samples when the scientific objectives require them.

The Astrobiology Drilling Program commenced in Western Australia in 2003 with the initiation of its first project, the Archean Biosphere Drilling Project (ABDP). Funding for the ABDP came mainly from the Japanese Government through Kagoshima University and from NASA through the NAI Team at Pennsylvania State University, but significant technical and logistic support was provided by the Geological of Western Australia and the University of Western Australia. Six diamond drill cores totalling ~1.4 km were obtained from astrobiologically important successions in the 3.3-3.5 Ga-old Pilbara craton of northern Western Australia.

Drilling in 2004-5 will also take place in Western Australia. The Deep Time Drilling Project (DTDP), a spin-off from the NAI's Mission to Early Earth Focus Group, will drill one long hole in 2004, aimed mainly at fossil biomolecules (biomarkers) and other geochemical indicators of early life. Then the DTDP and the ABDP will jointly drill several holes in 2003-2004. These efforts parallel two other drilling initiatives within the wider astrobiological community that are taking place in South Africa and Spain.

The ADP is managed by the NAI through a Steering Committee appointed by the NAI Director. Samples of cores obtained through ADP projects are available to the whole community, following a one year embargo, upon application to project PIs. See: www.nai.arc.nasa.gov/ADP for additional information.

Predicting The Biogenic Methane Flux And Productivity Of The Early Archean Biosphere

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Determining the CH₄ concentration in the Archean atmosphere (~3.8-2.5 Ga) is important for understanding Earth's early 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, concentrations based on thermodynamic considerations only (Kral et al., 1998; Kasting et al., 2001). We have developed a new model that incorporates kinetic and nutrient limitations in addition to thermodynamics. We have used this model to predict the biogenic CH, flux and the net primary productivity of the Archean biosphere prior to the advent of oxygenic photosynthesis. Our calculations simulate marine ecosystems in which primary productivity is dominated either by autotrophic methanogens or by H₂-using anoxygenic phototrophs.

The key factors limiting both CH₄ production and primary productivity in both cases are the downward fluxes of H, and CO from the atmosphere, both of which are limited by the rate of diffusion across the atmosphereocean interface. Our results indicate that the CH, flux from the early Archean biosphere would have ranged from ~ to 2.5 times the modern CH₄ flux, regardless of which organisms dominated productivity. In the anoxic Archean atmosphere, this range of fluxes would have produced CH₄ concentrations of ~100 ppmv to 5000 ppmv, enough to significantly warm the climate. We find that primary productivity is lower than today by ~500 to 4000 times for the methanogen-based ecosystem and by ~40 to 200 times for the anoxygenic phototroph-based ecosystem. Only the latter system is consistent with the geological record of carbon isotopes.

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Mass-Extinctions Due To Changes In The Galactic Environment.

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In its motion through the Milky Way Galaxy, the Solar system passes through clouds with higher hydrogen densities. Even if the density of the local interstellar medium increases to only ~10 H/cm³, the heliosphere can be effectively suppressed within 10 A.U. due to increased external hydrogen pressure. Such events probably happened thousands of times in Earth history. Here we show that when the heliosphere was suppressed (to 5-10 A.U.), the flux of the anomalous cosmic rays (ACR) increases dramatically into the Earth atmosphere. ACR particles are energetic, can penetrate deeper into the Earth's atmosphere and have enough energy to break N, molecules. We calculated the production rate of NOx due to ACRs in the lower stratosphere (10-30 km) as a function of latitude and showed that it should have been orders(!) of magnitude higher in comparison with the total rate of NOx production from N₂O. Using 2-D photochemical model, we evaluated how such a high NOx production rate would affect the global ozone layer.

We found that increased ACR fluxes caused a significant depletion of the global ozone layer and could cause numerous extinction events throughout Earth's history. Possible geologic evidence will be discussed.

Rock Magnetism Of The Black Shale In The Mt. Roe Basalt, Pilbara Craton, Western Australia

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We conducted preliminary paleo- and rock magnetic study on the early Archean rocks in Pilbara Craton, Western Australia. Archean Biosphere Drilling Project had drilled a continuous 300 m core from the Mt. Roe basalt (2770 Ma; Arbdt et al. 1990) in the Whim Creek region. Lithofacies of the drilled core are divided into Basalt Zone and Black Shale Zone (upper zone 72-124 m; lower zone 258-280 m). The Black Shale Zone contains iron sulfide nodule, which are divided into (1) ca. 10-20 mm radius rounded shape, (2) ca. 10 mm radius amoebic shape, and (3) ca. 5 mm thickness layer.

Initial measurements of whole core by the Multi Scanner Core Logger (MSCL) and the pass-through cryogenic magnetometer indicate that the lower Black Shale Zone correspond to high magnetic susceptibility and intensity interval. Curie temperature and hysteresis loop of the black shale and iron sulfide nodule by Vibrating Sample Magnetometer (VSM) indicate to contain ferrimagnetic iron sulfide. A moment of the iron sulfide nodule is 100 times stronger than black shale. Curie temperatures at 320 and 340°C correspond to monoclinic pyrrhotite (Fe₇S₈) and greigite (Fe₃S₄). Increments of moment at ca. 270°C suggest that the black shale contains hexagonal pyrrhotite (Fe₀S₁₀). A constricted hysteresis loop of the nodule may be produced by mixture of high and low coercivity. Including the evidence of the black shale rich in organic carbon, the occurrence of ferrimagnetic iron sulfide minerals suggests that microorganisms such as methanogen had created a strongly euxinic environment. Further, paleomagnetic measurements are going to reveal the relationship between the deposition of the black shale and formation of the iron sulfide.

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Geologic Evidence For An Early Archean CO₂/CH₄ Greenhouse

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Substantial geological evidence from rocks 3.5-3.2 Ga suggests that the Earth's early atmosphere supported an intense greenhouse that maintained surface temperatures of 70±15°C1 and that pCO2 in this early atmosphere was at least 100-1000 times the present value and perhaps as high as several bars. This data includes the oxygen isotopic composition of cherts representing siliceous sediments deposited under normal, open marine conditions1 unrelated to hydrothermal vents, the deposition of sodium bicarbonate (nahcolite, NaHCO3) as a primary evaporitic sediment in coastal brine ponds2, and compositions of first-cycle conglomerates, sandstones, and shales that indicate an aggressive weathering regime even in the absence of land vegetation^{3,4}. Such high surface temperatures before 3.2 Ga were probably provided by a mixed CH₄ and CO₂ greenhouse in which atmospheric CH4/CO₂<<1. Inefficient transfer of CO₂ to the oceanic crust combined with efficient tectonic recycling probably acted to maintain high atmospheric levels of CO, before 3.0 Ga. The principal mechanism of long-term, Archean through Proterozoic, CO, loss from the surface system and atmosphere may have been sedimentation on newly-formed blocks of continental crust, not loss to the mantle via subduction. The formation of the Earth's first large block(s) of continental crust 3.2-3.1 Ga, including most of the present-day Kaapvaal and Pilbara Cratons, triggered initial rapid depletion of atmospheric CO₂ through weathering and ushered in a interval of atmospheric, climatic, and very possibly biological instability.

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Investigations Into The Numerical Ages Of Postmiocene Fluvial Landforms In The Atacama Desert,

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The hyper-arid Atacama Desert of northern Chile is virtually devoid of precipitation and vegetation, yet we have observed a succession of fluvial landforms (stream terraces and alluvial fans) that may reflect regional periodic changes in climatic and/or tectonic regimes. Using cosmogenic radionuclide (CRN) analysis (¹⁰Be and ²⁶Al), we have begun to calculate

numerical ages of post-Atacama gravel fluvial surfaces in three watersheds along a precipitation gradient in the Atacama Desert. The results of our CRN analyses, combined with ⁴⁰Ar-³⁹Ar analyses of volcanic ash in several related terraces, provide an initial perspective into the ages of some of the oldest post-Atacama gravel surfaces in the region and are the beginning of an effort to determine if there is a regional synchronicity to the terrace and fans deposits of the central Atacama Desert. These ages will also enable us to determine atmospheric deposition rates and soil formation rates, both of which have not been done before but are vital to understanding the geochemistry and geomorphology of the Atacama Desert.

Our results indicate that the terraces and fans observed in the Atacama Desert are extremely stable, the oldest having been in place for at least 2-3 Myr, and probably more than 4 Myr, because ¹⁰Be and ²⁶Al are approaching secular equilibrium. These fluvial features appear to reflect the termination of a major incision event(s) that was characterized by a reduction in ability of streams to remove sediment and a massive infilling of valleys and basins. Recently, Nishiizumi et al. (in preparation) have used CRN analysis to date boulders on the surface of Atacama gravels (into which our surfaces are incised) and found that the samples were at secular equilibrium with respect to ¹⁰Be and ²⁶Al as well. However, with ²¹Ne, those authors were able to calculate CRN ages of 8.2-9.0 Ma, in accordance with independent age estimates of ash. Our CRN data indicate the lowest boulder erosion rates in the world outside of Antarctica (between 4 and 17 cm/Myr), suggesting that the application of Nishiizumi et al.'s method to our younger surfaces should prove profitable.

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Do early Archean Isua and Akilia rocks contain traces of life?

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The oldest known supracrustal rocks on the Earth from the Isua belt and the Akilia association in Greenland have gathered wide publicity as proposed hosts of the earliest traces of life [1, 2, 3]. Recent studies [4, 5, 6] have, however, shown inconsistencies in these interpretations. Carbonate-rich Isua rocks (metacarbonates) that were originally thought to be metamorphosed sediments containing organic remains, have been shown to have a deep-seated metasomatic origin, unsuitable for hosting traces of early Archean life.

The applicability of elemental carbon and its isotopic composition as a biomarker in high-grade early Archean supracrustal rocks has been placed in further doubt by our recent ion microprobe isotope measurements of individual carbon particles. The abiogenic carbon in Isua metacarbonate rocks that is formed upon abiogenic ferrous carbonate disproportionation, is found to be isotopically heterogeneous with variation of d13C values among individual particles exceeding 20 ‰ within cm-scale sample areas. Some of the graphitic particles in metacarbonates have d13C values within the nominal biogenic carbon field. Similar isotopic heterogeneity was also found among individual carbon particles in a sample from the Bouma sequence type graded beds [3] that have been regarded as the most promising Isua rocks to host early Archean biogenic carbon. However, isotopic heterogeneity and the occurrence of graphitic particles with heavy d13C values, far from the nominal biogenic carbon field, draw the biogenic origin of graphitic particles in graded beds into question. Our ion microprobe data thus highlight the need for careful assessment of processes, both biogenic and inorganic, responsible for the observed isotopic heterogeneities.

The suggested biologic significance of inclusion of carbon particles in apatite in Akilia and Isua rocks [2] is not supported by our findings. Detailed studies of numerous apatite crystals from the Akilia quartzite have failed to show any such association, in fact we have not been able to find any graphitic carbon particles ($> 2 \mu m$) at all in studied 15 different Akilia samples including the actual sample used by [2]. In Isua rocks carbon

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Source Of Oxygen On The Early Earth

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From reduced beginnings Planet Earth evolved slowly but seemingly inextricably toward an ever more oxidized state (Kasting 1993; Wiechert 2002). Starting from very low levels 4 Gyr ago the oxygen concentration in the atmosphere exceeded 10^{-5} PAL (Present Atmospheric Level) around 2.2 Gyr ago (Bekker, Holland et al. 2004), rising further over the next Gyr. Many researchers believe that the O_2 needed for the global oxidation was provided by early microorganicms that had "invented" oxygenic photosynthesis (e.g. (Des Marais 1997; Kasting 2002)).

We are pursuing a different approach. Previous studies (Freund 2002; Freund, Dickinson et al. 2002) have shown that igneous and high-grade metamorphic rocks contain oxygen anions in the –1 oxidation state, probably in the form of peroxy links in the structure of the constituent minerals. The peroxy oxygen is believed to be introduced through an internal redox conversion of O₃(X,Y)-OH pairs (X,Y=Si⁴⁺, Al³⁺ etc.), which split off H₂ and turn into peroxy links, O₃X-OO-YO₃ (Freund 2002; Freund, Dickinson et al. 2002).

If rocks contain peroxy, however, hydrolysis during weathering will cause hydrogen peroxide, H_2O_2 , to form. We hypothesize that this process could have injected significant amounts of oxygen into the surface and subsurface environments, leading to the oxidation of the Earth over the crucial first 2-3 Gyrs.

Heating crushed rocks to above 600°C releases O_2 due to disproportionation at the surface of mineral grains. We report on experimental efforts to quantify to the extent possible the amount of peroxy oxygen in common rocks (granite, anorthosite, gabbro) using a Rapidox 3000 Oxygen Analyzer from Cambridge Sensotec.

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A Consistent Record For The Rise Of Atmospheric Oxygen.

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Analysis of stratigraphic position of geochemical and geological indicators for the rise of atmospheric oxygen with respect to the 2.48-2.42 Ga plume breakout event, three Paleoproterozoic glacial events, and secular variations in carbon isotope composition of seawater reveals that the first reliable evidence for oxygenated atmosphere appeared between the second and

third Paleoproterozoic glacial events in South Africa. These include lack of or small mass independent fractionation in sulfur isotopes coupled with an increase in S isotope fractionation in early diagenetic pyrites in black shales of the Rooihoogte and Timeball Hill formations and the first appearance of shallow-water hematitic oölites and pisolites in the Upper Timeball Hill Formation (Bekker et al., 2004). These oldest evidence for the rise of atmospheric oxygen are time equivalent with carbonates of the Upper Duitschland Formation, South Africa that record positive carbon isotope excursion in composition of seawater with values as high as +10.1 % (Bekker et al., 2001). Units immediately overlying the third glacial diamictite worldwide provide multiple evidence for oxygenated atmosphere including red beds, increased S isotope fractionation and lack of mass-independent fractionation of sulfur isotopes of sulfates and sulfides, oxygenated paleosols, marine sulfate evaporates, and Ce anomaly. The data are consistent with the stepwise oxidation of the atmosphere between 2.45 and 2.22 Ga when transition from anoxic methane-rich atmosphere to oxygenated CO2-rich atmosphere led to climatic perturbations reflected by global glaciations. Glaciations were initiated by lowered atmospheric methane levels due to the rise of atmospheric oxygen and lasted until CO, degassed from the mantle reached levels sufficient to counteract low luminosity at that time.

Did A Gamma-ray Burst Initiate The Late Ordovician Extinction?

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Gamma-ray bursts produce a flux of radiation detectable across the observable Universe. A GRB within our own galaxy could do considerable damage to the Earth's biosphere; rate estimates suggest that a dangerously near GRB should occur on average one or more times per billion years. At least five times in the history of life, the Earth experienced mass extinctions that eliminated a large percentage of the biota. Many possible causes have been documented, and GRB may also have contributed. The late Ordovician mass extinction approximately 440 million years ago may at least partly be the result of a GRB. Due to severe depletion of the ozone layer, intense solar ultraviolet radiation is expected to result from a nearby GRB, and some of the patterns of extinction and survivorship at this time may be attributable to elevated levels of UV radiation reaching the Earth. In addition a GRB could trigger the global cooling which occurs at the end of the Ordovician period that follows an interval of relatively warm climate. The sudden glaciation had previously been identified as the probable cause of this mass extinction and we note that the intense rapid cooling that occurred at that time, which may have resulted from a GRB, also clearly played a very important role in driving the mass extinction.

Earth Science, Including Remote Sensing

Sedimentary And Biological Record In Ancient Iron Oxides Of Río Tinto Basin And Its Applications For The Exploration Of The Mars Hematite Deposits.

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In current and future missions to Mars designed to look for signs of extant or extinct life, is it highly likely that our first attempts will be carried out on Martian hematite deposits, as these may well be the best landing sites for remote rovers, such as the MER. However, as little is known about how climatic, hydrochemical and biological information is recorded and preserved in iron-rich materials on Earth, such an information may not be recognized in Martian deposits due to lack of biosedimentary models of these ferric materials.

In the Río Tinto Basin (southwestern Spain), ancient and recent deposits show abundant sedimentary and biological record in materials compositionally comparable to Mars oxides (Fernández et al., 2003, 2004).

Moreover, as these materials were formed under acidic conditions, as seen in the modern acidic river (pH= 0.9 to 3), the hydrochemical and biological interpretation of such a record is feasible.

The ferruginous materials forming the three terraces have ages ranging from recent to Tertiary (Kosakevitch et al., 1993). They were originated during the regional entrenching of the Tinto River on the Carboniferous basement. Although the primary composition of the ferruginous sediments was represented by sulfates, subsequent rock-forming processes have changed the original composition to iron oxides and oxyhydroxides, also favoring the structure preservation due to the iron resistance to alteration. Comparison with modern structure suggests that primary sulfate coating on original biological material favored the recording of environmental and biological information under the physicochemical conditions of the ancient river.

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Lake Superior Banded Iron Formation: Spectral And Geochemical Properties And Implications For The Martian Bulk Hematite Outcrops

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The Thermal Emission Spectrometer (TES) onboard Mars Global Surveyor discovered grey, crystalline hematite at Sinus Meridiani, Aram Chaos, and various small outcrops within the Valles Marineris. Among the proposed formation mechanisms for the bulk hematite is precipitation of ferric oxides in iron rich waters as in terrestrial banded iron formation (BIF). Our recent work shows increased hydration signatures associated with all hematite regions from both the Mariner 6/7 and the French ISM orbiting short-wave infrared spectrometers, further supporting an aqueous formation mechanism. The Meridiani outcrop is selected as the landing site for Opportunity, the second of the Mars Exploration Rovers.

Lake Superior Type BIF differs from other types of BIF due to its inferred sedimentary environment. Iron formation consists of four facies: sulfide, carbonate, silicate, and oxide. Their occurrence is controlled by the Eh/pH levels within the depositional environment. In the Lake Superior BIF, the iron oxide magnetite accompanies the carbonate, silicate, and oxide facies as it is a combination of ferrous (Fe2+) and ferric (Fe3+) iron and precipitates in intermediate to oxidizing conditions.

Samples from the oxide, carbonate, and silicate facies have been collected from northern Michigan from the Marquette and Gogebic iron districts. They have been measured for reflectance in the visible/near-infrared/shortwave infrared (0.4 to 2.5 $\mu m)$ and emittance in the thermal infrared (5 to 50 $\mu m)$. Geochemical analyses including thin section analysis, X-ray diffraction, and scanning electron microscopy were also performed on the samples to attain more detailed compositional information and to corroborate mineralogy identified with spectroscopy. We will present these results and discuss their implications for and application to the Opportunity landing site.

Physical, Chemical And Biological Analysis Of A Lacustrine Core Recovered From Haughton Crater, Devon Island, Nunavut, Canadian High Arctic

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Haughton Crater (75°22'N, 89°40'W) is a circular impact structure that has become a Mars analogue research site as a result of the activities of the NASA/SETI Haughton Mars Project (HMP). A Miocene paleolake formed within the crater basin post-impact, and its lacustrine deposits are of particular interest given their analogue possibilities to paleolakes on Mars. Members of the 1998 HMP team executed a drilling experiment (DRILLEX) to acquire post-impact rock units to rebuild the geological record of the crater, and to evaluate the drilling technology for future coring expeditions on Mars.

A 6.71 m core (AH98-3) recovered from the Miocene lacustrine deposits was investigated using a suite of physical, chemical and biological analyses for the purpose of reconstructing the aquatic environment of the paleolake. Specifically, a 1 cm thick band of sediment impregnated with hydrocarbons was recovered from the lacustrine core, and was investigated using geochemical techniques. The molecular organic and stable isotopic composition of this material indicated a terrestrial source for the hydrocarbon layer, with evidence of significant contributions from gymnosperms. Furthermore, through x-radiographic, grain size and magnetic susceptibility analyses, large-scale rhythmic changes between sand beds and fine silts were detected in the core. Preliminary diatom investigations revealed the remains of diatom fossils in the upper portions of the core, indicating that this paleolake may have supported an algal community. Although pollen, plant macrofossil and Neogene arctic vertebrate fossils have been previously identified in the lacustrine deposits (1, 2), no direct investigation or analysis of aquatic fossils, such as diatoms, has been published.

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Astrobiological Studies In Iceland

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Active hot-spot volcanism and east-west spreading on the Mid-Atlantic Ridge define the geology of Iceland, where Tertiary basalts dominate in the East and West and the central volcanic zone is partly covered with temperate ice caps, leading to frequent ice-volcano interaction. The poster presents a brief overview of astrobiology-related research in Iceland.

- 1) Subglacial lakes beneath the Vatnajökull ice cap. At least five subglacial lakes are situated beneath 300-600 m thick ice cover in the NW part of Vatnajökull (1). The Grímsvötn lake has recently been accessed with a thermal drill for geochemical and biological studies (2). Experience gained in such projects could benefit the planned sampling and study of Lake Vostok and other subglacial lakes beneath the Antarctic Ice Sheet.
- 2) Crystal growth in temperate and polar ice. We compare new data on crystal size, dust and major ion concentrations from ice cores drilled on the temperate ice caps in Iceland with similar data from the polar ice sheets (3) in the light of new ideas suggesting that microscopic veins on boundaries between ice crystals in deep Antarctic ice can be habitats for microbial life (4).
- 3) Martian hillside gullies and Icelandic analogs. Small hillside gullies seen on images from Mars Global Surveyor indicate the presence of subsurface liquid water on Mars (5). A recent pilot study of gully formations in the Tertiary basalt formation in Western Iceland showed gullies that bear striking similarities to the Martian phenomena, although the gullies in Iceland are more likely formed by surface runoff and snowmelt (6).

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Environment And Evolution

Divergent Adaptation of Escherichia Coli To Cyclic Ultraviolet Exposures

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As a consequence of adaptive evolution, populations under selective conditions change genetically and phenotypically after a number of generations in order to survive in that particular environment. When ultraviolet light (UV) or X-rays are present as selective factors under laboratory conditions, natural resistance of bacteria to these agents is normally increased by processes of mutation and selection (Wright and Hill, 1968; Mouton et al., 1970; Rames, et al., 1997; Ewing, 1995; Ewing, 1997). Since induced mutations occur randomly and apparently without any directionality, it is likely that among different populations, resistance mechanisms will tend to diverge after prolonged exposures to radiation. However, convergence can not be completely discarded if the most abundant or lethal kind of DNA lesion has to be preferentially managed by a particular DNA repair pathway or even by an specific repair enzyme. To examine which of these alternatives actually takes place, five subcultures of Escherichia coli, strain PQ30 were parallelly treated for 80 succesive UV irradiation cycles. At the end, five strains with different degrees of resistance were isolated and after characterisation it was clear that adaptation to cyclic UV irradiation was a consequence of random mutation and selection events, following different courses. Although these experiments are limited to laboratory conditions, they show that selection may promote genetic divergence even in populations living in identical environments, if they find alternative adaptive solutions.

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Ocean Science Research tools to Explore Earth's Surface and Subsurface Biosphere in Time and Space.

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The Ocean Sciences Division at the National Science Foundation is planning two major initiatives to explore the ocean surface and subsurface biosphere in both space and time. The Integrated Ocean Drilling Program (IODP), now getting underway, will build upon the scientific and technical advances of the Ocean Drilling Program. Increased understanding of the deep biosphere beneath the sub-seafloor ocean is a major scientific objective of IODP. New technology and the wider array of drilling platforms to be incorporated into this program will provide new avenues for experimentation and exploration of life in subseafloor environments. Many of the new ocean drilling technologies will be directly applicable to exploration for indicators of life in extraterrestrial environments through the collection of unweathered, unoxidized, and uncontaminated samples.

The Ocean Observatories Initiative (OOI) will construct a network of seafloor observatories at coastal, regional, and global scales using both fiber-optic cables and deep-sea moorings. This infrastructure will provide power and high bandwidth communications to enable a real-time observational presence in the ocean. In addition, this infrastructure will provide new opportunities for the investigation of ocean processes over a range of spatial and temporal scales and enable in situ monitoring of micriobial activity within the earths crust under varied environmental conditions.

Downhole observatories will be an important link between the surface (OOI) and subsurface (IODP) biosphere, and will provide the impetus for development of new research tools to explore the deep biosphere as an integral part of both OOI and IODP.

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An Improved Numerical Model For Determining Reaction Rates In A Subsurface Biosphere

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Some microbial communities live several hundred meters below the sea floor. To improve understanding of these communities, we have developed a numerical model that uses profiles of chemical and physical properties to quantify metabolic reaction rates at depth. A previous model estimates constant reaction rates in zones of equal length, a.k.a. 'reaction zones' (Berg et al., 1998). That model works well with profiles that are characterized by uniform spatial resolution and limited variations in reaction rates. Profiles with variable sampling intervals and/or highly variable reaction rates require a more complex model that can adjust to changes in sampling resolution and profile complexity. This has been accomplished in our new model. Application of our model to data from an extended sediment column (D'Hondt et al., 2003) demonstrates that it is flexible enough to handle the complexity of profiles in marine sediments of great depth. This flexibility is because (1) our model does not limit the number of reaction zones, and (2) it allows the reaction zones to vary considerably in length. Because this new tool enables researchers to quantitatively assess metabolic activities in deep subsurface environments, it may be useful to astrobiologists, as well as oceanographers.

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Unexpected Microbial Diversity Of The Living Stromatolites Of Shark Bay, Western Australia

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Stromatolites have been present on Earth for more than 3 billion years. Today, the only known examples of stromatolites forming in hypersaline coastal environments are in Hamelin Pool at Shark Bay, Western Australia. Despite their evolutionary significance, little is known about their associated microbial communities. By employing culture dependent and molecular biological approaches based on the characterisation of 16S ribosomal RNA sequences, the discovery of a wide range of microorganisms associated with these biosedimentary structures is reported in this study. The community was dominated by organisms of the cyanobacterial genera Synechococcus, Xenococcus, Microcoleus, Leptolyngbya, Plectonema, Symploca, Cyanothece, Pleurocapsa, and Nostoc. The levels of diversity corresponding to novel sequences that are unrelated to any other known cyanobacteria, and sequences that appeared to represent early branches in the cyanobacterial tree have also been found. We also report the discovery of potentially free-living Prochloron. The other eubacterial isolates and clones was found to cluster into 7 phylogenetic groups: OP9, OP10, Marine A group, Proteobacter, Low G+C Gram-positive, Planctomyces and Acidobacteria. The presence of sequences corresponding to members of halophilic archaea of the division Euryarchaeota and members of the Crenarchaeota, and methanogenic archaea of the order Methanosarcinales has also been demonstrated. We have also isolated 2 potentially novel halophilic archaea strains with phenotype similar to Halococcus. Although they might represent new species, further biochemical and genotypic characterisation need to be conducted for confirmation. This study has unveiled the diversity of microoganisms present in these modern marine stromatolites with the Hamelin Pool formation.

The Surprising Disparity Between Microbial Community Structure In The Presence And Absence Of Light: Implications For Astrobiology

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Due to the oxidized nature of the Martian regolith, it has been surmised that if extant life exists on Mars, then it must reside within the subsurface. With this assumption comes an inherent ecological bias that without the input of light energy, such subterranean life has restricted diversity through limited energy sources and competitive exclusion (Begon, Harper and Townsend, 1998). We have carried out a comparative study that suggests that the absence of UV radiation, rather than being a limiting factor, is actually conducive to microbial diversity.

We compared the microbial communities between two chemically and physically identical sulfidic hot springs, one in the presence of sunlight (the light spring) and one found in a cave (the dark spring). Due to sulfides and high temperatures, these springs did not support photosynthetic organisms or arthropod predation. We carried out a molecular phylogenetic analysis of the microbial communities in each spring. The microflora of the light spring was essentially colonial, with one phylotype dominating the community. In the 'dark' spring, 30 different phylotypes were identified, representing nine domains of Bacteria and one domain of the Archaea, despite the obvious similarity between the environments.

Our results may suggest that due to the necessity of developing complex SOS response systems to defend against the damaging effects of UV radiation, light may actually limit the potential species richness of microbial communities. Such results may therefore support the hypothesis of a rich subterranean microbial ecosystem on Mars and other planetary bodies in our Solar System.

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Iron Isotope Perspective For Molybdenum Enrichment In The Archean Lewin Shales And Carawine Dolomites Of The Eastern Hamersley Basin, Western Australia

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Iron isotopes have a potential for tracing Fe geochemical cycling because isotope fractionation occurs when its valence state changes depending on the surrounding redox environments (e.g., Beard et al. 2003). Molybdenum is a redox-sensitive metal, therefore Mo may also be a potential indicator of sedimentary redox conditions, because dissolved Mo can be fixed by organic matter and sulfide (e.g., Morford and Emerson, 1999). The inferred redox evolution of the atmosphere and oceans at around 2.2 ~ 2.0 Ga (GOE: Great Oxidation Event; e.g., Holland, 1994) should have changed the geochemical cycling of Fe and Mo.

To extract information on the paleoredox sedimentary environments in the Archean oceans before the inferred GOE, we combined geochemical analyses of Mo, S, and Fe(III)-Fe(II) contents and bulk Fe isotope compositions for Archean sedimentary rocks. In addition, we analyzed their isotope compositions of sulfide S and organic C ($C_{\rm org}$). We chose ~2.7 Ga old black shales of the Lewin Shale Fm. and the overlying carbonates in the ~2.6 Ga (?) Carawine Dolomite Fm. (drillcore RHDH2A) in the eastern Hamersley Basin, Western Australia (e.g., Simonson and Hassler, 1997). These sets of samples in a single drillhole of different Fe mineralogy and probably paleodepth for depositions should cover different regime of depositional environments.

We discovered distinct differences in the Fe isotope compositions between Lewin ($\delta 56\text{Fe} = +0.07 \pm 0.26 \%$; n = 8) and Carawine ($\delta 56\text{Fe} = -1.46 \pm 0.72\%$; n = 6) samples (normalized to bulk Earth) and an overall positive correlation between Mo contents and Fe isotope compositions. Moreover, we found an overall weak negative correlation between Fe(III) contents and bulk Fe isotope compositions, an overall negative correlation between S isotope compositions and Fe isotope compositions, and no major difference in their C isotope compositions.

difference in their C_{org} isotope compositions. The above observations may be explained by the different Fe mineralogy (sulfide vs. carbonate), the extent of bacterial sulfate reduction (BSR) and Fe reduction, the limitations of sulfate and reactive Fe(III) (FeR) for BSR, and source/type of organic matter for BSR. We hypothesize that the enrichment of Mo in the Lewin shales occurred when active BSR led to nearly complete utilization of Fe $_{\rm R}$ for BSR and the Fe isotope compositions approached to ~0%, whereas sulfate for BSR was not limited and thus the S isotope compositions did not exceed +5 % which may be those of oceanic sulfate. This study has implications for the evolution of the Earth's early atmosphere, hydrosphere, and biosphere.

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Heat Shock Proteins, Hypermutator Genes, And Astrobiology

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An interesting, and unexplored, connection of astrobiology to other fields is that between radiation damage repair, cancer, and aging. Cancer involves unchecked genetic hypermutation (Sarasin 2003). In many models, ageing

is tied to the accumulation of mutations. The main function of heat shock proteins and other chaperone proteins is apparently to allow misfolded proteins to function, allowing for a "hidden reservoir" of mutations that are expressed when heat shock proteins are diverted to managing environmental stress. Mutator genes in many species have a similar effect, unleashing hypermutation episodes in times of stress. Dysfunctional heat shock proteins are involved in carcinogenesis. A relevant question for astrobiology is: how did all this apparatus evolve and did astronomical effects play a role? These elaborate systems of environmental response are highly conserved among a huge variety of organisms, and so arose long ago when conditions may have been very different from today. Unshielded solar UV prior to the rise of an oxygen atmosphere, ubiquitous solar flares, and frequent bolide impacts may play a role in providing intrinsic fluctuations in the environment, and also in the mutation rate, when life first formed. Ubiquitous short timescale fluctuations in the mutation rate may play a role in the development of heat shock proteins and related architectures and hence in the determination of lifespan and oncogenesis. There are other issues concerning the origin of error repair mechanisms and the possible evolution of evolvability that may take on new perspectives in the astrobiological context of an early Earth where chaotic conditions were the norm.

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Solar Brightness Variability And The Evolution Of Life On Earth

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We have used our robotic telescopes located in southern Arizona to measure the brightness variability of 350 Sun-like stars ranging in age from 100 million years to 10 billion years. Our observations delineate the gradual decrease in brightness variability with time as Sun-like stars shed their angular momentum through magnetized stellar winds. As a star's rotation slows, the strength of its magnetic dynamo weakens and all of the phenomena associated with stellar magnetic activity (starspots, flares, radio, ultraviolet, and X-ray emission, coronal mass ejections, etc.) subside as well. Our cross-sectional study of Sun-like stars indicates that our own Sun's brightness was at least two orders of magnitude more variable in its youth than the relatively quiescent Sun we observe today. However, even on today's quiet Sun, significant radiation events occur that can damage satellite assets and terrestrial power grids and also threaten the lives and health of astronauts as well as passengers on high-flying aircraft. In its youth, the Sun's intense X-Ray, ultraviolet, and charged particle emissions would have been devastating to the Earth's developing biosphere. In addition, the associated extreme solar brightness variations would have precluded a stable terrestrial climate needed for the existence of complex life forms. We compare our time line of solar brightness variability with the geological record of the progression of life on the Earth. In particular, we note that the Cambrian explosion on Earth did not occur until the Sun's brightness variability had decreased to less than 1% of its youthful value, attaining a stability of roughly 0.1%. This suggests that the decrease in brightness variability of our Sun may have been an important prerequisite for the emergence of advanced species that occurred in the Cambrian explosion. Therefore, the study of brightness variability in Sun-like stars can be an important investigative tool in the search for life in the universe.

Autotrophic Geochemical Signatures In 2.5 Billionyear-old Microbial Communities

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2.5 billion-year-old microbial communities, Campbellrand platform, South Africa, produced complex structures that varied with depositional environment¹. In environments where calcite precipitation was rapid and sediment influx low, complex microbial structures with open, void-rich frameworks are preserved as organic inclusions in calcite cements. Cross cutting relationships demonstrate that specific communities enhanced local calcite precipitation; this calcite is ¹³C-enriched relative to neighboring calcite, which suggests that the communities were autotrophic carbon isotopic signatures have been identified in fresh water carbonates², but are rare in marine systems, possibly due to production of ¹²CO₂ during sulfate reduction and organic carbon oxidation. Sulfate reduction also enhances calcite precipitation rates³. An equal or greater rate of calcite

precipitation during sulfate reduction than peak autotrophic CO_2 removal would mask autotrophic isotopic signatures. However, during late Archean time, sulfate concentrations may have been low, as is true of most fresh waters, allowing preservation of autotrophic carbon isotopic signatures in calcite.

It is unclear whether the autotrophic CO₂ removal was due to photosynthesis or chemosynthesis. New stratigraphic correlations suggest that the microbial communities grew in water depths ranging from a few 10's of meters, where photosynthesis is reasonable, to at least 100 m, where the photon flux may have been too low to support substantial photosynthetic CO₂ fixation. Isotopic signatures have not been studied along depth gradients to date. Calcite precipitation rate decreased with depth, and deeper microbial structures are more commonly compacted. Thus, it may be difficult to find deep structures containing calcite that precipitated contemporaneously with microbial activity and likely to preserve evidence of metabolic processes.

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Statistics And Astrobiological Implications Of Cosmic-ray Fluctuations For Habitable Planets In The Interstellar Environment

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Galactic cosmic rays are believed to play a role as contributor to ozone layer chemistry, biological mutation rates, and climate. The solar wind modulates the low-energy galactic cosmic-ray flux in our solar system, but this modulation depends on the size and other properties of the heliosphere and the details of cosmic-ray propagation. It has been suggested for decades that the cosmic-ray flux on Earth, and presumably other habitable planets, should be greatly enhanced when the solar system traverses denser regions of the interstellar medium and reduced when it passes through voids, but the frequency of such events remains very uncertain. We attempt to quantify the problem using calculations of test planetary systems and their associated heliosphere analogues moving through two sets of continuous density and velocity fields representing the interstellar medium: (1) Synthetic 3-dimensional empirical models and MHD simulations, with temporal resolution spanning ~10³–10⁹ years, and (2) New absorption line observations of gas toward stars within about 500 pc. along a narrow cone representing the Sun's relatively recent historical Galactic trajectory.

Using a pressure balance approximation for the dependence of heliosphere size on external density and relative velocity, and a convection-diffusion solution to model the cosmic ray modulation, we follow the time series of cosmic-ray fluxes in the liquid-water habitable zone of parent stars of various masses. Gravitational focusing is treated in detail. From ensembles of these test particle time series we estimate the probability distribution of cosmic-ray fluxes and associated durations for a variety of model planetary systems, and show the dependence of the frequency of large variations on stellar mass and Galactocentric radius. Using observational data, we reconstruct the approximate history of the terrestrial cosmic-ray flux over the past 50 Myr. Implications for long-term fluctuations in planetary mutation rates, atmospheric chemistry, and climate are briefly discussed.

Evolutionary Adaptation To Freeze-thaw-growth Cycles (Without A Cryoprotectant) In E. Coli

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Mesophilic bacteria including E. coli generally are not well adapted to cold environments such as freezing and thawing. In order to study how mesophilic bacteria evolve in response to freeze-thaw (FT) stress, 14 populations of E. coli B evolved in a freeze-thaw-growth (FTG) regime for 500 generations (75 FTG cycles). To determine if adaptation had occurred in this regime,

clones from the FTG evolved populations and their progenitors were directly competed in the same environment as the evolution experiment. The viable cell density of FTG evolved lines relative to their progenitors was measured before freezing, after thawing, and after growth.

Preliminary results indicate that the FTG evolved lines have increased their fitness in the FTG regime by an average of >60% compared to their progenitors. This increase in FTG fitness can be attributed to both a) an increased ability to survive freezing and thawing; and b) increased growth fitness after freezing and thawing.

One group of the FTG evolved populations was initiated from clones that had previously evolved in growth conditions for 20,000 generations. Although we expected that this group would improve their FT survival more so than growth fitness, a substantial portion of the increase in FTG fitness was due to improved growth fitness. These particular populations have a substantially decreased lag phase after thawing compared to their progenitors, contributing to their improved fitness during the growth phase.

The Investigation Of Dynamic Myxobacteria Population Alterations According To Solar And Geophysical Activities.

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Bacteria belong to "biomarkers", which detection can testify to existence of life on planets and satellites in a solar system. Myxobacteria is unique group of micro-organism due to they can form a mulicellular structures (fruiting bodies), their vegetative cells can transform to endogenous anabiotic state (myxospores) – as the answer on environmental condition alterations. Myxobacteria exist as vegetative cells in suitable conditions. When conditions get worse (basically, when substrates become depleted) approximately 106 cells begin to form fruiting body that will contain resting cells of myxobacteria (Reichenbach & Dworkin, 1992). Experimental data that were found in ONU microbiology department illustrate the potential space and geophysical effect on viability of vegetative cells and on the fruiting body formation process.

The quantity viable vegetative cells were determined daily in different period of 1995 – 1996 years (152 tests) The quantity formed fruiting bodies in the Myxobacteria population were determined in summer 1998 (52 tests). All experiments were conducted in vitro with the maintenance of stability cell quantity in inoculation sample, nutrient medium, duration and condition of incubation. However, in spite of fully maintenance above listed, the number of viable vegetative cells changed from 20 to 500 cells per ml and formed fruiting bodies - from 400 to 1800 per population (10000 cells) and changed noticeably from one test to another and in different series of tests. The comparisons of alterations Sun and geomagnetic activity including data set obtained from space and ground-based observatory (solar X- and ultra-violet radiation, electron flux from solar "coronary hole", flare blast pressure in solar wind, planetary magnetic storm on Earth magnetosphere, and measuring data obtained by geomagnetic station "Odessa") were done for biological data of each test.

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Ecosystem Evolution And Biological Extinction Through Geological Time

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The history of life on Earth is characterized by the successive addition of new grades and clades of organisms, as well as background extinctions and episodic mass extinctions. Different taxa may represent novel trophic habits and strategies, producing diverse trophic landscapes at local and global scales. The two parallel histories of evolution and ecology have been documented for the Phanerozoic (570 m.y. to present) separately in some detail (Sepkoski et al., 1981; Bambach, 1983; Vermeij, 1977, 1987), and recently there have been attempts to understand coupling of the two (Bambach et al., 2002). Trophic systems have no doubt become more complex since life first appeared as a community of competing chemoau-

totrophic prokaryotes (Knoll and Bambach, 2000). Similarly, taxonomic richness has increased, both as a product of major evolutionary transitions (Maynard Smith and Szathmáry, 1995), as well as diversification within established clades (Sepkoski et al., 1981). Conversely, while background and mass extinctions have been documented extensively for the Phanerozoic, it remains unclear whether there is any relationship between the dynamics of extinction and the evolution of trophic complexity. This paper examines the relationship between extinction and trophic complexity by examining Phanerozoic diversity from both systematic and trophic perspectives.

Trophic diversity is assessed by assigning taxa to trophic habits, thereby revealing the appearance of new components of ecosystem structure over time. The effects of ecosystem structure on extinction are explored by representing fossil systems as networks of interacting trophically interacting taxa (Dunne et al., 2002; Montoya and Solé, 2002), and measuring the potential for secondary extinction and extinction cascades. This approach is applied to trophic systems reconstructed from an ecologically parameterized subset of Sepkoski's compendium of Phanerozoic marine genera, as well as several terrestrial communities from the Permo-Triassic of Russia.

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The Origin Of Adaptability And Human Beings Richard Potts

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Earth's environments can be characterized in terms of two parameters. First, the consistent (sometimes relatively constant) properties of environments make specific habitats recognizable and measurable, and create a predictable set of adaptive conditions. Second, the dynamic or unstable properties are expressed as significant environmental change and create uncertainty for organisms. Life's history has been shaped by processes that reflect these two parameters – adaptation to specific local habitats, each defined by a particular range of temperature, water, and resource conditions; and evolution of the ability to accommodate to environmental instability. The latter result, or adaptability, can be assessed in three ways: the ability of an organism to persist through substantial environmental change, to spread to new habitats, or to respond in novel ways to its surroundings. Although adaptability pervades biological systems – from the simplest replicating molecules to the most complex forms of life – the processes by which adaptability originates in organisms are not well understood.

The evolution of human beings can be considered an odd and unrepeatable phenomenon, making it difficult to draw general principles of evolution, applicable broadly to life's origin and evolution, from our own evolutionary history. One possible exception is the evolution of adaptability. Dramatic expansion in the hominin ability to interact with environments was expressed as a small population of tropical African apelike creatures eventually gave rise (after a 6-million-year history rife with diversification and extinction) to a single species, Homo sapiens, spread worldwide and capable of unprecedented alteration of Earth's biota and habitats. The idea examined here is that the major features of human evolution – from bipedal behavior to complex cognition and symbolic expression – arose not from the challenges of the African savanna, ice-age Europe, and any other single array of habitat conditions, but rather from the dynamic and unstable qualities of environments.

According to new data from oceans and paleoanthropological sites, the evolution of humans was associated with rising variability in the environments of natural selection, an overall drop in large mammal species diversity, and the persistence of organisms either able to disperse and track a narrow range of habitat conditions or able to expand their means of adaptability. The findings show that (1) adaptability is not well described by the traditional specialist vs. generalist dichotomy, (2) human evolution was characterized by both versatile and specific habitat adaptation, and (3) the traits that define Homo sapiens reflect the "ratcheting up" of adaptability as genetic selection responded to rising environmental variation — a phenomenon described as "variability selection".

One hypothesis to emerge from this case study is that adaptable responses to changing environments require complex interactions in genomal, developmental, and/or behavioral systems, as indicated by the evolution of gene interaction, phenotypic plasticity, and cognition. One implication relevant to astrobiology is that once a genetic lineage originates even in the simplest form, exposure to environmental variability will create conditions for rapidly evolving a critical degree of genetic and phenotypic complexity if the lineage is to buffer the unstable and unpredictable qualities of its surroundings.

Whole Genome Analyses On The Class Levels: Is There A Consensus Phylogeny?

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With availability of many completely sequenced genomes, it has been shown that every single genome has undergone many dynamic changes throughout evolution. Helped by horizontal gene transfers (HGT), gene duplications, deletion pressure, genome inversions and other genome rearrangements, even two strains of the same species can have very different gene content. Individual genes often have different evolutionary histories, casting doubts that phylogenies calculated from single genes reflect the organismal phylogeny.

We performed comparative genome analyses for two classes of Bacteria: the cyanobacteria where HGT is inferred to have been a major contributor in the evolution of the clade and the gamma proteobacteria, a more heterogeneous group, where HGT appears to have been less of a factor. The latter finding might be due to the close association that some of the gamma proteobacteria have with multicellular eukaryotes (parasitic, symbiotic, or commensal), or due to the reduced genome size of some of the organisms included in the analysis. Two different approaches were applied to assess a genome mosaicism using whole genome analysis for those two classes of bacteria.

The obtained results show that the extent of genome mosaicism is different for different classes of bacteria. In case of the cyanobacteria, even genes involved in the core metabolism characteristic for these organisms appear to have been horizontally transferred (e.g., ribulose bisphosphate carboxylase and genes from the chlorophyll biosynthetic pathway), whereas in case of the gamma proteobacteria only few genes were detected as transferred.

Effect Of Environmental Parameters In The Persistence Time Of Heterogeneous Replicator Populations

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Simple replicators with short generation time and subjected to high mutation rates form large and highly heterogeneous populations. While the presence of different classes of individuals permits rapid adaptation under environmental changes, the same high mutation rate might be detrimental if the environment fluctuates too strongly or too rapidly. In prebiotic times, replicators with these properties were likely abundant, much before the catalytic ability of different species (and with it the possibility to cooperate and to develop a metabolism) appeared. The characteristic persistence time for one such population in isolation is a very relevant quantity which determines the probability that the species contacts other species, that cooperative behaviour be selected, and that it eventually participates in a network of species interactions.

Phenomenological models of replicators subject to different

environments (selection pressures) give us insight into the persistence of the population in different situations. Three different cases are analysed and compared with experimental results obtained with populations of RNA viruses evolving in vitro: (i) replicators with different mutation rates experiencing frequent population bottlenecks [1,2]; (ii) replicators evolving under a harsh environment which increases their mutation rate, both in the presence and in absence of population bottlenecks [3]; (iii) replicators able to undergo a trasition towards genome fragmentation evolving in a mild environment [4]. We present analytical, numerical, and experimental results for the three cases. Finally, we will briefly present recent results which analyse the effect of surfaces on the generation of stable metabolisms, once the catalytic ability of the population and its specificity have been selected and fixed [5].

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UV Sheielding Of Early Earth By N2/ch4/co2 Organic Haze

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There is evidence that the atmosphere of the early Earth did not contain enough carbon dioxide to warm the surface in the epoch of the faint young Sun (Rye et al. 1995). Current suggestions focus on an additional greenhouse effect of methane (Pavlov et al. 2000). However, methane and ammonia, both strong greenhouse gases, are destroyed by UV light. Sagan and Chyba (1997) proposed that the early Earth had an organic haze layer produced, as on Titan, by methane photolysis in the presence of nitrogen. Such a layer would preferentially absorb ultraviolet light, thereby allowing ammonia and methane to persist in the atmosphere. However, as in the case of Titan, such a layer would also have an antigreenhouse effect (McKay et al. 1999) which could oppose or even cancel any greenhouse effect generated by the shielded methane and ammonia. The question of whether a combination of an organic haze layer and methane and ammonia gases can combine to produce a net greenhouse effect on the early Earth depends on the optical properties of the organic haze layer.

We have produced organic material (tholin) simulating a methane photochemical haze in a CO₂-rich atmosphere of the early Earth by irradiating gas mixtures in an inductively coupled cold plasma chamber at a pressure of 0.26 mbar. We added progressively higher levels of CH₄ by combining gas mixtures of N₂/CH₄ (9/1) and N₂/CO₂ (9/1) to change the ratio of CH₄/CO₂. Tholin was accumulated for 5 hours in each experiment; the onset of tholin formation is around CH₄/CO₂ \approx 0.5. As the mixing ratio of CH₄ is increased, the production rate of the brownish tholin film increases. IR spectra showed the C-H and N-H bands similar to that of Titan tholin. A decrease in the C-H bonds on decreasing CH₄/CO₂ is noted. Ether bands (C-O-C) were tentatively detected, but no detectable carbonyl (C=O) band was found. The absorption in the UV region for the early Earth tholin is found to be greater than the Titan tholin. The slopes of the optical properties suggest that a UV shielding by the early Earth tholin would be less efficient than those of Titan tholin.

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Timescales In Astrobiology: Molecular Clock Calibrations And Their Affect On The Precision Of Time Estimates

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Molecular clocks are useful tools for astrobiology because of the poor fossil record of early life. However, despite the abundance of sequence data from genomes of organisms, molecular time estimates rely on accurate calibrations, usually from the fossil record. The implicit assumption is that the fossil calibration time is close to the true time of divergence (Hedges & Kumar 2003). Only one calibration point is required for time estimation, although additional calibration points, if accurate, are desirable.

The colonization of land by plants and fungi, and origin of the major groups of animals, were events that likely affected the biosphere and are of interest to astrobiologists. However, different research groups have arrived at different conclusions regarding the timing of these events. In this analysis, we look critically at these studies to try and determine the cause of the differences. Claims that vertebrate calibrations have caused an intrinsic bias can be rejected, because use of invertebrate calibrations yield similar results (Pisani et al. 2004). Likewise, claims that particular methods are responsible can be rejected because the use of all types of methods in the same study yielded similar results (Hedges et al. 2004). Studies finding young (Phanerozoic) dates for these events rather than deep divergences in the Neoproterozoic appear to have used inaccurate calibrations.

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Characterization Of A New Class Of Membranebound Oxidoreductases In The Green Bacterium Chloroflexus Aurantiacus

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The filamentous anoxygenic phototrophic bacterium Chloroflexus aurantiacus does not contain any cytochrome bcl or b6f complex, which makes it unique among photosynthetic organisms. How then does it complete the cycle of light-driven electron transfer and how does electron flow interact with other membrane-bound electron transfer complexes such as cytochrome oxidase?

Chloroflexus contains two similar multi-subunit complexes with two cytochrome c subunits. One of them is expressed in anaerobic phototrophic conditions (Cp-complex), while the other is found under dark aerobic conditions (Cr-complex). In the published unfinished genome of the bacterium, five contigs were found that cover an operon encoding the Cp-complex and a two-ORF part of the Cr-complex operon. The identity of the subunits was determined using mass spectrometry after protease treatment. Searching for homologous ORFs of these operons, we found that they belong to a previously unknown class of oxidoreductase, which we have provisionally named the cytochrome-pterin complex. This class apparently originated from the broadly distributed soluble three-subunit molybdopterin oxidoreductases by acquiring additional subunits, namely two heme c-bearing subunits, one additional integral membrane subunit, and an unknown subunit with no homologs outside the class. Putative examples of this operon were found in Spirochetes, delta Proteobacteria and Planctomyces

The previously unknown cytochrome-pterin complexes probably work as oxidoreductases that transfer electrons from quinol to mobile periplasmic e-carriers, coupled to transmembrane proton pumping. Electrons are subsequently transferred either to cytochrome oxidase or the photosynthetic reaction center.

The bacteria that appear to contain the cytochrome-pterin complex do not form a separate phylogenetic cluster, but belong to different taxonomic groups. Therefore, the enzyme must have been distributed among bacteria through lateral gene transfer.

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What Can Complete Genomes Tell Us About Early Animal Evolution?

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Complete genome sequences are now available for several vertebrate (human, mouse, rat, fish) and invertebrate (fruit fly, mosquito, worm, tunicate) animals, as well as from fungi and plants. The number of genes in each genome ranges from 6,000 to more than 20,000, with each gene coding for a protein with typical length of 300-400 amino acids. This represents several orders of magnitude more data for evolutionary research than previously available. Potentially, these valuable new data will accelerate our understanding of early life. However, at the same time they create analytical challenges and the need for more sophisticated methods. Distinguishing gene duplication from speciation events and accommodating rate variation are two of the most difficult issues and they will be addressed here. With some new bioinformatic approaches we have conducted complete genome sequence analyses and our results bear on the early evolution of animals and the rise in complex life on Early Earth.

Numerical Models For The Study Of The Accumulation Of Mutations In RNA Viruses

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Due to their high mutation rates, RNA viruses organize in extremely heterogeneous populations that are a reservoir of viral variants with potential adaptive capacity. The accumulation of mutations in the viral genome can be enhanced through bottleneck events, such as those occurring during plaque-to-plaque transfers, or through the use of mutagens. Usually the increase in the mutation fixation rate is associated to fitness decreases that could lead viral populations to extinction. In experiments carried out with several clones of foot-and-mouth disease virus subjected to 130 plaque-to-plaque transfers there was no extinction of the population, in spite of a linear accumulation of mutations through the process. There is an initial stage characterized by an exponential decrease in the average fitness. After a variable number of transfers, a statistically stationary state is reached in which there are large fluctuations around a constant fitness mean value (Lázaro et al., 2003). To understand the differences in the accumulation of mutations that take place along those two stages, we have carried out numerical simulations using parameters based in the experimental results. The model for the plaque-to-plaque transfers reproduces the biphasic kinetics of the experimental process. This model has also allowed us to determine the existence of different stationary states characterized by an average fitness value that depends on the population size (Lázaro et al., 2002). A related model that mimics the action of mutagens to increase the mutation rate predicts the existence of an error threshold, above which the viral population becomes extinct with a high probability. The parameters leading to the persistence or to the extinction of the populations will be discussed in the presentation.

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Water Loss From The Biological Structure As The Main Effect Of The Low Magnetic Environment

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Earth's magnetic field is essential to the life of every living cell. Scientific measurements show that the strength of the magnetic field has decreased over the centuries. Furthermore, biological systems colaps if shielded from the earth's magnetic force. Our researches suggest that the main point in biological structure which is affected by the low magnetic environment is the water molecule. The effects of magnetic field were examined on the inorganic substrat utilisation, organic synthesis, enzymatic synthesis and on ultrastructure of non-differentiated tissue cultures and of plant organs. The shielding level was about 10⁻⁶ of the terrestrial magnetic field. The main effect on the biological structures is an important water loss. The shielded magnetic field induces a stimulation of the utilisation of the oxidised and reduced forms of the nitrogen in soybean and sunflower tissue cultures. In all the long time shielded variants the phosphorus utilisation decreases. The iron uptake by soybean and potato cultures showed a 50% and 38% increase respectively. The lipid content was higher at soybean (15%) and sunflower (9%) and was lower in potato cultures (12%) in shielded variants as compared to control. Dry matter accumulation in shielded variants was higher in soybean and sunflower tissue cultures and lower as compared to the unshielded controls in potato cultures. It was found that an acidic isoperoxidase (A4) is expressed only in the roots of shielded bean plantlets. Its synthesis was strongly associated to the absence of magnetic field. Two zones were identified with a specific esterasic activity only in the shielded sunflower plants. In the root cells, ultrastructure was affected by shielded magnetic field at nucleus, mithocondria and vacuole. In the mesophyll cells, affected parts were cell wall, chloroplasts, mithocondria and nucleus. In solution, the degree of molecular alignment with the static magnetic field is proportional to the product of the anisotropy of the molecular magnetic susceptibility and the square of the magnetic field strength. Unstructured water with fewer hydrogen bonds is a more reactive environment.

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Molecular Memory In Quasispecies Of Retroviruses: Experimental Data, Theoretical Model And Evolutionary Implications

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RNA viruses replicate as complex distributions of genomes characterized by a continuous process of mutant generation, competition and selection, termed viral quasispecies. Quasispecies was developed as a general theory to understand the dynamics of the first replicative molecules in the context of the origin of information and early evolution of life, and has also provided an interpretation of the great adaptative potential of pathogenic RNA viruses. Among them, retroviruses are characterized by a replication cycle that involves two disparate phases: i) retrotranscription of viral RNA to DNA, and ii) replication and expression as cellular genes in the form of integrated proviruses.

Viral quasispecies may possess a molecular memory of their past evolutionary history, imprinted on minority components of the mutant spectrum. Here we report experimental evidence and a theoretical model for memory in retroviral quasispecies in vivo. Apart from replicative memory associated with quasispecies dynamics, retroviruses may harbour a cellular memory derived from their integrative cycle. Different sets of sequences of molecular clones exemplify the two kinds of memory in human immunodeficiency virus type 1 (HIV-1). The phylogenetic analysis provide evidence of reemergence of sequences that were hidden in cellular or anatomical compartments for extended periods, and recovery of a quasispecies from minority preexisting genomes. We develop a three-component model that incorporates the essential features of the quasispecies dynamics of retroviruses exposed to selective pressures, which is in agreement with the experimental data. The evolutionary implications of molecular memory for retroviral quasispecies will be presented.

A Genomic Timescale Of Prokaryote Evolution And Early Earth History

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A clear understanding of the history of our biosphere may reveal general principles applicable to other worlds. For example, it is widely believed that the metabolic activities of prokaryotes shaped the early evolution of the atmosphere on Earth. However, the important details of this, including the relative abundance of atmospheric gases through time and the evolutionary history of ecologically important organisms, have not yet been resolved. In particular, if organisms that could produce methane in large quantities did not exist before a certain point in time, models that postulate a methane atmosphere, prior to that time, would not be favored. Fossils are of little help in timing the origin of methanogens, but the availability of complete genomes of many species of prokaryotes provides abundant data for molecular clock analyses.

In this study we estimated divergence times of the major groups of prokaryotes with shared proteins from the complete genomes and proteomes of 73 species. We conducted protein sequence analyses using a supergene approach and with local-clock time estimation methods and carefully selected calibration points. The results support the existence of species and groups of prokaryotes permitted some conclusions to be drawn regarding the timing of biological production of methane on the early Earth and other events in the evolution of the biosphere.

Functional Gene Survey In Guaymas Basin: Vestiges Of Earth's Early Genotypes?

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The basal positions of anaerobic, hyperthermophilic archaea and thermophilic bacteria in rRNA phylogenetic trees suggest that life might have originated in association with hydrothermal energy sources. Similar microbial energy sources may have existed on early Mars or Jovian satellites where evidence suggests a significant water history. The first biogeochemical evidence for early metabolic processes like methanogenesis, sulfate reduction and anaerobic methane oxidation dates back from the middle to late Archaean and to the early Proterozoic.

Our study is based on the modern hydrothermal vent, the Guaymas Basin (Gulf of California, Mexico) which provides an unusually wide metabolic menu of electron donors and carbon compounds that sustain highly diverse bacterial and archaeal communities. This habitat provides diversified ecological niches for sulfate-reducing, methanogenic, and methaneoxidizing prokaryotes (Teske et al. 2002). Our aim with the ongoing survey of the Guaymas Basin is to recover novel, deeply-branching phylogenetic lineages of these ancient microbial groups. We carried out a functional gene survey of genes that code for dissimilatory sulfite reductase dsrAB (Dhillon et al. 2003). Our phylogenetic analysis based on highly conserved siroheme-Fe4S4-binding active centers of dissimilatory and assimilatory sulfite reductases demonstrated that the structure of the active center remains conserved in all known dissimilatory and assimilatory sulfite reductases. Riley et al. 2003 stated that many of the early proteins and fragments of proteins must have been ancestors of the complex protein world that exists today. Our study also implies that the basic molecular design for the reaction center of sulfite reductase enzymes has evolved only once (Dhillon et al.

To complement this survey of ancient functional genes, the Guaymas

Basin sediments were surveyed for the key gene of methanogenesis, methyl coenzyme M reductase (mcrA), alpha subunit. (Dhillon et al.2004).

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Water Loss From The Biological Structure As The Main Effect Of The Low Magnetic Environment

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Earth's magnetic field is essential to the life of every living cell. Scientific measurements show that the strength of the magnetic field has decreased over the centuries. Furthermore, biological systems colaps if shielded from the earth's magnetic force. Our researches suggest that the main point in biological structure which is affected by the low magnetic environment is the water molecule. The effects of magnetic field were examined on the inorganic substrat utilisation, organic synthesis, enzymatic synthesis and on ultrastructure of non-differentiated tissue cultures and of plant organs. The shielding level was about 10⁻⁶ of the terrestrial magnetic field. The main effect on the biological structures is an important water loss. The shielded magnetic field induces a stimulation of the utilisation of the oxidised and reduced forms of the nitrogen in soybean and sunflower tissue cultures. In all the long time shielded variants the phosphorus utilisation decreases. The iron uptake by soybean and potato cultures showed a 50% and 38% increase respectively. The lipid content was higher at soybean (15%) and sunflower (9%) and was lower in potato cultures (12%) in shielded variants as compared to control. Dry matter accumulation in shielded variants was higher in soybean and sunflower tissue cultures and lower as compared to the unshielded controls in potato cultures. It was found that an acidic isoperoxidase (A4) is expressed only in the roots of shielded bean plantlets. Its synthesis was strongly associated to the absence of magnetic field. Two zones were identified with a specific esterasic activity only in the shielded sunflower plants. In the root cells, ultrastructure was affected by shielded magnetic field at nucleus, mithocondria and vacuole. In the mesophyll cells, affected parts were cell wall, chloroplasts, mithocondria and nucleus. In solution, the degree of molecular alignment with the static magnetic field is proportional to the product of the anisotropy of the molecular magnetic susceptibility and the square of the magnetic field strength. Unstructured water with fewer hydrogen bonds is a more reactive environment.

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Inferring The Paleoenvironment During The Origins Of Modern Bacteria Based On Resurrected Proteins

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Features of the physical environment surrounding an ancestral organism can be inferred by reconstructing sequences of ancient proteins made by those particular organisms, resurrecting these proteins in the laboratory, and measuring their properties. Here, we resurrect candidate sequences for elongation factors of the Tu family (EF-Tu) found at ancient nodes in the bacterial evolutionary tree and measure their activities as a function of temperature. The ancient EF-Tu's have temperature optima of 55-65 °C. This value appears to be robust with respect to uncertainties in the ancestral reconstruction. This suggests that particular ancient bacteria were thermophiles, and neither hyperthermophiles nor mesophiles. This conclusion can be compared and contrasted with inferences drawn from an analysis of the lengths of branches in trees joining proteins from contemporary bacteria, the distribution of thermophily in derived bacterial lineages, the inferred G+C content of ancient ribosomal RNA, and the geological record combined with assumptions concerning molecular clocks. The study illustrates the use of experimental paleobiochemistry to explore the character of ancient life.

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Functional Gene Survey In Guaymas Basin: Vestiges Of Earth's Early Genotypes?

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The basal positions of anaerobic, hyperthermophilic archaea and thermophilic bacteria in rRNA based phylogenetic trees suggest that life might have originated in association with hydrothermal energy sources. Similar microbial energy sources may have existed on early Mars or Jovian satellites where evidence suggests a significant water history. The first biogeochemical evidence for early metabolic processes like methanogenesis, sulfate reduction and anaerobic methane oxidation dates back from the middle to late Archaean and to the early Proterozoic. These metabolic functions predated the photosynthetic oxygenation of Earth's biosphere and appearance of free oxygen in the atmosphere and water column.

In modern hydrothermal vents, the Guaymas Basin hydrothermal vents (Gulf of California, Mexico) provide an unusually wide metabolic menu of electron donors and carbon compounds that sustain highly diverse bacterial and archaeal communities. The hydrothermal sediments of Guaymas provide anaerobic conditions superimposed by extensive thermal gradients, from cold sea water to superheated vent fluids. This habitat provides diversified ecological niches for sulfate-reducing, methanogenic, and methane-oxidizing prokaryotes, and is most likely to harbor physiologically and phylogenetically diversified lineages (Teske et al. 2002, 2003). Our aim with the ongoing survey of the Guaymas Basin is to recover novel, deeply-branching phylogenetic lineages of these ancient microbial groups. We carried out a functional gene survey of genes that code for the alpha and beta subunits for dissimilatory sulfite reductase (dsrAB) and the alpha subunit of methyl coenzyme M reductase (mcrA). The dsrAB gene survey revealed a deeply branching clade of sulfate-reducing prokaryotes without cultured representatives, as reported previously (Dhillon et al. 2002; Dhillon

In an effort to study the evolution of sulfite reductases, our phylogenetic analysis based on highly conserved siroheme- and Fe4S4-binding active centers of dissimilatory and assimilatory sulfite reductases demonstrated that the Guaymas dsrAB lineage has equal phylogenetic depth as the mutually exclusive, deep branches of cultured sulfate-reducing prokaryotes. These include the gram-positive dsrAB lineage; the delta-proteobacteria plus delta-derived dsrAB genes; Archaeoglobus; and the newly discovered Thermodesulfobium lineage, from geothermal hot

springs. Thermodesulfovibrio remains the most basal sulfate reducing bacterium known. Since the earliest proteins on Earth would have arisen before cellular life was formed, many of the early proteins and fragments of proteins must have been ancestors of the complex protein world that exists today (Riley et al. 2003). Our study on the phylogeny of the active centers of all deeply-branching dsr lineages indicates that the divergence of the two paralogous subunits of the holoenzyme (alpha and beta subunits, dsrA and dsrB) predates the bacterial-archaeal split. Further, the structure of the active center remains conserved in all known dissimilatory and assimilatory sulfite reductases, implying that the basic molecular design for the reaction center of sulfite reductases enzymes has evolved only once on the early Earth (Dhillon et al. 2004).

To complement this survey of ancient functional genes, the Guaymas Basin sediments were surveyed for the key gene of methanogenesis, methyl coenzyme M reductase (mcrA, alpha subunit). In contrast to the dsrAB results, the Guaymas mcrA genes could be assigned to known families of methanogens, the Methanosarcinales, Methanomicrobiales, and Methanococcales. This methanogen community structure was broadly confirmed by archaeal 16S rRNA gene sequencing. Within the Methanosarcinales and Methanomicrobiales, several novel mcrA phylotypes were identified. In particular, several mcrA lineages within the physiologically diversified Methanosarcinales had no close relatives, neither among the classical, cultured methanogenic species and genera, nor among the recently identified mcrA genes that were assigned, on the basis of phylogenetic congruence, to methane-oxidizing ANME lineages (Hallam et al. 2003). Further analyses will resolve the phylogenetic and structural peculiarities of these unusual mcrA genes.

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Cladogenesis, Coalescence And The Evolution Of The Three Domains Of Life

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Using a very simple model with constant number of species, and rates of speciation equaling rates of extinction we explore the large-scale structure of the tree of life, and consequences from horizontal gene transfer for the concept of a most recent common ancestor of all living organisms (cenancestor).

A simple null hypothesis based on coalescence theory already explains some features of the observed topologies of the tree of life. Therefore, it does not appear warranted to invoke more complex hypotheses, or to derive complex scenarios involving bottlenecks and extinction events, to explain those features of the tree of life that are compatible with the null hypothesis. Simulations of genes and organismal lineages suggest that there was no single common ancestor that contained all the genes ancestral to the ones shared between the three domains of life. Rather each contemporary molecule has its own history and traces back to an individual molecular cenancestor, but these molecular ancestors were likely to be present in different organisms and at different times.

Niche Specialization And Succession Of Microbial Communities

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Previous work in partially closed ecosystems (e.g., bioreactors, rhizosphere of controlled-environment grown plants) has shown consistent changes in two indicators of niche specialization, decreased culturability and an increased rate of dilution-to-extinction, with succession (Garland and Lehman 1999). It is not known, however, if these same trends are observed in natural systems more open to invasion. This study evaluated the relationship between structural diversity and functional richness in microbial communities colonizing sterile leaf litter. Leaf-litter bags containing γirradiated smooth cordgrass (Spartina alterniflora) were deposited on the surface of a micro-tidal salt marsh at the Merritt Island National Wildlife Refuge on Kennedy Space Center, FL in late summer and periodically sampled over 3-4 months. Three replicate leaf-litter bags were sampled after 1-140 days incubation, and processed for determination of bacterial abundance by direct count and plating onto R2A and for dilution-extinction community level physiological profiling on BIOLOG GN2 plates. Replicate sub-samples were collected from each bag and from each of 10 positive BIOLOG wells and stored at -80°C for community level molecular profiling by T-RFLP to measure relative structural diversity within functional groups over time. Culturability rapidly declined from >25% to less than 10% in the first two weeks. The rate of decline in functional richness with inoculum density fit the rectangular hyperbola model for all sampling points in both studies. The asymptotic level of functional richness ($R_{\scriptsize max}$) remained between 85-90 throughout the course of both studies, but K, the inoculum density at half maximal richness, increased by over 3 orders of magnitude.

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The Evolution And Fate Of Nitrogen On Mars

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Nitrogen is an essential element for life. Specifically, fixed nitrogen (i.e., NH₂, NH₄, NO₂, or N that is chemically bound to either inorganic or organic molecules and is releasable by hydrolysis to NH, or NH, is the form of nitrogen useful to living organisms. Nitrogen on present-day Mars has been analyzed only in the atmosphere. The inventory is a small fraction of the nitrogen complement presumed to have been received by the planet during its accretion. Where is the missing nitrogen? Answering this question is crucial for understanding the probability of life's origin and evolution on Mars, and for future astrobiological exploration of this intriguing planet. The two main processes that could have removed nitrogen from the atmosphere include: 1) non-thermal escape of N-atoms to space; and 2) burial within the regolith as nitrates and nitrites if Mars possessed water on its surface. Nitrate will be stable in the highly oxidized surface soil of Mars, and will tend to accumulate in the soil. Such accumulations are observed in certain desert environments on earth. Some NH₄+N may also be fixed and stabilized in the soil by inclusion as a structural cation in the crystal lattices of certain phyllosilicates replacing K. Analysis of the Martian soil for traces of NO, and NH, during future missions will supply important information regarding the nitrogen abundance on Mars. We hypothesize that Mars soil, as typical of extremely dry desert soils on Earth is likely to contain at least some of the missing N as nitrate salts and some fixed ammonium bound to aluminosilicate minerals.

The UV Resistance Of Deinococcus Radiodurans As A Model Organism For Life Under Martian Conditions

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Deinococcus radiodurans, a gram positive bacterium whose ability to survive extremely high damage to its DNA which is for example induced by genotoxic chemicals, ionizing radiation, UV radiation or desiccation is still not completely understood. Because of its radiation and desiccation resistance, this extremophile is a prime candidate for possibly surviving environmental conditions as they occur on Mars and during a hypothetical interplanetary space travel.

So far just minor work has been done on the damaging effects of UV radiation, especially polychromatic UV radiation in the UVB and UVA range, and desiccation/vacuum exposure, which is known to induce DNA damages similar to radiation. Therefore, we started to further investigate the radiation resistance and the repair mechanisms of Deinococcus radiodurans, concentrating on the effect of polychromatic UV radiation and desiccation in the wild type strain and ionizing radiation and UV radiation sensitive mutants.

The results of this ongoing project will be of great interest to questions concerning planetary protection, space craft disinfecting measures and the search for life on other earth like planets in general.

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Evolution Of A Martian From An Earthling, A Small First Step.

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We are using the technique of directed evolution to create a halotolerant strain of Escherichia coli. We see this as a first step towards evolving an organism capable of surviving near Martian surface conditions. The initial E. coli strain is capable of strong growth in LB broth with up to 1.0M NaCl added. After six rounds of selection, we have isolated a population that prefers to grow in LB broth with at least 3.5M NaCl added. We plan to continue the serial dilution selection protocol and will augment it with mutagenesis techniques if necessary. Once we fully establish the directed evolution protocols on this model system, we plan to use them on candidate organisms to expand any preexisting desirable traits for survival on Mars.

Europa

Jovian Magnetosphere Radiation Belts As A Continuous Energy Source That Could Sustain Liquid Water In The Fracture Zones Beneath Meteorite Craters In Europa's Surface Ice

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We have shown for the first time that a meteorite impact could trigger the conduction of a surface electrical charge, caused by the Jovian magnetospheric radiation belts, into the fracture zone of the resulting impact crater in Europa's surface ice. During a simulated hypervelocity impact using the Ames Vertical Gun Facility, the electrical charge (+/- 1.5 kv) was conducted into the fracture zone of the impact crater as electrical energy as measured by electrodes implanted into the ice. During impact a large electrical discharge was observed followed by melting of the ice then re-freezing of the liquid water as measured beneath the crater in the fracture zone. Conduction of electrical energy was a factor of 10 greater then the control experiment where no charge was placed on the ice surface. The additional surface charge energy from Jovian magnetosphere radiation belts could account for the apparent observed liquid water flooding and dark material (Borucki et al) in meteorite craters such as Tyre, Pwyll, and Cilix on Europa than would normally be seen from shock melt.

Fracture zone water would take many times longer to freeze than water from shock melt as predicted by Thompson/ Sagan and Artemieva / Lunine. The slurry pools could then be kept in a liquid water state by the conduction of electrical energy from feeder lines that drain electrical charge from outer crater regions of Europa's ice surface. The profound significance is that life could develop to higher level and thrive in a warm liquid water environment slightly below the surface ice in the meteorite fracture zones.

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Conductivity measurements of MgSO₄ dominated aqueous solutions and implications for the salt content of a Europan hydrosphere.

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Using magnetometer data from the Galileo spacecraft it is possible to constrain estimates for the salt concentration of the putative Europan ocean. Here we consider the salt content to be dominated by the ions of magnesium sulphate [1, 2, 3] and compare measured variations in conductivity [5, 6], as a function of concentration and temperature, with the upper and lower limits of the specific conductivity required to best fit the magnetometer data.

The magnitude of the Europan induced magnetic field, as measured by Galileo, requires electrical currents through a near surface layer with a specific conductivity greater than 5.8x10⁻⁴ S cm⁻¹ [4]. Assuming a near-freezing liquid water ocean with a salinity dominated by the bi-bivalent (2: 2) ions of MgSO₄, we find a lower limit for the salt concentration of 1.72 g kg⁻¹. The upper limit from the magnetometer data places the specific conductivity of the near-surface water layer at 2.75x10⁻² S cm⁻¹, comparable to that of Earth's oceans. Translating this value into a magnesium sulphate concentration results in an upper limit of approximately 250 g MgSO₄ per kg H₂O. Estimates of upper and lower limits for mixed ion solutions consistent with compositional models will also be presented.

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The search for life on Europa: Limiting environmental factors, potential habitats, and Earth analogues

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The putative ocean of Europa has fueled considerable speculation about the potential habitats for life on Europa. The objectives of this paper were to review: (1) the limits for biological activity on Earth with respect to temperature, salinity, acidity, desiccation, radiation, pressure, and time; (2) potential habitats for life on Europa; and (3) Earth analogues and their limitations for Europa (Marion et al., 2003).

Biological activity can occur over (1) the temperature range from -20 to 121° C, (2) the salinity range from $a_{\rm w}$ (activity of water) = 0.6 to 1.0, and (3) the pH range from 0 to 13. The potential habitats for life on Europa are the ice layer, the brine ocean, and the seafloor environment. The dual stresses of

lethal radiation and low temperatures on or near the icy surface of Europa preclude the possibility of biological activity anywhere near the surface. An ice layer turnover time of 10 million years is probably rapid enough for preserving in the surface ice layers dormant life forms originating from the ocean. Model simulations demonstrate that hypothetical oceans could exist on Europa that are too cold for biological activity (T < -20°C). These simulations also demonstrate that salinities are probably high, which would restrict life to extreme halophiles. An acidic ocean (if present) could also potentially limit life. Pressure, per se, is unlikely to directly limit life on Europa. But indirectly, pressure plays an important role in controlling the chemical environments for life.

Our understanding of the physio-chemical environments of Europa is, however, poorly constrained. Major uncertainties – such as the thickness of the ice layer and brine ocean, heat flow and temperature profiles, and the composition of the brine ocean – make a compelling case for future missions to Europa in the search for life beyond Earth.

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Oxidation history of Europa's ocean and mantle – A case of redox reversal

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The oxidation states of Europa's interior and ocean are critically important controls on the nature of potential life there. Analogies to interior and ocean of the Earth, or to carbonaceous chondrites, are valuable, but Europa must be considered in its own context: a major solar system body accreted over an extended (>0.1–1 Myr) period of time at 5.2 AU from the Sun, and which then underwent a prolonged (>0.5–1 Gyr) period of thermochemical evolution [1].

In current formation models, Europa is largely composed of materials condensed in solar orbit prior to Jupiter's formation (solar composition non-volatiles plus water ice and organics). Vaporization of ice and volatile organics would accompany infall into the "jovian subnebula," but more than enough H₂O would remain to thoroughly alter rock (+ metal?) during and after accretion. Europa's primordial interior would be hydrated and at least partially oxidized and surrounded by a "modest" (~50-km deep) reduced ocean [1]. Loss of H₂ to space would result in ocean oxidation [2], but mass balance considerations and the low permeability of serpentinite and crack and pore closure under pressure would limit oxidation of the deep interior

Interior dewatering reactions, driven by long-term radiogenic and tidal heating, would result in eruption of hot, $\rm H_2$ -charged aqueous fluids and a major thickening of the ocean (to ~150 km) [1]. The oxidation state of the ocean was likely buffered by $\rm H_2$ loss to space (although $\rm H_2S$ may accumulate), so significant disequilibrium between "juvenile" fluids and the ocean should persist, and could be exploited by primitive organisms. Renewed aqueous oxidation (of rock and, if $\rm H_2$ drops below FMQ, FeS) and further heating should ultimately have yielded a dry, relatively oxidized interior, an FeS-rich core, and a volcanic supply of $\rm S_2$, $\rm SO_2$, and $\rm CO_2$ (from carbonate) to the ocean — though not necessarily sulfate [1].

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Convection and ocean-surface exchange on Europa.

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The surface of Europa is peppered by topographic domes, interpreted as sites of intrusion and extrusion of icy material from below. If Europa's floating ice shell is sufficiently thick (tens of kilometers), then it will convect: warm ice near the ice shell's base will rise buoyantly toward the surface, and cold near-surface ice will sink downward. We have performed numerical modelling of convection within Europa's ice shell, successfully simulating the non-Newtonian (temperature- and stress-dependent) rheology of ice. The model results predict a cold and stiff stagnant lid is formed in the top of the ice shell, through which thermally convecting ice does not penetrate.

Instead of forming by thermal convection alone, ice domes may be manifestations of thermal convection that induces compositional segregation within Europa's ice shell. Low-melting-point impurities (hydrated salts and/or sulphuric acid) may melt and drain from warm upwellings, allowing sufficient buoyancy for relatively clean icy plumes to create the observed surface topography by means of compositional buoyancy, if the ice shell has a small effective elastic thickness and contains low-melting-point impurities at the few percent level. This process would allow material originating near Europa's ice-ocean interface to breach the near-surface stagnant lid, potentially transporting oceanic and astrobiologically relevant materials to the surface where they could be examined by spacecraft.

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Using Fluorescence Biological Analysis (FBA)to Examine the Subsurface of Europa for Signs of Life.

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Europa is not only one of Jupiter's Icy Moons, but it is also one of the prospective highlights of NASA's search for life outside of our earthly parameters. Two important components essential to life include the present of water and a source of energy. As a result of these two factors, multiple theories suggest the possibility of life on Europa. The surface of Europa is composed of thick layers of ice produced by the combination of an underwater ocean and extremely low temperatures. The underwater ocean is a result of expected volcanic activity along the ocean's floor. The area between the thick layers of ice and the underwater ocean is potential breeding ground for a host of bacteria, cells, and biomolecules. The fluorescence biological analysis system is a direct result of cutting edge technology and innovative biological research. This system consists of an orbiter and a penetrator with various tools and instruments needed to complete this mission. The orbiter will use jet propulsion to launch the penetrator, forcing it into the surface of Europa in order to examine the subsurface in situ. Samples of water will be collected and immediately examined using fluorescence biological analysis. Fluorescence is a proven method used for locating organic molecules that are present within a specific region.

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Evolution of Intelligence

Information Theory And Animal Communication Complexity: Relevance To Fi

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Quantitative measures of the temporal distribution of animal signalling systems can provide statistical indicators of the organizational complexity of communication systems that arise through ecological and evolutionary processes. Specific mathematical frequency distributions of signalling system structure should occur for a communication system to function effectively. Such signal distributions are the result of the interactions among signallers, receivers, and their environments and within their evolutionary contexts. Presenting data from three animal models, we will discuss how predictions on the structure and organization of animal communication systems can be made from information theoretic measures in light of behavioural ecology and evolutionary theory (McCowan et al. 1999, 2002). These basic principles underlying communication and its complexity are an essential component toward understanding of the evolution of intelligent life on Earth.

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How To (And Not To) Recognize Intelligent Brains Without Seeing The Behaviors

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Our intuitions about neuroanatomical "complexity" can be a poor guide to determining the true functional complexity, or intelligence, of a brain. I first discuss a number of misleading signs of intelligence in brains, including brain size, convolutedness, number of synapses per neuron, white matter to gray matter ratio, number of cortical areas, and total number of areaarea connections. I then describe two distinct approaches to recognizing intelligent brains. (1) The first is the encephalization quotient approach, and consists of variations on the well-known idea of correcting for body size. I provide evidence that the encephalization quotient really is a good sign of an intelligent brain (Changizi, 2003). I also discuss many other neuroanatomical features that are good signs if one similarly corrects for body size. (2) The second approach to recognizing intelligent brains is the differentiation approach, and looks for signs that there are a greater number of functions implemented in the brain. There are two methods falling under this approach. (a) The behavioral-differentiation method: I provide evidence that behavioral networks (i.e., networks that elicit behaviors) such as the brain appear to accommodate greater behavioral repertoire size by increasing the number of types of building block (such as muscle types for mammalian behavior), and therefore the number of these types is a proxy of behavioral complexity. (b) The node-differentiation method: I provide evidence that functionally more complex networks tend to have greater node-differentiation, and thus this may serve as a measure of greater intelligence. Analogies are made to other behavioral networks as well, such as organisms (cell networks), ant colonies, businesses, electronic circuits, and computer software (Changizi, 2004).

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Could There Be A Truly "Universal" Grammar For Languages?

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Science fiction authors often imagine encounters with equivalently intelligent extraterrestrial species in which communication is accomplished on the model of translating between very different human languages. Yet many linguists would argue that translation is possible between human languages only because the domain of possible structural differences between them is vastly restricted. They assume this is due to sharing a common genetically inherited universal grammar (UG). To the extent that the genetic version of the UG conjecture is true, inter-stellar communication might prove so difficult as to be unmanageable except via elaborate computational translation aids. So many consider mathematics to be the only hope for a lingua galactica. Multiple lines of evidence, however, now suggest that the restricted structural variety of languages may be an emergent consequence of many non-genetic factors. Semiotic constraints (analogous to those constraining mathematical systems), self-organizing dynamics associated with a population of agents acquiring and communicating symbolic forms, and brain-language coevolutionary processes that are particularly sensitive to information processing constraints may all contribute to narrowing the domain of possible language structures in humans. These are universals in a general sense, and can be expected to contribute to convergent and parallel patterns of evolution of natural symbolic communication systems in nonterrestrial organisms.

The Diversity Of Brain Organization Implies Diverse Psychologies

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The evolution of intelligence has commonly been viewed as a matter of the progressive expansion and functional improvement of a "plan" of brain design that is essentially conservative. For example, it is widely accepted that there is a basic uniformity across species in the microstructure of mammalian cerebral cortex. Recent studies, however, have revealed unexpected structural diversity in vertebrate and mammalian brain organization, including—for the first time—identification of evolutionary specializations of human brain microstructure that are unrelated to brain size. Brain evolution, like the pattern of life itself, is tree-like rather than scale-like.

If brain organization is diverse, behavioral and cognitive systems are probably diverse as well. This is a situation the behavioral, neural, and cognitive sciences are presently ill-equipped to deal with. For one thing, current theories of brain organization are insufficiently rich to permit us to relate evolutionary changes in structure to changes in function. For another, the discipline of comparative psychology, with a few notable exceptions, is nearly dead - we don't have a vibrant program of research exploring phyletic differences in cognition. Finally, and perhaps most fundamentally, the traditional view that the psychological differences between species can be reduced to a unitary scale of intelligence is so deeply rooted that it is very difficult for scientists to imagine what minds might be like if they are qualitatively different from human minds, rather than merely greater or lesser versions of human minds.

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The Origin(s) And Evolution Of Large Brains In Dolphins

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Because evolution manifests itself along a continuum from simple to complex life, one of the questions posed by astrobiology is: How has the planetary environment influenced the evolution of complex, multicellular life? The present study is part of a larger research program aimed at addressing this question with quantitative comparative studies of living and fossil species. Second to humans in relative brain size, dolphins and whales possess large highly elaborated brains (Marino, 1998). The present study asks: How did the large brains of dolphins evolve? To investigate this question we measured brain and body size for 36 fossil dolphin and whale species using Computed Tomography and analyzed these data along with those for living species. Here we provide the first quantitative description and statistical tests of the pattern of change in brain size relative to body size in dolphins and whales over 47 million years. We show that brain size increased significantly in two phases in their evolution. The first occurred near a critical Eocene-Oligocene boundary (~ 33 mya) and the second occurred within one group only, Delphinoidea, by the mid-Miocene (~15mya).

These findings, when compared with human brain evolution, provide several initial insights. First, despite the conventional wisdom about the selective advantage of increased brain size, there is no detectable overall evolutionary tendency towards larger brains in dolphins and whales. Second, unlike the recent time course of human brain evolution, the large brain size of many modern dolphin species was achieved as early as 15 mya with no evidence for change since then. Third, unlike the initially speciose human evolutionary tree that was pruned to a single large-brained lineage, our findings with dolphins show that multiple large-brained species can coexist for much longer periods of time.

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Insect Brains: Circuits, Evolutionary Convergence, And Evolutionary Potential

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The insect brain comprises uniquely compact neuronal circuits mediating sensory integration and motor control. These experimentally accessible systems provide a rich source of data from which to design neuromorphic circuits for use in robotics. The insect brain also contains exquisitely evolved brain centers performing many of the higher functions expected from vertebrate brains, including those of primates. Examples are: analogues of the hippocampus, which mediate place memory and context dependent behaviors; analogues of the cerebellum that mediate fine control of motor actions, especially those requiring the breaking of symmetry; and circuits providing locomotion, balance and stance. Neural architectures and circuits in olfactory and visual centers provide remarkable examples of evolutionary convergence with their vertebrate counterparts. The most sophisticated insect brains, exemplified by certain Hymenoptera (wasps, ants, bees) have centers that have even undergone cortex-like parcellation. Nevertheless, insect brains are constrained by the arthropod exoskeleton, where large size is at the cost of manoeuvrability. However, it is easy to imagine on the basis of what has already been achieved by insects that a slight decrease in gravity and a concomitant increase in atmospheric density could allow insects to evolve into quite large animals having cerebral capacities comparable to those of small primates. Given that the packing densities of insect neurons can be more than an order magnitude greater than that in the most densely packed vertebrate brains (e.g. those of certain birds, or the primate cerebellum's granule cell layer), and that many insect nerve cells can multitask, the evolutionary potential of insects is as remarkable as their achievements.

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Brain Architecture And The Evolution Of Intelligence: Does Form Provide Clues To Function?

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Animals on Earth vary tremendously in their cognitive abilities. However, animals also encounter a huge range of environments, behavioral needs, and physical challenges. This makes direct comparison of intelligences among species difficult. In search of relationships linking form to cognitive function, we have performed structural analyses of brain anatomy in a wide range of vertebrates. In particular, we have examined mammals and birds, two groups of vertebrates separated by over 300 million years of evolutionary divergence. In these very different groups, social complexity and cognitive ability are strongly correlated with a single quantitative factor, the fraction of brain volume occupied by the forebrain. This fraction can range from 40% to 80%, reaching the highest values in humans, chimpanzees, crows and parrots, species that are among the most behaviorally complex on Earth. Our analysis suggests that forebrain volume fraction may be an anatomical measure of function that can be generalized across a wide range of vertebrate brains.

In the long term we seek to recast these scaling observations in terms of general cellular circuit "design" principles. For instance, vertebrate forebrains are rich in connections that link one part of the forebrain to another. These internal connections play an essential role in complex information processing. We are now investigating, at the cellular level, how these internal connections, axons, scale up with forebrain size. In mammalian brains, using transmission electron microscopy we have found that from shrew to whale the fastest predicted axonal cross-brain conduction times are 1-2 milliseconds, independent of brain size. Since faster conduction requires thicker axons, the fastest axons occupy disproportionate amounts of space in big brains. Because big brains cost more energy to operate and build, the speed and complexity of overall information processing in the brain may be limited by the functional properties of individual axons.

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Extreme Environments

Abiogenic Reaction Versus Microbial Respiration Rates In The Deep Subsurface

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To determine what limits life in the deep subsurface we analyzed the geochemistry and biomass abundance of ~150 samples of fracture water from 0.8 to 3.2 km depth in the Witwatersrand Basin, South Africa. Isotopic data and theoretical calculations indicate that radiolysis of water generates H₂ and oxidants at a rate of >0.1 to 1 nM yr⁻¹. Stable isotopic data suggest that H, utilizing microbial sulfate reduction and abiogenic synthesis of hydrocarbons by Fischer-Tropsch mechanisms takes place at depths greater than 1.5 km, whereas H, utilizing methanogenesis tends to be restricted to depths less than 1.5 km. Noble gas subsurface residence ages tend to increase with depth to values as high as 20 to 160 Myr. The same abiogenic processes should be taking place on Mars and if the deep subsurface has been effectively sealed by the overlying cryosphere then ~1014 moles of CH and comparable amounts of H, should have been generated over the past billion years. We also estimated the maximum potential free energy flux for the microorganisms and the maximum consumption rate for each site. The calculations revealed a good correlation between redox reactions dominating the free energy flux and the isotopic and 16SrDNA analyses. The maximum consumption rate, however, exceeds radiolytic production rates by 5 to 6 orders of magnitude. This implies that either 99.999% of the observed cells have been metabolically inactive for millions of years or microbial consumption is restricted to fractures while production is disseminated throughout the matrix and focused into the fractures by diffusion.

Molecular Basis For Survival Of Halobacterium In Space Conditions

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Extremophiles are excellent model systems for exobiology studies due to their adaptations to environments considered 'extreme' on Earth, and which can be found elsewhere in the solar system. We used a halophilic microorganism, Halobacterium sp., as model system for a molecular-level study of cell survival under space conditions. We found that Halobacterium is highly resistant to exposure to desiccation and high vacuum (10-6Pa), and to radiation, with survival without loss of viability up to 110J/m2 of UV-C and 1000Gy of gamma-ray. We further investigated Halobacterium stress response to high doses of solar radiation using a combined functional genomic and genetic approach. We focused our study on UV-damage repair due to implications for exobiology and research into human-related UV-damage effects such as various cancers.

Halobacterium UV-response was characterized by analyzing simultaneously, along with gene function and protein interactions inferred through comparative genomics approaches, mRNA changes for all 2400 genes following UV irradiation at 250J/m2. In addition to photoreactivation, three other putative repair mechanisms were identified including a methylation-directed mismatch repair, four oxidative damage repair enzymes, and two proteases for eliminating damaged proteins. This analysis has also facilitated the assignment of putative functions to several key proteins in the UV response. Finally, a UV-induced down regulation of many important metabolic functions was observed during repair, and seems to be a phenomenon shared by all three domains of life.

These findings enhance the current molecular-level model of microbial survival under the types of extreme conditions predicted to exist on planetary bodies such as Mars and Europa.

Remote Sensing And In Situ Sampling Of Extremophiles In Saline Terrestrial Environments

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Planetary exploration is fundamentally dependent upon remote sensing techniques. We have developed techniques for the detection and classification of microbial populations through infrared remote sensing at terrestrial analogue sites. Extreme salinity levels feature biota dependent upon "abnormal" conditions, which may represent forms of life that could possibly inhabit extraterrestrial planets. Our research group has conducted field studies and in situ sampling of organisms in large-scale salt evaporation ponds, whose extreme environments play host to representatives from all three domains of life: Eukaryotes, Prokaryotes and Archaea. By combining laboratory and field measurements incorporating pigment absorption characteristics of these microbes with remotely-sensed data from the Jet Propulsion Laboratory's Airborne Visible and InfraRed Imaging Spectrometer (AVIRIS), we have been able to demonstrate direct links between microbial populations and infrared signatures.

Most organisms are stenohaline: limited to narrow ranges of salinity concentrations, while others can occur over extended ranges. Initial results indicate a correlation between salinity levels and flux in microbial diversity, culminating in an environment predominately populated by Archaea. As salinity increases, concentrations of any given organism peak and decline. This is demonstrated by pigment analysis coupled with inflared measurements. Overlapping ranges of various biota give rise to a rich and varied tapestry of spectral color signatures, which can be unravelled to reveal the component organisms. These infrared color signatures could prove to be useful biomarkers in the search for extreme life not only on, but also beyond Earth - particularly on Mars and Europa, and possibly even beyond our solar system.

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Control Of Photosynthetic And High Light/radiationresponsive Genes By The Histidine Kinase DspA: Negative And Positive Regulation And Interactions Between Signal Transduction Pathways

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The genetic amenable cyanobacterium Synechocystis sp. Strain PCC6803 has been used to study the molecular responses of cells to strong light/ radiation. Understanding stress responses will help develop strategies to overcome stressful problems encountered by space pilots. The study of the effects of space environment on photosynthetic organism may contribute to the construction of a self-sustainable space station in the future. We have deleted a gene for a sensor histidine kinase, dspA or hik33, in Synechocystis sp. Strain PCC6803. In low and moderate light the mutant grew slowly under photoautotrophic conditions, with a doubling time of ~40 h, and had severely reduced photosynthetic oxygen evolution. When the mutant was maintained in low or moderate light in the presence of glucose, its growth rate was only somewhat lower than that of wild-type cells. However, the mutant was light sensitive and rapidly died in strong light/radiation. Furthermore, levels of many transcripts encoding genes associated with photosynthesis were altered in the mutant relative to wild-type Synechocystis sp. Strain PCC6803 both in low light and following exposure to high light: (1) There was constitutive expression of several high light-inducible genes, including hli, psbAIII and gpx2. (2) There was little increased accumulation of sodB mRNA in high light. (3) The cells failed to accumulate cpcBA and psaAB mRNAs in LL in the presence of glucose, although a normal decline in the levels of these mRNAs was observed during exposure to high light. These results suggest that DspA is involved in controlling sets of photosynthetic and high light-responsive genes, either directly or indirectly. These results suggest that DspA acts as a global regulator that helps coordinate cellular metabolism with growth limitations imposed by environmental conditions.

A Method For Estimating Low Levels Of Hydrogen Metabolism In Deeply Buried Sediments

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The microbial communities inhabiting deeply buried sediments are of considerable interest to geochemists and astrobiologists because they are important in global biogeochemical cycles, and can serve as models for extraterretrial ecosystems. The metabolic rate of these bacterial communities can be extremely low and is therefore challenging to measure directly. Hydrogen gas plays a key role in anaerobic microbial ecosystems because it couples two diverse metabolic groups of microbes: it is produced by carbon-oxidizing fermenters, and it is utilized as an electron source by species that reduce inorganic compounds, such as sulfate.

We are developing a tritium-based radioassay for hydrogen gas metabolism in deep sediments by modifying an assay that was designed for water column measurement (Schink et al., 1983). The procedure is based on the isotopic exchange between dissolved tritiated hydrogen gas and the hydrogen in water; this reaction is catalyzed by hydrogenase, an enzyme that all hydrogen-producing and hydrogen-consuming microbes possess. Preliminary tests were carried out on open-ocean sediments from the eastern equatorial Pacific, as part of Ocean Drilling Program Leg 201. The experiments were conducted with the expectation that the rate of isotopic exchange should correlate with the metabolic activity inferred from reversemodeling of sediment pore-water chemicals. Preliminary results meet this expectation only partially, and more validation is needed. With further development, this relatively simple assay might become ideal for routine use and be useful for future planetary exploration.

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Inorganic Salts In Atacama Soils Provide Critical Indicators Of Long-term Hyperaridity And The Dry Limit Of Life On Earth

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In the hyperarid core of the Atacama desert in northern Chile, biology is virtually absent from soils (Navarro-González et al. 2003). Deposition of very small amounts of water by fog to Atacama soils becomes critical to the few microorganisms that can survive in this extreme environment. In this context, understanding inorganic soil chemistry is critical to tracing the long-term water balance in these Mars-like soils.

Here, we present our work on isotopic tracers of sulfate (34S and 17O) and associated calcium (water soluble 87Sr/86Sr) in dry deposition and soils along a climate gradient from the hyperarid core of the Atacama to sites that receive slightly more rain (~12 mm y-1). Depth trends in isotopic tracers vary systematically along the climate gradient and demonstrate that even under hyperarid conditions, moisture-dependent transport processes induce distinct and interpretable isotopic signals in water-soluble salts with soil depth.

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Relevance Of The Iron Cycle For The Search Of Life On Mars

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The geomicrobial characterization of an extreme acidic environment, the Tinto River1, 2, has recently proven the importance of the iron cycle3, not only in the generation of the extreme conditions of the habitat4, but also in the maintenance of an unexpected level of microbial diversity, mainly eukaryotic5. Considering the important concentrations of iron present on Mars, and the physico-chemical properties of this element which can be used as an electron donor or electron acceptor in respiration, for the maintenance of a constant pH, and for radiation and oxidation protection, the possible existence of an active geomicrobial iron system on Mars will be outlined and the current investigations using the Tinto River as a terrestrial analog presented.

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Eukaryotic Biodiversity In The Tinto River (Sw Spain): An Extreme Acidophilic Environment

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To understand the possible environments for life on other worlds, we should begin by investigating the limits to life on our own planet. Thus, interest in discovering extreme environments and the organisms that inhabit them has grown over the past years, not only for what they can tell us about the adaptability of life on this planet, but also as analogues for conditions on other bodies in our solar system, such as Mars or Europa. In this regard, one of most interesting environments in astrobiology is the Tinto River (SW, Spain), characterized by the extreme low pH of the water (from 0.9 to 3.0) as well as by high concentrations of heavy metals (López-Archilla et al 2001, Fernández-Remolar et al. 2003). In spite of these extreme environmental conditions, the eukaryotic presence in the river is surprisingly high in terms of diversity and abundance. In total, 24 morphotypes have been observed, species of the Bacillariophyta, Chlorophyta,, Rhodophyta, and Euglenophyta phyla as well as heliozoans, ciliates, rotifers, cercomonads, amoebae, fungi and yeast have been detected. The phytobenthonic biomass reached maximum values during summer and late summer (June/ September), and the dominant species along the river are Chlorophytas, Euglenophytas and Bacillariophytas. The biomass varied considerably from year to year, especially for green algae. Although significant differences were found in total biomass, the species composition remains mainly constant during the year.

Identification of algae and heterotropic protists were carried out by applying two molecular approaches, cloning and sequencing of 18S rDNA

and Denaturing Gradient Gel Electrophoresis (DGGE). The sequences obtained were aligned to 18S rDNA sequences obtained from the National Center of Biotechnology Information Database by the BLAST search. Traditional microscopic observations were also performed in order to validate the molecular analysis.

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Microbial Assemblages In The 19-meter Ice Cover Of Lake Vida, Antarctica As A Potential Analogue To Icy Environments Beyond Earth

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Lake Vida, located in the McMurdo Dry Valleys, Antarctica, is an "ice-sealed" lake with ~19 meters of ice covering highly saline water (>245 ppt) (Doran et al. 2003). Radiocarbon dating in a Lake Vida ice core implies that lower portions of the ice cover, the saline lake, and the microbes have not been in contact with the atmosphere or the land for a few thousand years. We are examining the microbial assemblages within the permanent ice cover of Lake Vida. Total bacteria concentrations ranged from 1.06 X 105 to 1.98 X 106 per milliliter of ice melt water. Several hundred bacterial isolates were recovered from the ice using traditional culturing techniques. Nucleic acid extraction values ranged from 0.37 to 10.16 ng DNA per milliliter of ice melt water filtered, yielding ~ 4.26 fg DNA per cell which is within the range of typical recovery from bacterial cells. PCR screening indicates recovery of bacterial DNA from all depths examined in the ice cover and eukaryal DNA recovery in the upper 14 m.

The persistence of microbes within icy environments on earth leads to the possibility that microbes may inhabit ice on other moons or planets during past or present times. An understanding of microbial life within the ice cover of Lake Vida addresses astrobiological concepts such as the limits of life on Earth, potential habitats for life on other planets, and the methods necessary to search for and to analyze potential life from other planets.

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Comparative Genomic Study Of Exiguobacterium Strains Isolated From Siberian Permafrost.

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Terrestrial permafrost sediments frozen for thousands to millions of years and inhabited by microorganisms may serve as relevant models for microbial life on Mars and other cryogenic bodies. Since bacteria survive in Siberian permafrost for several million years and tolerate prolonged exposure to subzero temperature, similar organisms, or their fossils, might be expected to occur in frozen Martian subsurface horizons.>

Five strains of the low-GC gram-positive bacterium Exiguobacterium were isolated from permafrost core samples collected in the Kolyma lowland of Northeast Eurasia. The buried permafrost had remained continuously frozen at stable temperature of ca. -10°C, and the ages of the samples varied between ca.10,000 years and 2.5-3 million years (Gilichinsky, 2002).

Genetic fingerprinting using Southern blots with DNA probes derived from the genomic sequence of one of the isolates were employed for the comparative analysis of Exiguobacterium strains from the permafrost and type strains of Exiguobacterium grown under different conditions. A putative transposase sequence found to be repeated in the genome of one of the strains (strain 255-15, isolated from a 2.5-3 million year old sample) was utilized as probe in Southern blots and yielded high-resolution fingerprints which could differentiate the different permafrost isolates from each other, and from the type strains. Hybridisations of large DNA pieces obtained by digestion with AscI and separated by pulsed field gel electrophoresis (PFGE) showed that the transposase gene copies are located in different regions of the genome. When EcoRI-digested DNA was used, the number of hybridising bands varied from 1 to 8, and was characteristic of the strain. We found that the hybridisation patterns were remarkably stable following growth at 4 degrees C, and following repeated freeze-thawing of cold-grown cells. However, in the case of two of the strains (one of the permafrost isolates and one of the type strains) bacteria grown at 25 degrees C, with or without exposure to repeated freeze thawing, occasionally had alterations in their hybridisation patterns, suggesting instability in the location and number of the putative transposase genes under these conditions. Our data suggest that the putative transposase gene of Exiguobacterium strain 255-15 can be employed to differentiate among different strains, and can serve as indicator for the impact of different temperature regimes and repeated freeze-thawing on genomic stability of the organisms.

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Determining Favorable Conditions For Endolithic Growth From Physics Considerations.

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Endolithic organisms are being studied to better understand how early life might have faired on earth several eons ago and where it might be found elsewhere in the universe. We have investigated two questions: Could minerals with a band gap in the visible or near UV have protected microbial life from solar UV on Mars or the early earth before ozone arose? And to what extend are processes like capillaries providing a microenvironment where water is common?

Endolithic life has been found in several types of rocks including carbonates, sandstone, sulfates, granites, and basalt. In some desert environments, the light intensity falls off with depth in rocks such that photosynthetic organisms can be found in only the top few millimeters. We have examined these habitats from a physics viewpoint and have asked the following questions: 1. Is UV light preferentially absorbed or scattered out of certain minerals? 2. Which compounds found in common minerals block UV?

Our results indicate that light transmission through sandstone is wavelength dependent. A 1 μ m layer of Fe2O3 in 1mm of rock can drastically reduce UV exposure while still allowing light in the photosynthetic zone (>600nm). Also, the small pore spaces in the same rock could allow water to exist despite low atmospheric pressure due to capillary action. An environment that protects cryptoendolithic bacteria from harmful UV and prevents desiccation reopens the possibility for life in the photosynthetic zone at the surface of Mars.

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Hyperthermophilic Archaea are thought to be relatives of some of the first organisms to arise on earth. Viruses may have arisen at the same time or potentially even earlier than the earliest known organisms (Rice et al., 2004). Therefore viruses of hyperthermophilic Archaea may be the oldest known organisms. As expected for ancient organisms, viruses of hyperthermophilic Archaea have both novel morphology and novel genetic structures. The novel structures offer potential as bio-markers for ancient viruses from both terrestrial and extra-terrestrial sources.

We study the best, but still poorly-understood virus-host system in hyperthermophilic Archaea; Fuselloviruses and Sulfolobus solfataricus. We use a combined genetic and comparative genomic approach to understand virus function. Genetically we disrupted open reading frames in the virus SSV1 both randomly and specifically and analyzed the mutant viruses. This defined essential and non-essential regions of the genome, and led to the development of genetic tools for Sulfolobus (Jonuscheit et al., 2003). For our comparative genomic studies we completely sequenced three new Fusellovirus genomes, one each from Iceland, Kamchatka, Russia and Yellowstone National Park, USA. and compared their phenotypes (Wiedenheft et al., 2004). Comparison with known Fuselloviruses from Japan and Iceland (Stedman et al., 2003) indicates an astounding amount of sequence diversity. It also led to the identification of a core set of sequences apparently required for virus function and variable regions responsible for the differences between viruses.

Using a culture-independent approach we have also found astounding diversity both within and between habitats containing Fuselloviruses.

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Sampling Thermal Spring Deposits: Biocomplexity Preserved On A Microhabitat Scale

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The high gradient of temperature, salinity, and pH existing in thermal spring systems makes them ideal environments to look for diversification on a microhabitat scale. In large, thermal spring pool deposits of the extinct Garabatal hydrologic system in Cuatro Cienegas (Mexico) snail shell abundance was found to be non-random, and correlated with substrate preference patterns observed in living systems. A novel method

of statistical analysis using combinatorial analysis was implemented. This method allowed us to assign significance to unique snail combinations, and showed correlations that are not easily detected by traditional geostatistical techniques. GIS analysis allowed us to analyse these patterns spatially, and to reconstruct water flow patterns otherwise obscured by the effects of subsidence and erosion. We were able to see differences between snail distribution patterns in paleoenvironments of low flow, terminal pools with muddy substrates and high water-flow pools with springheads, and increased abundance of hard substrata. The presence of increased vegetation at the edge of pools was also evidenced by increases in snail abundance of species preferring this microhabitat. A map of spring microhabitats was constructed based on snail abundance, and serves as a statistical model with which to assess the spatial variability of life on extinct thermal spring deposits with unknown biologic communities, such as spring deposits which may have existed on Mars.

Oxygen Tolerance By Methanogens

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Methanogens are described as obligately anaerobic (Staley, 1989), and methods developed to work with methanogens typically include anaerobic media and buffers (Boone et al., 1989), gassing manifolds, and possibly anaerobic chambers (Sowers and Noll, 1995). However, we have observed that some exposure to atmospheric molecular oxygen may have limited, if any, effect on viability of certain methanogens. In experiments where we needed methanogenic cells free from their respective media, we painstakingly washed the cells with anaerobically-prepared buffer in sealed tubes. Cells were centrifuged four times followed by replacement of supernatant medium or buffer with fresh buffer in an anaerobic chamber. To determine if the time, effort and supplies required to maintain anaerobic conditions were necessary to maintain viability, we compared anaerobically-washed cells to cells that were washed in the presence of atmospheric oxygen. Anaerobic tubes were opened, cultures poured into plastic centrifuge tubes, centrifuged, and suspended in fresh buffer, all in the presence of atmospheric oxygen. Total oxygen exposure time was approximately 1.5 hours. Washed cells from both aerobic and anaerobic procedures were inoculated into methanogenic growth media under anaerobic conditions and incubated at temperatures conducive to growth for each methanogenic strain tested. Methane production was measured at time intervals using a gas chromatograph. Results showed no real differences in methane production for four species of methanogens after five days of incubation. One species did demonstrate greater methane production following anaerobic washing after two days of incubation. It is unclear as to whether this was an indication that only a few cells survived oxygen exposure or that most of the cells survived, but it took time to "recuperate". In another experiment, one of the species was simply exposed to atmospheric oxygen for up to 52 hours followed by anaerobic incubation. Cells remained viable as indicated by increasing methane production. Thus, it appears that at least a few species of methanogens can tolerate atmospheric oxygen for relatively extended periods of time. This is of astrobiological importance for two reasons. Microorganisms that might exist below the surface of Mars, most likely anaerobic, may on occasion, be exposed to the small concentration of molecular oxygen in the martian atmosphere for limited periods of time, and researchers working with methanogens may not have to take stringent precautions to keep oxygen out of their experimental procedures.

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Microbial Diversity In Spain's Río Tinto: A Three-domain Approach

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The Río Tinto in Southwestern Spain is a naturally occurring extreme ecosystem with a pH of 1.7-2.5 and iron concentrations as high as 20 g/L. The river serves as an excellent model of an iron world operating not only in the absence of oxygen (Archean), but also at increasing concentrations of oxygen (Proterozoic and Phanerozoic). Microbial investigations in the Río Tinto may provide clues to ancient pathways or metabolisms no longer used by microbes living under less extreme conditions.

A striking aspect of the Río Tinto is the contrasting phylogenetic diversity between the prokaryotic and eukaryotic communities. While the river does not support complex metazoan life (although rotifers and insect larvae have been observed), unicellular eukaryotes are abundant and more diverse than prokaryotes. Along with chemolithotrophic prokaryotes, photosynthetic protists represent the main primary producers in the river. Morphological studies reveal diverse heterotrophic and photosynthetic eukaryotes including fungi, various green algae, amoeboid protists, flagellated protists, and ciliates. Recent 16S-like rRNA gene-based studies demonstrate even greater eukaryotic diversity than seen at the light microscope level. These studies have been restricted to domain-level investigations of prokaryotes (Bacteria and Archaea) OR eukaryotes (Eukarya) but combined studies have not been undertaken. In this project we employ a new technique called SAGT (see the Palacios et al. poster) in combination with traditional fulllength rRNA gene sequencing of novel taxa to explore the river's diversity at the three-domain level of life. Our sampling for molecular surveys takes into account spatial and temporal scales and concomitant physico-chemical measurements.

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Metagenome Of An Extreme Deep-sea Microbial Symbiosis

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One of the specialized communities found at hydrothermal vents on the East Pacific Rise is dominated by polychaetes from the family Alvinellidae. Alvinellids make complex chitin tube colonies on the flanks of black smoker chimneys. In these colonies several hundred animals live within centimeters of chimneys spewing 450°C superheated water. The 2.5-cm long, filament-covered alvinellids live at temperatures of 80°C, the highest known for metazoans, and are briefly exposed to temperatures of 105° C (Chevaldonne). The alvinellid worms share their community with 40–50 strains of ϵ -proteobacteria present as microbial coats covering the alvinellids' back filaments. It is speculated that the microbes may aid the host in tolerating high temperatures, resisting toxic heavy metals, or providing a direct food source.

The alvinellid microbial community is the subject of our current project to understand the functional metagenomics of this community consortia. As part of our project we have sequenced over 200,000 environmental microbial DNA clones and preliminarily identified genes by database comparisons. The different genes and gene variants will be arrayed on microarray slides, taken back to the environment, and used as targets for probing with message

libraries made from new environmental extractions. The goal of our study is to dissect the functional genomics of this environment leading to physiological assignment of genes and discovery of the core metabolism for the community. Our project allows for dissecting microhabitat heterogeneity in this complex deep-sea hydrothermal vent microbial/invertebrate community and provides a model system for understanding environmental metagenomes of other extreme ecosystems.

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Natural Uv Damage And Repair Observed In Yellowstone Extremophiles

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Understanding the consequences of ultraviolet radiation (UV) is one of the most important considerations in early Earth studies. Extremophiles, known to inhabit early Earth without the protective layer of the ozone, have developed several mechanisms to alleviate the effects of elevated UV radiation. Cyanidium caldarium, one such extremophile, is a thermophilic red alga frequently associated with hot-spring environments.

In this study, we examined whether UV radiation would induce high levels of DNA damage and subsequent DNA repair in response to temperature fluctuations. These experiments were conducted at Nymph Creek, Yellowstone National Park during the summer months of 2002. C. caldarium was exposed in situ to three temperature treatments, ice (4°C), ambient (23°C) and stream (~42°C) conditions. UV damage was measured using the ratio of oxidized versus non-oxidized 2-deoxyguanosine. UV radiation fluctuations were measured using photosynthetically active radiation (PAR) readings.

The results showed that although PAR peaked in May (2056 uE/m2/s), C. caldarium exhibited minimal damage at all temperatures examined (0.009-0.0017). In July, damage levels of stream and ambient samples increased 2-fold (0.0037-0.0044). August registered slightly higher DNA damage peaks in the ice and stream treatments 0.0047 and 0.0038 respectively, however September demonstrated an overall decrease (0.0029-0.008). PAR measurements did not correlate with DNA damage levels from stream and ambient temperatures. C. caldarium exposed to ice treatments however, demonstrated damage levels that mirrored PAR measurements. These results suggest that DNA repair mechanisms may be temperature-dependent in C. caldarium.

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Viruses From Yellowstone's High Temperature Acidic Environments.

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Viruses are the most abundant source of genetic material on Earth and therefore are an obvious target for looking for life on non earth based bodies. Of the three domains of life (Eukarya, Bacteria, and Archaea), the least understood is Archaea and their associated viruses (Snyder, 2003). The astrobiology community has interest in Archaea because many are extremophiles, with species that are capable of growth at some of the highest

temperatures and extremes of pH of all known organisms. Phylogenetic rDNA analysis places many of the hyperthermophilic Archaea at the base of the universal tree of life, suggesting that thermophiles were among the first forms of life on earth. Very few viruses have been identified from Archaea as compared to Bacteria and Eukarya. We report here the structure of a hyperthermophilic virus isolated from an archaeal host found in hot springs in Yellowstone (Rice, 2004). The sequence of the circular dsDNA virus genome shows that it shares little similarity to other known genes in viruses or organisms. The structure reveals tertiary and quaternary relationships in dsDNA virus capsids that span all three domains of life, suggesting that these viruses shared a common ancestor preceding the division of the three domains of life more than 3 billion years ago.

We also report on our efforts to directly monitor changes in the viral populations in Yellowstone thermal features (Snyder, 2004). We have sampled at approximately 30 day intervals the viral populations, microbial diversity, and water chemistry in three high temperature acidic thermal features. The goal is to determine if there is a correlation between changes in the geochemistry of these environments and changes in the host and viral populations. A surprisingly high level of change in virus population structures is observed.

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Archaeal Phylotypes In Low Activity Deep Subsurface Sediments, ODP leg 201, site 1231

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The search for life in Martian subsurface environments raises several questions. For example, what kinds of subsurface life can we expect under severe carbon limitation and low microbial activities, and how different can we expect the subsurface biosphere to be from once-existing surface ecosystems in terms of community composition etc. To address these questions we studied the microbial diversity in sediments from site 1231 of the Ocean Drilling Project (ODP). This site is characterized by small concentrations of organic carbon and low biologic activity rates (Shipboard Scientific Party, 2003). We extracted and amplified DNA in PCR reactions with primers for 16S rRNA genes from samples collected at 5 and 44 mbsf. Three types of organisms was detected: a group of euryarchaea from 5 mbsf was related to uncultured organisms from a variety of terrestrial, aquatic and subsurface habitats, while two groups of organisms from 44 mbsf were related to euryarchaea or crenarchaea from hydrothermal vents. Thus, the archaeal community at the organic-poor, low-activity site 1231 differs fundamentally from other, previously studied deep subsurface archaeal communities from sediments with higher activity levels (Reed et al 2002, Marchesi et al 2001). The abundance of organisms from hydrothermal environments among the close relatives of the archaea in the organic-poor, cold sediment at site 1231 is remarkable given the differences in chemical and physical characteristics between these two types of environments. One can hypothesize that some of the organisms detected in the hydrothermal fluid are not indigenous to vent systems but originate in cooler sediments from which they are flushed out as seawater enters the hydrothermal system.

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Sub-Basement Fossil Soils Cored From The North Pacific (ODP Leg 197): A Model Of Their Formation And Use As Analogues For A Deep Subsurface Biosphere On Mars

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We suggest that preserved organic material from deep sub-surface fossil soils in isolated diagenetic settings make them suitable model systems to develop hypotheses regarding a potential present and past deep biospheres on Mars. The model system we report here is that of sub-basement fossil soils from the Ocean Drilling Program (ODP-Leg 197). The detection of past life through the fossil record, or a chemical biomarker buried deep beneath the surface of a planet is a fundamental step toward understanding the presence and evolution of life onthat planet. This is particularly relevant for Mars where high near-surface UV flux interacting with possible oxidant(s) [e.g., 1] would affect possible near-surface extant life and the stability of organic molecules. However, microbial life could have been preserved at depth on Mars [2-3] where conditions are different from the surface. Hence, the need to identify new suitable terrestrial analogs for Martian subsurface environments decoupled from the surface.

Early Eocene organic-poor paleosols (C-org.=0.01-0.12%; N-tot=0.01-0.006% [5-6]) are Fe oxides/oxyhydroxide-rich and during Leg 197 were collected as a core beneath the volcanic basement (~310 mbsf) at Nintoku (~41°20°N; ~170°23°E) and Koko (~34°56°N; ~172°9°E) seamounts [4-5]. Fossil soil isolation from the atmosphere and the ocean is based on 1) a literature-based model [6]; and 2) new geochemical data differentiating buried soils (δ13C-org =~-26â;δ 15N-tot =-9.5â to +2.5â) from exposed counterparts (Hawaiian oxisols with δ13C-org =~-17-to-23â; δ15N-tot up to +8.5â) [7-8].

The model proposed for the formation paleosols and surface decoupling includes: a) Sub-aerial weathering from igneous rock; b) heating and burial beneath meters of lava flow (~1-2 Ma); and c) complete subsidence below sea level with isolation from the atmosphere and the ocean (~48-~55 Ma until present). During each phase various organics may have produced or overprinted (terrestrial plants and past/present microbials) and different physiological types of microbes (Archea, Bacteria, Eukarya) selected by the changing environment. They are: 1) An extinct population, e.g., oxygenic phothosynthetic Cyanobacteria, in the sub-aerial soil horizons; 2) a secondary post burial anaerobic community that arose after initial heating; 3) still living/viable potential chemolithoautotrophs (i.e., Fe/Mn-reducers from deep subsurfaces [e.g., 9]); and 4) some contamination caused from drilling/samples manipulation.

Geomicrobiology of nutrient-limited subsurface Earth systems will establish a new analog for a possible subsurface biosphere on Mars, and be relevant for the understanding of samples from future Mars drilling/sample return missions [3] and Planetary Protection.

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Life Without Water - Anhydrobiosis In Plants

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Life on earth depends on the availability of water. Hardly any animals and higher plants can survive desiccation. However, many lichens, some bryophytes and algae, a few higher 'resurrection plants', and the seeds of most higher plants are desiccation tolerant. They can survive 'anhydrobiosis', a state of suspended animation in which they stay alive for indefinite periods until water is available. Desiccation tolerant plants then revive, and seeds imbibe and eventually germinate. Therefore, if any living organisms can travel through space, desiccation tolerant plants and seeds are the most likely to be able to make the journey. We are currently exploring these possibilities in the 'Interplanetary Pioneers' project of the NASA Ames NAI team.

Here we report on biochemical mechanisms that confer desiccation tolerance. We first consider damage caused by water removal and point out that free radicals (Abele 2002) are a major cause of death in intolerant tissue. In seeds reactive oxygen species (ROS) are mainly formed in the respiratory electron transport chain. In desiccated photosynthetic tissues there is a specific problem - chlorophyll molecules continue to be photoexcited during desiccation, but the energy not used in carbon fixation causes formation of ROS eventually resulting in break-down of macro-molecules and sub-cellular structures.

As a consequence, anhydrobiosis and prolonged longevity in the desiccated state depend on the ability to scavenge ROS. The antioxidant glutathione is of the essence for all life forms discussed here. Some of the other 'classical' antioxidants are absent in lower plants. For example, it is uncertain whether bryophytes and lichens contain ascorbate ('vitamin C'), and fungi do not contain tocopherol ('vitamin E'). They may however use secondary products with antioxidant properties that are exclusively produced by them. Overall, desiccation tolerant plants and seeds all have an extremely robust antioxidant system. In particular their ability to maintain antioxidants during desiccation, or rapidly re-establish normal levels during rehydration, sets them apart from desiccation intolerant organisms (Kranner et al., 2002).

At the same time as desiccation tolerant plants have evolved an enhanced ability to scavenge ROS (Kranner & Lutzoni, 1999), specific mechanisms have also been selected for that avoid ROS production, for example by dissipating excess excitation energy as heat. These mechanisms protect the photosynthetic apparatus in the dry state and enhance tolerance of UV radiation, making desiccation tolerant plants even more likely to be able to withstand the rigors of space.

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Thermo-haliophile Ecosystem In Badwater, Death Valley National Park, California

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Badwater is the lowest, saltiest, and hottest, place in North America. This extreme environment is located 86 meters (282 feet) below sea level with temperatures often reaching above 50 degrees Celsius. The elevation and surrounding mountains contribute to the formation of a salt flat present year round. Despite these extreme conditions, life can be found just below

the surface of this salt layer. Mars regolith is expected to have high salt concentrations. By studying the Badwater salt flats we will gain a better understanding of how salts influence temperature and the preservation of life. In this paper we examine the physical, environmental, and geological conditions contributing to the survival of the thermo-haliophile ecosystem in the Badwater salt flat.

Uncultured Archaea In Organic-poor Subsurface Sediments Of The Equatorial Pacific Ocean (ODP Leg 201, site 1225)

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The population structure and metabolic activity of subsurface microorganisms in situ is poorly studied and remains largely unknown (D'Hondt 2002). As a working hypothesis, deep subsurface microbial communities might differ from near-surface microbiota in phylogenetic composition and physiology, as a consequence of extreme deep-subsurface environmental conditions. A microbial survey of subsurface environments on Earth is a first step towards assessing the potential for subsurface life on other planets.

The archaeal community of marine subsurface sediments in ODP site 1225 in the eastern equatorial Pacific was analyzed by 16S rDNA sequencing and denaturant gradient gel electrophoresis (DGGE). We compared the phylogenetic composition of the archaeal community of a marine deep subsurface sediment sample (06WR, 7.75 meters below the seafloor [mbsf]) with a near-surface sample (01WR, 0.105 mbsf) from the same sediment. The most frequently retrieved clones from sample 01WR belonged to three groups of Crenarchaeota, the Marine Group I (MGI), the Marine Benthic Group A (MBGA) and the Deep-Sea Archaeal Group (DSAG). In contrast, all clones retrieved from the deeper subcore (7.75 mbsf) were members of MBGA, forming two separate clusters within the MBGA which differ from the clones in subcore 01WR. The presence of the MGI archaea in the near-surface sample is almost certainly a seawater contribution; these crenarchaeaota dominate the prokaryotic picoplankton in the mesopelagic watercolumn (Karner et al. 2001). The MBGA archaea are generally found in benthic marine sediments (Vetriani et al. 1999); the DSAG archaea are found in benthic marine sediments and hydrothermal vents (Vetriani et al. 1999, Takai et al. 1999, Takai et al. 2001). The latter two clone groups apparently represent widely distributed archaea in benthic marine sediments and the subsurface. The sequence data indicate a partial overlap of cold-sediment and hydrothermal vent-associated archaeal populations in the marine subsurface.

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Molecular And Organismal Characterization Of Microbial Communities At The Lost City Hydrothermal Field

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The Lost City Hydrothermal Field (LCHF) is a new type of hydrothermal system hosted on 1.5 million year-old ultramafic oceanic crust Mid-Atlantic Ridge. Fluid circulation is primarily driven by exothermic serpentinization reactions that result in highly reducing, high-pH fluids containing high

concentrations of hydrogen and methane. These fluids emanate from gigantic carbonate edifices that can reach 60m in height. We have performed a set of microbiological and molecular analyses on samples collected from the LCHF during an expedition to the site in April-May 2003. Diverse communities of bacteria are prevalent within fluids as well as on the carbonate structures, as evidenced by microscopic observation and 16S rDNA clone libraries. The sequences represented in these clone libraries share similarity with 16S rDNA sequences from bacteria associated with hydrothermal vents as well as non-hydrothermal deep sea environments. The groups of bacteria represented in the clone libraries vary widely, even between samples taken from the same structure, suggesting environmental variation on a microscale. Also, a Methanosarcina-related organism collected from a LCHF carbonate rock sample has been cultivated in enrichment culture at 70°C. We are currently performing molecular and biochemical experiments to characterize the physiology of this organism. Because the type of hydrothermal system typified by the LCHF requires only the formation of oceanic crust and not necessarily modern tectonic or volcanic activity, it may be a useful analog for habitats widespread on the early Earth and possibly other planets.

The Dry Limit For Photosynthetic Life On The Earth

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Lithophytic cyanobacteria function as the sole primary producers in the world's driest deserts. This poster presents our results on the distribution and survival of these photosynthetic microbes, which inhabit the crevices (chasmoendolithic), undersides (hypolithic) and sides (perilithic) of translucent stones in the Atacama (Chile) and Taklimakan (China) Deserts. In each desert, we measured the percentage of translucent stones with attached cyanobacterial colonies and monitored nanoclimate parameters along natural precipitation gradients. Our results show that colonization varies from 28% to <1% and that, overall, these decreases parallel declines in mean annual precipitation. Finer-scale variations amongst the two deserts, however, cannot be explained solely by rainfall, but instead indicate fog and/or dew may be important moisture sources. Soil r14C signatures in the Atacama suggest slow but active organic carbon cycling by lithophytic communities. In the hyperarid core of the Atacama Desert, the virtual absence of cyanobacteria suggests that the availability of liquid water has reached the dry threshold for photosynthetic life, and thus primary production, on the Earth. Indeed, the rarity of photoautotrophic communities (0.08-0.4% of translucent stones) observed at our hyperarid sites in the Atacama and Taklimakan Deserts indicates the detection of past or present lithophytic microbes on Mars may require prolonged search strategies and capabilities heretofore unparalleled by those envisioned based on even the most extreme Earth analogs.

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Microbial Diversity Of Benthic Mats Along A Tidal Desiccation Gradient

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We investigated the influence of desiccation frequency, as indicated by position along a tidal gradient, on microbial community structure, diversity, and richness of microbial mats. We independently characterized cyanobacterial, bacterial, and archaeal groups, and their spatial variations for two microbial mat systems: subtidal hypersaline mats and intertidal sand flat mats. Community fingerprints based on 16S rDNA were obtained via denaturing gradient gel electrophoresis (DGGE) using PCR primers specific for each group. Fingerprints for all three groups were consistently similar (> 83% according to WPGMA analysis) along a km-long transect in subtidal mats. Here, pair-wise comparison analysis yielded minimal variation in diversity and richness for all five sampling sites. Fingerprints of the three sites along an intertidal transect were heterogeneous (< 32% similarity according to WPGMA analysis) with clear shifts in community structure for all three microbial groups. Here, all groups exhibited statistically significant increases in richness and diversity from the upper to lower intertidal (as desiccation frequency decreases). Regression analysis yielded a strong correlation between diversity or richness estimates and position along the tidal gradient for both the Archaea and Bacteria, with Cyanobacteria exhibiting a weaker correlation. These results suggest that desiccation frequency can shape the structure of microbial mat communities, with Archaea being the least tolerant and Cyanobacteria most tolerant.

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Sub-basement Fossil Soils Cored From The North Pacific (ODP Leg 197): A Model Of Their Formation And Use As Analogues For A Deep Subsurface Biosphere On Mars

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We suggest that preserved organic material from deep sub-surface fossil soils in isolated diagenetic settings make them suitable model systems to develop hypotheses regarding a potential present and past deep biospheres on Mars. The model system we report here is that of sub-basement fossil soils from the Ocean Drilling Program (ODP-Leg 197). The detection of past life through the fossil record, or a chemical biomarker buried deep beneath the surface of a planet is a fundamental step toward understanding the presence and evolution of life on that planet. This is particularly relevant for Mars where high near-surface UV flux interacting with possible oxidant(s) [e.g., 1] would affect possible near-surface extant life and the stability of organic molecules. However, microbial life could have been preserved at depth on Mars [2-3] where conditions are different from the surface. Hence, the need to identify new suitable terrestrial analogs for Martian subsurface environments decoupled from the surface.

Early Eocene organic-poor paleosols (C-org.=0.01-0.12%; N-tot=0.01-0.006% [5-6]) are Fe oxides/oxyhydroxide-rich and during Leg 197 were collected as a core beneath the volcanic basement (~310 mbsf) at Nintoku (~41°20'N; ~170°23'E) and Koko (~34°56'N; ~172°9'E) seamounts [4-5]. Fossil soil isolation from the atmosphere and the ocean is based on 1) a literature-based model [6]; and 2) new geochemical data differentiating buried soils (δ^{13} C-org =~-26% $_{c}$; δ^{15} N-tot =-9.5% $_{c}$ to +2.5% $_{c}$) from exposed counterparts (Hawaiian oxisols with δ^{13} C-org =~-17-to-23% $_{c}$; δ^{15} N-tot up to +8.5% $_{c}$) [7-8].

The model proposed for the formation paleosols and surface decoupling includes: a) Sub-aerial weathering from igneous rock; b) heating and burial beneath meters of lava flow (~1-2 Ma); and c) complete subsidence below sea level with isolation from the atmosphere and the ocean (~48~55 Ma until present). During each phase various organics may have produced or overprinted (terrestrial plants and past/present microbials) and different physiological types of microbes (Archea, Bacteria, Eukarya) selected by the changing environment. They are: 1) An extinct population, e.g., oxygenic phothosynthetic Cyanobacteria, in the sub-aerial soil horizons; 2) a secondary post burial anaerobic community that arose after initial heating; 3) still living/viable potential chemolithoautotrophs (i.e., Fe/Mn-reducers from deep subsurfaces [e.g., 9]); and 4) some contamination caused from drilling/samples manipulation.

Geomicrobiology of nutrient-limited subsurface Earth systems will establish a new analog for a possible subsurface biosphere on Mars, and be relevant for the understanding of samples from future Mars drilling/sample return missions [3] and Planetary Protection.

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Water Diffusion In The Extremely Unsaturated Atacama Soils: Desert Crust Formation And Its Implications For Evaporation And Infiltration Of An Experimental Rain

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The Atacama Desert is one of the most arid deserts with a minimal amount of rain. Here we report on experiments and theoretical models of the movement of water through the top layers of the soil. We address two questions: 1) the availability of water for life and 2) the transport of salts by water. In the core arid region of the Atacama Desert there appears to be no microbes in the soil. This may be owing to the lack of moisture. Another interesting feature of this region of the Atacama Desert is the abundance of nitrate deposits near the soil surface. Of particular importance is the relevance of the salt layers with respect to water vapor diffusion and liquid water transport. Data collection and analysis of results from an in situ experimental rain demonstrate the role of soil crustation that may impede or enhance the infiltration of water or the evaporation of water. A crust that impedes the infiltration of any additional rain may also impede the evaporation of soil moisture thereby increasing the residence time for the water in the soil available to microbes. The residence time of water may be non-linear

Conceptual Design For The Development Of An In Situ Hydrothermal Vent Probing And Sampling Device For Microbial Analysis

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Present day laboratory-based experimental constraints limit the verification of the existence of life to temperatures no higher than 113°C. This project seeks to probe for the existence of life at higher temperatures by collecting pristine samples from a 360°C deep-sea hydrothermal vent and performing laboratory bioassays on the returned samples. These hydrothermal vents, known to contain organic material, have been sampled before using various sampling devices. The findings of such studies are questionable because (1) the samples were contaminated by the surrounding cold water, and (2) the in-situ bioassay techniques had not yet been validated. The proposed "Hydro-vent Bio-sampler" will be capable of probing the source, collecting, filtering, and storing samples, and holding them at high temperature during return transit. Collected samples will be contained at several temperature points within and surrounding the hydrothermal vent (e.g., 3 to 360°C), and returned intact, uncompromised, to the surface for laboratory bioassays.

This project will contribute to NASA's Search for the Origins of Life program in two crucial ways. First, it will enhance the overall understanding of terrestrial life in extreme environments using validated bio-assessment protocols. Additionally, it will develop and demonstrate a probe/sample-containment device with applications for both terrestrial and extraterrestrial exploration in extreme environments. An additional key initiative of the Origins program is to design and implement Planetary Protection measures into sampling devices as they are conceptualized, rather than adding them as an afterthought. The proposed project will significantly contribute to that goal by developing a probe with built-in bio-containment capabilities.

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The Eucarya And Archaea Of A Hypersaline Microbial Mat.

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The overarching goal of this work is to describe and understand the organismal composition within the domains Archaea and Eucarya for the microbial ecosystem of a hypersaline microbial mat. Sea salt is crystallized by solar evaporation at North America's largest saltworks, the Exportadora de Sal, in Guerrero Negro, Baja California, Sur. Sea water flows through a series of evaporative basins with an increase in salinity until saturation is reached and halite crystallization begins. Several of these ponds are underlined with thick microbial mats. To date, it has not been known what kinds of organisms comprise these complex microbial ecosystems. Here, we report a survey of the stratified microbial communities for the distribution of representatives of both Eucarya and Archaea in layers of the mats. This survey uses molecular approaches, based on cloning and sequencing of SSU rRNA genes for phylogenetic analyses, to determine the nature and extent of archaeal and eucarval diversity that constitute these ecosystems. Analyses to date indicate the ubiquitous dominance of uncultured organisms of phylogenetic kinds not generally thought to be associated with hypersaline environments. Additionally, the numbers of different kinds of Archaea is dramatic, given that they occur in hypersalinity. Hypersaline eucaryal diversity was higher than expected. In addition to an abundance of nematodes, an entirely new, deeply rooted eucaryal kingdom was found. Collectively, the results indicate that the diversity of life is extensive even in this seemingly inhospitable "extreme" environment.

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Gene Expression Changes Associated With Oxidative Stress In The Cyanobacterium Synechocystis Sp. PCC 6803

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Microbial mats are complex associations of organisms widely regarded as a model for early Earth ecosystems. One major component of many microbial mats is photosynthetic cyanobacteria, thought to be responsible for the rise of oxygen in the Earth's atmosphere 2-3 bya. Cyanobacteria, as with other microbial mat species, must cope with a diverse array of environmental stresses, including oxidative stresses, differing light conditions and varying levels of nutrients. The genome sequencing and the construction of a full genome microarray of the cyanobacterium *Synechocystis* sp. PCC 6803 (Postier et al, 2003) has provided valuable information as to the potential transcription factors that regulate the response to oxidative stress and the transition from exponential to stationary growth (i.e., when nutrients are limited). By using model organisms such as *Synechocystis*, we can begin to examine global gene regulation changes within the microbial mat communities *in situ* and further our understanding of how early Earth ecosystems coped with environmental stresses at the molecular level.

We constructed a knock-out mutant of one such transcription factor, sigma B (sll0306), because it was sensitive to oxidative stress and resembled other bacterial genes known to be involved in regulating shifts in growth phase. We then isolated mRNA from wild-type *Synechocystis* sp. PCC 6803 and the *DsigB* mutant grown for 3 d (exponential) and 5 d (stationary) and DNA microarray experiments were performed using the loop design as previously described (Singh et al, 2003). Preliminary results indicated that about 25% of the 3165 genes demonstrated significant changes in the expression between exponential and stationary growth of *Synechocystis* sp. PCC 6803 and that the *DsigB* mutant had an important effect on this transition. Two up-regulated genes of particular interest were *sigH* and *isiA*, which demonstrated a 15- and 12-fold increase, respectfully. Both genes have been reported to be involved in the oxidative stress response of cyanobacteria and further emphasized the interaction of the cellular responses to oxidative stress and nutrient-induced growth limitations.

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Remote Sensing And In Situ Sampling Of Extremophiles In Saline Terrestrial Environments

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Planetary exploration is fundamentally dependent upon remote sensing techniques. We have developed techniques for the detection and classification of microbial populations through infrared remote sensing at terrestrial analogue sites. Extreme salinity levels feature biota dependent upon "abnormal" conditions, which may represent forms of life that could possibly inhabit extraterrestrial planets. Our research group has conducted field studies and in situ sampling of organisms in large-scale salt evaporation ponds, whose extreme environments play host to representatives from all three domains of life: Eukaryotes, Prokaryotes and Archaea. By combining laboratory and field measurements incorporating pigment absorption characteristics of these microbes with remotely-sensed data from the Jet Propulsion Laboratory's Airborne Visible and InfraRed Imaging Spectrometer (AVIRIS), we have been able to demonstrate direct links between microbial populations and infrared signatures.

Most organisms are stenohaline: limited to narrow ranges of salinity concentrations, while others can occur over extended ranges. Initial results indicate a correlation between salinity levels and flux in microbial diversity, culminating in an environment predominately populated by Archaea. As salinity increases, concentrations of any given organism peak and decline. This is demonstrated by pigment analysis coupled with infrared measurements. Overlapping ranges of various biota give rise to a rich and varied tapestry of spectral color signatures, which can be unravelled to reveal the component organisms. These infrared color signatures could prove to be useful biomarkers in the search for extreme life not only on, but also beyond Earth - particularly on Mars and Europa, and possibly even beyond our solar system.

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An Iterative Microscopic Approach To Detect And Characterize Microorganisms Within Deep-sea Hydrothermal Ecosystems

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The upper temperature limits to microbial life are not only of general scientific interest, but are significant in delineating the extent of a subsurface biosphere and may be fundamental to the understanding of early Earth ecosystems. The current upper temperature boundary is 121°C (Kashefi, 2003), however this value is constantly being challenged with new organisms isolated from deep-sea hydrothermal systems. Additionally, in situ observations at deep-sea hydrothermal vents consistently reveal the presence of intact microbial cells in fluids well above 300°C and in endolithic ecosystems that must also be sustained at very high temperatures (Schrenk, 2003). However, whether these organisms are metabolically active in situ or transient in their occurrence remains equivocal. In order to address this concern, we have developed and applied a multi-faceted approach, using several independent lines of analysis, to probe putative microbial structures within deep-sea hydrothermal ecosytems.

Anaerobic hyperthermophiles grown under varying laboratory conditions and mineral surfaces deployed within thermal-chemical gradients at deep-sea vents were used in the development of the described method. Epifluorescence microscopy was used to characterize the background fluorescence of samples prior to the application of nucleic acid and membrane specific stains. Subsequently, the targeted molecules were degraded with specific enzymes and the stain was reapplied to confirm the disappearance of fluorescent signal. In the cultures intact, ribosome-

containing cells could be distinguished from inactive and membrane-compromised cells, which were most abundant during sub-optimal growth conditions. The mineral surfaces documented the existence of abundant and active microbial communities in moderate temperature environments and the absence of cells within extremely high temperature environments. The approach described here not only provides a means to confirm the biological nature of pseudo-microbial structures but also provides insight into their structural intactness, identity, and activity. In combination with detailed phylogenetic and geochemical analyses this approach can elucidate the processes occurring near and above the known upper temperature limits to life.

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Volatile Organic Biomarker Release From Microbial Communities In Extreme Environments

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The detection of microbial communities in extreme terrestrial or extraterrestrial environments involves a search for both the structures of organisms and any metabolic products that may be released into the surrounding environment. The issue of leakage of low-volatility biomarkers, and the resultant metabolic cost to the community, is more commonly considered (e.g. McDonald and Sun 2002), but leakage of volatile organic compounds from microbial communities under low-nutrient conditions as a source of biomarkers is not well understood.

The extent to which volatile organic compounds will be released into the overlying atmosphere by a microbial community is, to first order, a function of the partitioning between the aqueous medium of the cell interior and the gaseous medium of the surrounding air, following Henry's law, as well as the rate of diffusion through any cell wall or extracellular sheath that may be present. This paper presents a simple mathematical model for gas-phase biomarker release and compares it to experimental data from endolithic microbial communities. Such an analysis is necessary to evaluate the importance of organic carbon and nitrogen loss from endolithic microbial communities to the atmosphere, as well as to determine the detection limits needed in the search for extraterrestrial organisms using gas chromatographic or spectroscopic instruments.

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Comparison Of Psychrobacter Strains From Puerto Rican And Siberian Samples

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Low temperature predominates in interstellar space and most of the planets, satellites and meteors. Before understanding how organisms emerge from or adapt to extraterrestrial environments, we must first comprehend how terrestrial organisms respond to the space environment at the genetic and the evolutionary levels. Permafrost resembles outer space environments because it is extremely cold and ice is not bioavailable; therefore, the permafrost could be used as a model for an extraterrestrial environment. Vishnivetskaya et al. (2000) developed strategies for the isolation of aerobic, oligotrophic bacteria from ancient permafrost sediments and successfully

isolated members of the genus Psychrobacter, a psychroactive bacterium not usually associated with mesophilic environments.

The bacteria isolated from the Siberian permafrost have been exposed to temperatures below 0°C 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 environments. In order to test this hypothesis, we intend to compare various physiological traits between the bacteria isolated in the permafrost and the nearest relatives isolated from tropical environments. Several samples were taken from different ecosystems in Puerto Rico and bacteria were isolated using the media developed for the cultivation of Psychrobacter (Bowman et al. 1996). Psychrobacter specific 16S rRNA primers were used to identify positive isolates from fish and mangrove sediments. This presentation includes the preliminary description of Psychrobacter strains isolated from Puerto Rico, emphasizing the physiological comparison between the Puerto Rican and Siberian strains using traditional and molecular typing tools.

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Bacterially Mediated Ice Formation: Implications For Cloud Formation And Life In Frozen Environments

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Even though frozen habitats on Earth are known to contain liquid water due to salt and organic impurities that depress the freezing point in support of microbial life, surprisingly little is known about how cold - loving or psychrophilic bacteria interact and cope with the solid phase (ice) itself. Recent investigations of wintertime Arctic sea-ice samples have indicated that association with surfaces (including ice crystals) is an adaptive strategy for maintaining activity at subzero temperatures (to -20 °C, Junge et al., 2004). Questions remain, however, as to how bacteria can interact with ice directly.

In this pilot study, we investigated psychrophilic bacteria for their potential to induce ice formation, creating their own attachment sites, using a combination of microbiological and atmospheric science approaches in the laboratory. Ice nucleation activity (INA) of selected sea-ice bacterial isolates and their polymers, extracted from spent growth medium by ethanol precipitation and dialysis, were examined using the droplet freezing assay and a new freezing-tube technique. First tests revealed that many isolates, when present in marine growth medium, nucleated ice in the temperature range of -6 to -17°C. In many cases, droplets began to freeze at about -5°C, similar to the high ice-nucleation temperatures observed for terrestrial bacteria with INA. The extracted polymers also had the ability to nucleate ice at relatively warm temperatures but to a lesser degree. These preliminary results suggest that some ice-forming nuclei (IFN) in this population have INA at sufficiently high temperatures to be involved in both sea-ice and cloud formation. Future work will examine the implications for survival and growth of polar marine bacteria confronted with freezing conditions, as well as for bacterially mediated ice initiation in polar clouds on this planet and possibly elsewhere.

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Biology And Water Chemistry Of Several Hyperalkaline Springs Emerging From Mantle-Like Rock

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Dilute (< 100 ppm TDS) hyperalkaline (pH > 11.5) springs associated with aquifers in the Cedars, a serpentinizing peridotite body in Northern California, appear to support a diverse microbiological community. The host rock, peridotite, is mantle-like in composition. When exposed to water near Earth's surface the minerals in peridotite tend to be converted to serpentine, i.e. the rock undergoes serpentinization. Peridotite was probably much more common on Earth's surface early on than today. Peridotite is also likely to be common on juvenile terrestrial planets in our solar system or around other stars of similar metallicity to Sol. Hence, water-rock-life interactions in this system may offer a window into such processes on early Earth or on other terrestrial bodies.

We have examined the water chemistry and microbiology of several different springs in this complex. We have successfully grown several cultures isolated from this environment at pH > 10 in the laboratory. We have also sequenced 16S rDNA genes from several springs and found that genetic diversity, though significant in all samples, is lowest in the most dilute and highest pH samples. This diversity is remarkable given that the water here is very dilute and contains almost no protons to drive PMF. According to ICP-MS analysis, these spring waters generally contain ≤ 2 mM Ca^{2+}, Mg^{2+} and Na^+ and much less of all other cations save Fe^{2+} . Dissolved pCO $_2$ is $<10^\circ$ atm. Thus, as it emerges from the aquifers the water contains little in the way of either redox couples or carbon. When this water comes in contact with the atmosphere it literally sucks carbon dioxide out of the atmosphere, becoming supersaturated with respect to calcium carbonate.

Travertine aprons around many of the springs can grow tens of centimeters thicker in a single dry season though many aprons are partially or even completely destroyed during the rainy season. Given the enormous degree of supersaturation the water should reach, Cedars carbonates are most likely abiogenic in origin. However, initial examination suggests they could serve to preserve fossil microbes from this environment.

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Molecular and morphological characterization of free-floating filamentous cyanobacterial mats from geothermal springs in the Philippines

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A novel cyanobacterial mat type is characterized from near-neutral pH, low sulphide geothermal springs of 45-60 °C in the Philippines. Mats were free floating, several metres in diameter and several cm in thickness. The upper surface of mats was covered in a waxy scytonemin-like layer, solvent extracts of which absorbed light strongly at 384nm. Light microscopy revealed mats to posses highly ordered layers of air spaces at both the macroscopic and microscopic level, apparently as an adaptation to buoyancy. Morphospecies composition was exclusively filamentous, with Fischerella-like and Oscillatoria-like taxa closely associated throughout mats. Abundant heterocystous cells were observed in Fischerella filaments, suggesting nitrogen fixation occurs in these mats. Morphological structure did not vary among mats from pools of different temperature, but several 16S rDNA-defined genotypes were resolved by DGGE with some displaying greater thermophily than others. Sequencing of fourteen DGGE bands (Genbank accession numbers: AY236467-AY236480) yielded nine novel Fischerella sequences, whilst the five Oscillatoria sequences showed high similarity to other thermophilic Oscillatoria sequences. These data are relevant to astrobiology in that they expand our knowledge of oxygenic photosynthetic community diversity in geothermal environments, which serve as modern analogues for early life on Earth and other planets.

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MESSAGE: Microbial Experiments In The Space Station About Gene Expression.

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With the growing interest in prolonged missions it is important to study in detail the different aspects of microbial activity in closed environments such as space vehicles, space stations and planetary bases. The early detection of physiological and metabolic changes in bacteria that are present in space crafts or space stations is crucial for a variety of biosafety issues including pathogenicity for the crew and the biodetoriation of materials. Nonetheless, bacteria are also essential for long-term manned missions for the recycling of waste and the production of food. To study the effects of space conditions (radiation, gravity, etc) on such bacteria and to search for characteristic 'spaceflight responses', experiments were performed during two separate visits to the International Space Station (ISS). Two environmental model bacteria, Ralstonia metallidurans CH34 (ATCC43123) and Rhodospirillum rubrum SH1 (ATCC25903), were grown during these 10-day space flights. Space- and ground-grown cells were compared on molecular (proteins, RNA, DNA analysis) and physiological (flow cytometric analysis - FCM) level. Distinct changes in gene expression (by 2D-gel analysis) and physiology (FCM) were observed. A total of twelve proteins over-expressed in space conditions could be identified. The most significantly induced gene under space conditions encodes the acetone carboxylase γ-subunit (AcxC). Growth of insertion mutants of acxC and the stress protein gene dpsA was not affected by space flight but flow cytometric data clearly showed a different physiological response of dpsA mutant cells when exposed to space conditions. The intracellular esterase activity and Ca2+ concentration was significantly higher in space grown dpsA mutant cells and significantly more DNA and RNA could be fluorescently stained per cell. To elucidate which genes are involved, transcriptomic and proteomic analysis (i.e. wild type vs. mutant) is in progress. A first microarray of 663 stress-related genes has been designed for R. metallidurans and a 48-gene test-chip is currently being tested. In time, a complete genome DNA chip for all 7000 R. metallidurans will be constructed.

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Hyperthermophilic Archaea: The Earliest Organisms Adapted To Extreme Environments

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The microorganisms belonging to the domain Archaea populate almost any environment previously thought hostile expanding the limits to life (-40°C to +115°C; ca 120 Mpa; aw of 0.6 for ionic strength, and 1<pH<11). More, phylogenetic studies predict that the last common ancestor was thermophilic. The study of Archaea provides useful answers in Astrobiology regarding the adaptation of life in other planets and the chemical-physical conditions compatible with abiogenesis and evolution of early life.

We faced some crucial questions dealing with these organisms: how are Archaea related to other domains of life regarding gene organization/expression and basal metabolism? How can proteins from hyperthermophiles withstand to high temperatures? Here we describe the characterization of the first alpha-fucosidase from Archaea (Cobucci-Ponzano et al 2003). This enzyme, which modulates signal transduction and cell-cell interaction, could be involved in biological events still unravelled in Archaea. In addition, the alpha-fucosidase is expressed in-vivo by programmed translational frameshifting, which is known sofar only in Bacteria and Eucarya, indicating that this mechanism of gene expression is universal. Finally, we show that an archaeal beta-glycosidase is stabilized by ion-pair networks (Cobucci-Ponzano et al 2001), and that this mechanism is of general application to hyperthermophilic enzymes.

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Low-temperature Growth Mechanisms Of Bacteria Isolated From Siberian Permafrost, Habitat Analogue For Martian Permafrost

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The determination of low-temperature growth mechanisms is particularly relevant to the search for extraterrestrial life at sites such as the cold-dry surface of Mars, the extensive permafrost regions of Mars, and the cold-icy surface of Europa (1,2). Hence, permafrost and the microorganisms isolated from it are potential analogues for the discovery of active, reproducing life elsewhere in the solar system (3).

Psychrobacter cryopegella was isolated from brine lenses within ~40,000 year-old Siberian permafrost and with an in situ temperature of about -10°C (4). This bacterium can reproduce at -10°C, suggesting that it may have survived permafrost burial by actively growing. We have identified cold acclimation proteins (CAPs) in P. cryopegella to reveal mechanisms that enable subzero growth.

CAPs were identified by comparing protein expression patterns during growth at four different temperatures (16, 6, -4, and -10°C). Total proteins were visualized by 2D SDS-PAGE and detected, matched, and analyzed using Melanie 4 (trial version, Swiss Institute of Bioinformatics). CAPs were defined as proteins uniquely or preferentially expressed during growth below 0°C. Proteins were excised from gels, digested with trypsin, fragments resolved by LC/MS/MS, and identified by comparison with ORFs from Psychrobacter 273-4.

Of the 756 proteins detected, 27 were classified as CAPs and, of these, 18 matched genes within the genome of Psychrobacter 273-4. Six unknown and 3 conserved hypothetical proteins were also found. Potential functions of the 18 genes included: amino acid metabolism (6), energy production (4), transport (3), and stress response (2). Literature searches of the proposed gene products revealed that 8 had been identified as cold or salt stress response proteins in other organisms. Several of these proteins were involved in the production or transport of compatible solutes, suggesting the importance of compatible solutes to growth at subzero temperatures.

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Subsurface Colonization Of Opaque Rocks - Periglacial Processes Create A Novel Habitat For Photosynthetic Life

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The colonization of the subsurface of rocks by phototrophs normally requires that the rock is sufficiently translucent for visible light to penetrate to the underside. We document the colonization of the underside of opaque stones in the arctic and Antarctic polar desert by cyanobacteria. Stones were colonized most extensively around the edges of sorted polygons where freeze-thaw continuously moves the rocks, creating spaces around their

edges where light can penetrate. Within the interior of the polygons, where the rocks are surrounded by fine soil, rocks were not colonized. Stones were found to be colonized to a mean depth of approximately 3 cm. The hypolithic organisms in the high arctic represent a previously unappreciated habitat for life in extreme polar deserts. These data show how an otherwise biologically detrimental stressor, freeze-thaw, can be of benefit to microbial communities in extreme polar deserts by expanding their available habitat. The data reveal the potentially important link between periglacial processes and microbial habitat formation. Finally, the data may have relevance to the search for life in the polar desert of the planet Mars. The edges of sorted polygons, which have been imaged on the planet by satellites, might be high-priority places to search for evidence of past life.

Microbial Ecological Diversity In The Río Tinto, An Extremely Acidic, Heavy-metal Laden River In Southwest Spain

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The discovery of active microbial communities in extreme environments extends the range of environmental parameters that might be compatible with life on other planetary bodies. Located in Southwestern Spain, Río Tinto is a high priority study site for astrobiologists because it is regarded as an analogue for an earlier, wetter Mars [1]. The activity of chemolithotrophic microorganisms in Río Tinto produces high concentrations of Fe (~20 mg/ ml) and sulphuric acid (mean pH 2.3) from polymetallic sulfides. Using a novel molecular technique SAGT (Serial Analysis of Gene Tags) we determined relative numbers of different kinds of microorganisms at key locations (Origin, Anabel's Garden and Berrocal) in the Río Tinto (see Amaral Zettler et al. poster for details). Consistent with FISH data [2], Acidithiobacillus sp. and Leptospirillum ferrooxidans, and to a lesser extent Acidiphillium sp. and Ferromicrobium sp. accounted for the most abundant kinds of microbes in the river system. Moreover, SAGT detected species not previously seen in Río Tinto including Sulfobacillus and uncultured bacterium AS6; both are associated with other acidic environments (3). We also found minor populations that are not represented in molecular databases and they may represent completely novel kinds of microbes. Alpha and Beta ecological diversity indices show that Anabel's Garden and Berrocal have similar microbial population structures whereas Origin harbors a more diverse and unique bacterial community.

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Effects Of Ultraviolet Radiation Over Bacillus Sp. And Protective Role Of Ferric Iron

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The origin of life on Earth had to deal with high doses of irradiation taking into account the complete inexistence of protective oxygen components in the early atmosphere (Kasting, 1993). It is known that some elements like ice (Cockell et al., 2003) can protect life from uv radiation. Other elements could also play an important role in the protection of the first forms of life.

Archean oceans had to be acidic if high concentrations of iron were present as suggested by the geological record (Holland, 1973; Amils et al., 2003).

The effects of UV light over the DNA of the cells is well understand (Sinha and Häder, 2002) but the effects of different doses of UV light on the growth of microorganisms and the role of some protective elements over this growth needs to be studied. Here we focus on the effects of different UV doses over the growth rates of a microbial model and the protective effect of ferric iron, an element present in the primitive ocean.

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Expanding The Subseafloor Biosphere To Ridge Flanks And Beyond

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It has been hypothesized that life may have originated and evolved near deep-sea hydrothermal systems, and that extant organisms living in these likely analogues of early habitats may still harbor metabolic, physiological, and genetic characteristics of early archaean life. Microbes unique to the subseafloor in oceanic crust could provide insight into metabolic processes, strategies for growth, and survival of life forms in the subsurface of solar bodies with a water history. On earth, ridge-flank environments constitute approximately 65% of the ocean basin area. Despite this potentially enormous habitable volume, very little is known about the presence, diversity, or distribution of microbial populations in off-axis igneous crust. This study examines a subseafloor environment in ridge-flank oceanic crust at Baby Bare Seamount, a sedimented basaltic outcrop located on 3.5 Ma crust on the eastern flanks of the Juan de Fuca Ridge. Using a novel extraction technique, subcrustal fluids were obtained, and the presence of a subseafloor habitat explored by analyzing the microbial community and geochemistry of these fluids. We found evidence for an anaerobic microbial community consisting of thermophiles belonging to the Thermosipho spp., Thermococcales spp., and Desulfurobacterium spp., as well as novel uncultured archaea. Chemical, phylogenetic, and culturing results will be presented and compared with Axial Seamount, a young, active volcano located on the Juan de Fuca Ridge known to host a subseafloor microbial population.

Novel Cryptoendolithic Microbial Communities In Yellowstone National Park's Geothermal Environment

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Microbes inhabit some of the most extreme environments on Earth by growing hidden inside the pore space of rock. Such "cryptoendolithic" life is ubiquitous on Earth and is a significant focus of the search for life on other planets. We have discovered a variety of novel photosynthesis-based cryptoendolithic microbial communities in the Rocky Mountain West of the USA that occur in different rock types and environmental settings. To understand the kinds of microbes that comprise these communities, we used DNA sequence-based molecular phylogenetic methods to identify the organisms present without the need for cultivation. Previous work from this study and a study of Antarctic cryptoendolithic communities(de la Torre, et al. 2003) shows that there are distinct kinds of moderately diverse cryptoendolithic communities that are inhabited by similar kinds of unique microbes.

We recently discovered that the geothermal environments of Yellowstone National Park, USA, host a variety of novel cryptoendolithic communities. In many examples, these communities thrive in higly acidic (pH 1) sinter substrates that are laden in heavy metals. In contrast to previously described cryptoendolithic communities that are often dominated by similar kinds of cyanobacteria or eukaryotic green algae, acidic Yellowstone communities

are dominated by organisms related to the euacaryotic red algae, Cyanidium caldarium, and remarkably, large numbers of Mycobacterium species. Electron microscopy studies reveal significant mineralization that could preserve biosignatures of these communities in the geologic record. Biosignatures of both living and fossil cryptoendolithic communities potentially will provide important clues in searching for present and past life on Earth, Mars, and other planets where life occurs.

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Metabolic Activity In Deep-sea Sediment Columns

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We have determined rates of sulfate, iron and manganese reduction, as well as sulfide precipitation in deeply buried marine sediments from a range of representative environments. Rates were calculated based on high-resolution pore fluid measurements and a numerical diffusion/reaction model (presented at this conference, Manor et al.). At Ocean Drilling Program Sites 1225 and 1226 in the Eastern Equatorial Pacific, which represent deep open ocean regions, sulfate reduction occurs through the entire sediment column. The dissolved sulfide distribution indicates that nearly all of the sulfide produced precipitates locally and there is minimal diffusive loss from the sediment column or reoxidation as is common in shallower environments. Thermodynamic calculations indicate saturation or near saturation with iron monosulfide (FeS) and greigite (Fe₂S₄) throughout most of the sediment column while pyrite (FeS2) appears to be highly supersaturated with respect to equilibrium with So. This is taken as evidence that FeS₂ is formed by FeS precipitation followed by conversion to FeS₂ via $FeS+H_2S=FeS_2+H_2$ (Rickard, 1997) rather than by $Fe^{2+}+HS-+S^0=FeS_2+H^+$.

This local precipitation of FeS combined with dissolved iron distributions imply that iron and sulfate reduction both occur throughout the sediment column at nearly the same rates or that there is an additional unidentified solid phase sink of dissolved iron. We propose that the rates may be equivalent as a result of competition between microbially mediated oxidation of hydrogen by sulfate and iron with a thermodynamic control of the rates that depend on the in situ free energies. Thus there is a negative feedback control on dissolved iron and sulfide driven by the dependence of the rate of microbially mediated reactions on the available free energy.

Thermodynamic calculations demonstrate that dissolved manganese may not be precipitated out of the pore water as manganese monosulfide (MnS) or hydroxide. Instead, manganese carbonate (MnCO₃) is saturated or near saturated at some depth intervals, which may explain the precipitation of dissolved manganese at these depths. In some other depth intervals while pore water profiles indicate solid phase Mn precipitation, both MnCO₃ and MnS are undersaturated, indicating a yet unidentified phase as the sink.

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An Insitu Method For Detecting Organic Chemicals In Deep Ice Environments

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Ice cores and ice boreholes provide a unique, albeit limited, view into past ecological records, climatic conditions and biota. With modern insitu instrumentation we were able to view sidewalls and bottoms of hot-water drilled boreholes in Antarctica (Ice Stream C region in 2000-2001) for physical structure, glacial processes and extraction of climatic information (Carsey, et al., 2002 & 2003). The images provided an amazing view of the layered regions below 1000 m depth where pressure drives residual, insitu atmospheric gases into clatharate structures, resulting in 'clear' ice that has significant transparency for visible light. These same clear ice structures

were observed in cores taken from above Lake Vostok in the accretion ice region (150 – 300 m above the lake roof). We examined one Vostok core in which two very large single crystal ice units intersected producing a visible light discontinuity. Fluorescence techniques provide superb sensitivity to a limited class of chemical compounds. With low intensity 365 nm light nothing unusal was observed – no visible fluorescence, no unusual scattering. With a few second examination at 254 nm, blue fluorescence appeared at the ice crystal intersection plane. These data will be presented along with supporting laboratory studies that indicate insitu borehole instrumentation can detect and characterize some organic chemicals and possibly bacterial and elementary life forms. The application of this technique to studies of Lake Vostok, the icy Galilean satellites and Mars polar environments will be discussed.

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Viral Integration In Extremely The Thermophilic And Acidophilic Archaeon Sulfolobus Solfataricus.

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A key step in our understanding where to search for life in outer space is to understand the limits at which life can exist on earth. Our lab is using viruses of hyperthermophilic organisms to elucidate these limits, and the adaptations of life needed for survival in extreme environments.

The hyperthermophilic archaeon Sulfolobus solfataricus is a member of one of the largest and most ubiquitous genus in the Crenarchaea. These extreme thermophiles typically live in terrestrial hot springs at temperatures upwards of 85°C and pH as low as 1. Species of this genus have been found around the world in Japan, Russia, Iceland, and in the Americas[1].

The SSV viruses in the family Fuselloviridae infect Sulfolobus and are among the best-characterized viruses in the Crenarchaea Despite this, little is known about their replication[2]. In order to learn more about this, we are studying one of the only genes of known function in these viruses, the integrase gene. Belonging to a large family of tyrosine recombinases that includes Lambda integrase, the SSV integrase gene is thought to facilitate insertion and removal of the viral genome in a specific site in the host[3].

The first step of my research is to create viruses lacking functional integrase genes to determine if the gene is necessary for viral replication. Because the viral genome has been observed in both a plasmid and integrated form in the host it is not known if integration is necessary for immediate survival, or is a long-term survival strategy.

Further work will characterize the integrase gene more specifically and compare the function of this integrase to other members of the family Fuselloviridae. In addition, we are also studying the effects of stresses such as UV radiation on viral induction and virus survival.

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A Soil Carbon Cycle Without Life? The Content And Residence Times Of Soil Organic Carbon In The Atacama Desert. Chile

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Soils in the hyperarid core of the Atacama Desert in northern Chile represent the dry limit of life on Earth (Navarro-González et al. 2003). To understand the transition in C dynamics from soils that receive slightly more rain (\sim 12 mm y⁻¹) to these nearly abiotic soils, we quantified C pools and radiocarbon (14 C) signatures at three sites along a precipitation gradient in the Atacama desert of northern Chile.

As precipitation decreases from $\sim 12~\text{mm y}^{-1}$ to near zero, surface soil organic C concentrations decrease by an order of magnitude and organic C cycling slows dramatically, with mean residence times increasing from decades to $\sim 10^4$ years in the desert core. At the most arid site, fossilized soil carbon and roots present in lower horizons (>100 cm) are close to radiocarbon dead, indicating that they have been preserved by hyperaridity for at least 50,000 years, and possibly since stabilization of the modern soil surface, two million years ago.

Trends in the character of soil organic C along the gradient and with soil depth track oxidation processes. In surface soils, the ratio of formic acid to benzene increases with decreasing precipitation, suggesting a high degree of oxidation at the driest site. This ratio also generally increases with soil depth. In general, the core of the Atacama represents the dry limit of life not only in terms of numbers of organisms, but also in terms of rates of organic C cycling.

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Chasmoendolithic Colonization Of Impact-shattered Rocks – A Geologically Non-specific Habitat For Microorganisms In The Post-impact Environment

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We report the chasmoendolithic colonization of impact-induced fractures within sedimentary rocks from the 15 million-year old Ries crater, Germany (chasmoendoliths are organisms that inhabit the interior of macroscopic cracks/fractures). Fractures caused by the high temperatures and shock pressures of impact do not presume any particular geological attributes of the rock and so may be general to many impact structures and any rock type, sedimentary and non-sedimentary. Within the fractures organisms gain the advantages of protection from wind scouring of the surface, reduced UV radiation flux and water can be trapped within fractures and even preferentially retained by capillary action. The organisms we report are cyanobacteria, but potentially any organisms might gain the advantage of this impact-induced habitat. Supplied with water initially from post-impact hydrothermal systems and later from ground water and precipitation, the chasmoendolithic habitat is potentially one of the longest-lived habitats resulting from impact. The search for chasmoendolithic habitats in Martian craters might be a high priority exobiological search strategy.

Habitable Planets

Obliquity Variations Of Extrasolar Terrestrial Planets

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A planet's obliquity, which is the angle between its orbital angular momentum and its rotational angular momentum, is an important factor in determining its climate and habitability. For small obliquities, as well as obliquities close to 180 degrees, the planet receives more radiant energy from its star at equatorial latitudes than near its poles, whereas the poles are heated the most for obliquities near 90 degrees. Jacques Laskar has analyzed possible obliquity variations of the planets in our Solar System. His study also considers the same planets with different rotational periods, and the Earth without the Moon. He finds, using frequency map analysis, that the obliquity of the Earth is stabilized by the Moon, and can vary by at most a few degrees. In contrast, the obliquity of Mars can range from 0 to 60 degrees, and a hypothetical moonless Earth's axial tilt could be close to 0 degrees or as large as 85 degrees. Numerical integrations by Laskar and others have shown that Mars' obliquity indeed varies over most of its permitted range on time scales of tens of millions of years. In contrast, our analysis shows that the obliquity of a moonless Earth appears to be confined to the range of ~ 12 - 38 degrees over time scales of 100 million years. Results of ongoing longer integrations will be presented, and their implications discussed.

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The Influence Of Plate Tectonics On The Microbial Colonization Of Planetary Surfaces

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Plate tectonic processes, especially the intrusion of buoyant granite magmas into mountain chains at continental margins, allow the extensive crystallization of quartz in the Earth's crust. Erosion introduces the quartz into the sedimentary domain, where it is the predominant component. By contrast, planets without subduction experience less crustal differentiation and will have volcanic-dominated surfaces: Dune forms on Mars are believed to be dominated by volcanogenic grains, including feldspar, olivine, pyroxene, and glass. Sand-sized quartz grains are commonly translucent while most other minerals are opaque. This has a potential influence on the nature of land-dwelling microbial colonies in surface sediments, which is important as the uppermost millimetres of sediment beneath the surface are proposed as a favourable environment for any extant or past life on Mars, with protection from extremes of temperature and ultraviolet irradiation. There is a well-documented contrast in light penetration and resulting photosynthesis between light (quartz-rich) and opaque sediments. Soil science data imply that phototrophic microbes can occupy a depth many times as great in quartz sands. The high transmissitivity of quartz-rich sands allows colonization by phototrophic microbes in terrestrial environments as diverse as marginal marine and polar desert, where low levels of radiation reach 10mm depth. Phototrophic bacteria are most photosynthetically active under near-infrared radiation, so as longer wavelengths have greater depth penetration, the potential for colonization in translucent sand is realized to a maximum. Conversely, the high chemical reactivity of volcanic sands makes them more suitable hosts to chemoautotrophs which derive their energy from oxidation reactions.

Strategies for seeking microbial life on other planets by the detection of photosynthetic pigments, based on analogues in terrestrial quartz-rich sands should consider that an opaque mineralogy may engender distinctive patterns of microbial colonization.

72 Detectability Of Habitable Planets With The Space Interferometry Mission

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The Space Interferometry Mission (SIM) has design specifications that are sensitive up to a maximum of 1 microarcsecond (mas) precision astrometry. This precision would allow for the detection of terrestrial planets within our solar neighbourhood. If the Earth were viewed revolving around the sun from 10 pc away, it would cause an astrometric wobble of .6 mas. Based on the same standards, a minimum mass of 1.6 earth masses, $M_{\rm E}$, at 1 AU would be needed to be detectable around a solar mass star 10 pc away. A terrestrial planet with 5 $M_{\rm E}$, a three s detection threshold, is more realistic considering the satellite has not been built yet and the technology is still in the testing phase.

Stars selected by two key SIM projects were evaluated for the possibility of detecting a planet within the habitable zone, HZ, around the star. The possibility of detecting a habitable planet with SIM depends on the model used to define the HZ around the star. Planets in a HZ farther from a star cause a larger astrometric wobble and are therefore more readily detectable. The HZ for each star was computed using a radiative transfer model including approximations for the greenhouse effect, run-away glaciation, idal locking, stellar evolution and other possible effects on the HZ. Using this HZ, the minimum planet mass needed for detection around a given star was computed. This analysis allows for the ranking of the stars by habitable planet detectability, a key component for the SIM and TPF missions.

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The Effect Of Density Enhanced Structures Of A Nebula On The Formation Of Terrestrial Planets And Water-delivery Mechanisms

Nader Haghighipour, Carnegie Institution of Washington, Washington, DC The results of a study of the effect of the appearance of gas density enhancements in the habitable zone of a nebula on the rate of formation of planetesimals and protoplanetary embryos, and also the collisional coalescence of such bodies to terrestrial planets are presented. It has been shown that if during the evolution of the nebula, the density of the gas is locally enhanced, combined with gas-drag, pressure gradients can cause solids to rapidly migrate toward the location of maximum density (Haghighipour and Boss, 2003a&b). Such rapid migrations increase the accumulation of small solids, particularly around the midplane, and enhances the rates of their collisions and coagulation to larger objects. For instance, Haghighipour (2004) has recently shown that, as a result of sweeping up of the submicron-sized particles of the background material, dust grains can grow to centimeter-sized objects and settle on the midplane in a very short time. The rapid accumulation of such solids on the midplane increases the rates of their collision and coalescence to larger objects. Here, the results of an extension of Haghighipour's (2004) work to the formation of meter-sized and larger bodies such as planetesimals and protoplanetary embryos are presented and, within the context of the core accretion model, the application of the results to faster formation of terrestrial planets in the habitable zone of a sun-like star are discussed. The effect of gas-drag induced migration of asteroid- and comet-sized objects, and their collisions with habitable planets as a water-delivery mechanism is also presented.

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Exploring The Public's Understanding Of The Role Of Water In Astrobiology

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With recently successful Mars missions and profound announcements concerning the future of space exploration, the need to successfully communicate astrobiology's scientific findings has never before been such a high priority. Despite the numerous complex concepts involved in understanding and appreciating astrobiology research, scientists often find themselves in the challenging position of trying to describe these findings to the general public. Nowhere is this more critical than our current focus on the search for water on Mars. Ongoing research into conceptual understanding of non-scientists reveals that there are numerous naïve ideas regarding the importance of finding water that must be considered during formal and informal presentations. Our research focuses on how best to present the vital role of water in astrobiology to the general public. We find that although 90% of people can identify that water is important for life, few are able to demonstrate a robust understanding of why water is important. If astrobiologists wish to continue enjoying the public's support in our research endeavours, the public will need to have a more detailed appreciation of the significance of discoveries of the presence of water on extraterrestrial bodies. This work is being supported in part by NASA NAI-

Surface Uv Fluxes On Earth-like Planets Around F, G, And K Stars

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One of the characteristics that makes Earth's surface habitable is the fact that most of the ultraviolet (UV) radiation is blocked by the ozone layer. UV radiation can damage the cells and genetic material of modern organisms. If Earth-like planets exist around other stars they would need to have similar UV protection in order to be considered suitable for surface life, especially land life.

The photochemical model from Pavlov and Kasting (2002) was coupled with the radiative-convective climate model adapted from Pavlov et al. (2000) to reproduce the atmospheres of planets around an F2V (σ Bootis), a G2V (Sun), and a K2V (ϵ Eridani) star and determine the UV flux that would reach the surface of those planets. The simulated atmospheres contained variable concentrations of O_2 , from the present level (1 PAL) to 10^{-5} PAL. Oxygen molecules are dissociated by UV light, forming an ozone (O_3) layer and protecting life from this radiation. For atmospheres with 1 PAL of O_2 we find that the UV flux from the F2V star produces more O_3 on its planet $(1.56\times10^{19}~\rm cm^{-2})$ and therefore the 200-400 nm UV radiation reaching the planetary surface is 0.4 times that on Earth. At the same oxygen level the K2V planet receives 1.6 times more radiation than does Earth due to its thinner O_3 layer $(6.64\times10^{18}~\rm cm^{-2})$. At lower O_2 levels the ozone layers on all three planets become too thin to provide a significant UV shielding.

The relative effectiveness of different wavelengths in inducing damage is described by action spectra. The action spectra for erythema (skin cancer) and DNA damage were convolved with the surface UV fluxes and normalized to a dose rate of unity for Earth at 1 PAL of $\rm O_2$. The atmospheres of the F2V and the K2V planets offer better protection from UV damage than does Earth at high $\rm O_2$ levels. For $\rm O_2$ concentrations <10-2 PAL none of the planets looks habitable at its surface. At low $\rm O_2$ levels, planets around F stars are particularly at risk because of their high intrinsic UV luminosities.

Ozone is relevant on habitable planets not only as protection against UV radiation but as a possible spectroscopic biomarker (Segura et al, 2003). Therefore, our study will be extended to M stars in order to asses the ozone concentration produced by photolysis and the possible detection of this biosignature by the Terrestrial Planet Finder mission.

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Making Other Earths: Simulating The Formation Of Habitable Planets

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We present results from simulations of late stage planetary accretion, focusing on the delivery of volatiles (primarily water) to the terrestrial planets. Our simulations include both planetary "embryos" (defined as Moon to Mars sized protoplanets) and planetesimals. We investigate volatile delivery as a function of Jupiter's mass, position and eccentricity, the position of the snow line, and the density (in solids) of the solar nebula, which is a function of stellar metallicity. In addition, we simulate the formation of terrestrial planets in systems with "Hot Jupiters": gas giant planets very close to their parent stars, which have likely formed farther from their stars and undergone orbital migration.

In all simulations, we form 1-4 terrestrial planets inside 2 Astronomical Units (AU), which vary in mass and volatile content. In over 90% of the simulations we form a terrestrial planet between 0.8 and 1.5 AU, and in roughly one quarter of our simulations we form a potentially habitable planet between 0.9 and 1.1 AU. These planets range from dry worlds to ''water worlds' with 100+ oceans of water (1 ocean = 1.5×10^{24} g), and vary in mass between 0.23 and 3.85 earth masses.

We find that an eccentric Jupiter produces drier terrestrial planets with higher eccentricities than a circular one. In cases with Jupiter at 7 AU, we form what we call ''super embryos," 1-2 earth mass protoplanets which can serve as the accretion seeds for 2+ earth mass planets with large water contents. The composition and distribution of terrestrial planets in systems with "Hot Jupiters" is significantly different than for those in systems with giant planets past 4 AU. However, potentially habitable, Earth-like planets can form and remain on stable orbits in these systems.

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Planetary Cycles Of Life

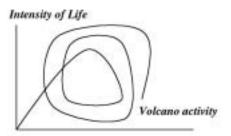
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Tracks of life on microorganism level are founded in the Earth at more and more exotic places. It indicates that life may arise in the Earth under various conditions and exist mechanisms creating of life. The role of such kind of creators may play volcanoes (Potashko 2004). As all planets pass through the stage of volcanic activity so all planets pass through the stage of life. Analogy between volcanoes and comets is applied.

Against panspermia

Current understanding of essence of life assumes that it's sufficient only to begin a life on a heavenly body + some conditions and life has to exist and evolve. The assumption is proposed that an existence of life on heavenly body is preconditioned by mechanism of continuous generating of life. It's impossible to pansperm the life. Life exists if there's a mechanism of producing it from the simplest forms. Life begins not from blank paper because any point of the Earth has definite physical and biological properties. The destiny of life on heavenly body depends upon volcanic activity (VA).



When volcanic activity is on the decrease on a planet – the life is on the decrease too.

Some of asteroids, which alter their orbits, may have volcanic activity. Therefore life probably is glimmering on these ones. If mission "Galileo" was turned off from Jupiter's satellite Europe hence landing on asteroid has to be considered from the point of a biocontamination view – like landing on the Eros.

VA blows life into a planet – from one side. From other side VA is a destroying force of biolife. Volcanic ashes in atmosphere during VA may close the Sun for months and years. As a result the planet temperature drops down sharply – scenario of the «nuclear winter», i.e. the biblical Flood. When the clouds will disappear intensity of life will grow –quantities of populations as well as individuals – it will take place «nuclear summer» (Andreev 2002). One may suppose this mechanism is responsible for the mass extinction 250 and 60 million years ago.

The crust of a planet of the Earth group is formed at the outer edge of the body. The planets after asteroid belt like Jupiter or Saturn probably form their "crusts" in the center of the body. Due to we may watch internal kitchen of element forming in detail. This processes lead to the organic life (Potashko 2003), which we may detect at their atmospheres of the planets: Jupiter, Saturn, Neptune, Uranus and Pluto. But their satellites look like earth planet group — with outer crust.

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Planet Formation In Binary Star Systems?

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Binary stars constitute about half of the stars seen in the night sky and so the question of whether or not they can support the formation of planetary systems similar to our own is an important one in the search for life outside our Solar System. Previous theoretical work suggested that binary star systems might not be able to permit the formation of planetary systems, because of the compressional heating associated with spiral arms and shock fronts driven in the stars' protoplanetary disks by tidal forces during the periodic close encounters between the two stars. As a result, the disks could

become too hot to allow solid bodies to exist, preventing planet formation by the collisional accumulation mechanism, and too hot for giant planets to form by the disk instability mechanism. If true, this theoretical work would rule out half the stars on the sky as being possible abodes for life. However, new theoretical models suggest that binary stars are quite capable of forming planetary systems similar to our own. The key difference in the new calculations appears to be the inclusion of the third (vertical) dimension in the hydrodynamic calculations, allowing for a new means of cooling the disks: vertical convection. Vertical convection appears to be capable of cooling disks on time scales (tens of years) short enough to permit protoplanetary disks to remain cool enough to form planets, even in binary star systems. 3D radiative hydro calculations of the evolution of an initially marginally gravitationally stable disk show that the presence of a binary star companion may actually help stimulate the formation of dense clumps that could become giant planets. Earth-like planets could also form in the inner regions by the traditional collisional accumulation of progressively larger, solid bodies.

Laboratory Studies Of The Photochemical Formation Of Organic Aerosols In CO₂-Rich Environments

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The photochemical processing of gases in the anoxic atmospheres of early Earth and Mars to form aerosols may have had a significant impact on their climate histories and, hence, on both the stability of liquid water on their surfaces and on their habitability. Our recent investigations have demonstrated that organic aerosols can be formed photochemically from pure methane1. If such photochemical particle production can also occur in CO₂- and N₂-rich atmospheres, such hazes may have provided a UV shield for UV-labile greenhouse gases such as ammonia and methane as well as for life at the surface^{2,3}. However, whether or not such organic hazes can form from the irradiation of CH4 in CO2-rich atmospheres has not been tested experimentally. Moreover, whether or not such hazes may have warmed or cooled the surface or serve as a UV-shield depend on the optical properties of the aerosols and their size distribution⁴, which have also not been investigated experimentally. As part of the BioMARS team, a University of California Berkeley-led NASA Astrobiology Institute, we have investigated photochemical processes that may lead to organic aerosol formation under atmospheric conditions relevant for early Earth and early Mars. We will present laboratory results showing that the formation of organic aerosols occurs at significantly higher CO₂/CH₄ ratios than previously expected.

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Exploring The Production Of Polycyclic Aromatic Hydrocarbons In Titan Hazes Using An Aerosol Mass Spectrometer

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Studies of organic haze aerosols analogous to those in the atmosphere of

Titan have been performed in the laboratory for many years, and the solid materials produced have been shown to provide an excellent match with the optical properties of Titan's haze (Khare, Sagan et al. 1984). There has been a great deal of interest in determining the chemical structure of the haze material as a key to understanding the complex chemistry of Titan's atmosphere. Recent results from laboratory simulations have observed a rapid formation of aromatic ring structures, suggesting that the formation of polycyclic aromatic hydrocarbons (PAHs) may play an integral role in haze production (Khare, Bakes et al. 2002). The observed PAHs may provide a mechanism for both the particle formation and nitrogen incorporation into the haze (Ricca, Bauschlicher et al. 2001).

We have conducted experiments simulating haze production on Titan and analyzed the resulting aerosols using an Aerosol Mass Spectrometer (AMS). The AMS, which provides real-time analysis of the chemical composition of the particles, has allowed us to examine their chemical structure without collection or exposure to laboratory air. Our results for Titan-like haze particles produced from a mixture of 10% CH4 in N2 show a strong presence of PAHs, consistent with previous results. Further, we have been able to identify specific PAHs present from the mass spectral signature. We have also studied how the particles vary as the CH4 is reduced to 1% and 0.1% levels. Here we find that the overall particle production rate decreases as CH4 is decreased. In addition, the appearance of the PAHs greatly diminishes, and the aromatic structures no longer appear to be a major contributor to particle composition. Thus, the chemical composition of Titan haze particles may be more sensitive to atmospheric CH4 concentrations than previously thought.

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Humans in an Astrobiological Context

An Investigation Into The Use Of Stretch Bands As An Alternative Means Of Exercise For Astronauts In The Microgravity Environment Of Space

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The aim of this research was to investigate whether a resistance band based exercise programme, designed to minimise the detrimental musculoskeletal effects of microgravity in Space is equally effective for both male and female subjects. The six week exercise programme devised targeted all major muscle groups, utilising Xer tubes for upper body and resistance elastic bands for lower body. These simple devices are economical to buy, easy to store and use on for e.g. the International Space Station (ISS) where space is at a premium.

Muscle hypertrophy served as an initial index of effectiveness, by providing a measurement of mean strength of improvement (%) for both male and female subject groups at post-training compared to the initial baseline measurements (pre-training). Strength was assessed by both isometric handgrip dynamometry, and cable tensiometry, together with isotonic measurements of 1 rep max chest press for upper body and squat for lower body. Both male and female groups demonstrated similar strength improvement in both isometric strength tests an the lower body isotonic test. However, the female group exhibited significant greater strength improvement in isotonic upper body strength (p>0.05). This maybe related to physiological gender differences. Importantly, lower body response was similar for both male and female groups, which has greater significance for astronauts since lower body musculature is more susceptible to microgravity induced muscle atrophy and bone demineralisation.

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The Outcomes Of Experiments For Impact Estimation Factors Of Cosmic And Geophysical Environment To The Human Organism State

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Real biological systems (including systems of human organs) develop and function under circumstances of constant Sun-Earth bonds and changing influence of cosmic environment and geophysical situation.

In a whole series of papers it have been observed the results of electrical conductivity of acupunctural points measurements in connection with state of solar and geomagnetic activity. The method of these investigations consists in using of Voll method, based on the electric characteristics changes of acupunctural points of human skin depending on the organism condition. For the detection of the solar-geophysical factors latitudinal dependence impact and account of local features, such measurements were begun on January-April and October-December 2002 in Odessa collaborating with IZMIRAN and they have been surveyed during coordinated time. In this paper we present the preliminary results which have been obtained during the realizing investigations. According to the temporal changes in Odessa during all this period it could be seen that different acupuncture points in the definite moments have reacted to the stresses coordinately. All observed period have been characterized by the similar solar and geomagnetic activity. The process of estimations every point's reaction changes during every month, respectively, have characterized by the certain trend, reflected the total process of solar and geomagnetic activity and distinctive reactions to the active events (solar flares, magnetic storms), according to specific results of measurements, which have been made in Odessa gravitational and magnetic anomalies.

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Hypersaline Environments

Elevated Nutrient Loading Increases Microbial Mat Gross And Net Oxygen Production In A Long Term Manipulation

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Subsequent to the evolution of oxygenic photosynthesis, the availability of nutrients likely posed a limitation to net carbon fixation by the biosphere. The relative difference in the rates of photosynthesis (which produces oxygen and requires nutrients) and respiration (which consumes oxygen and liberates nutrients) is the proximal control on the rate at which oxygen accumulated in the Earth's atmosphere. While phosphorus has been suggested to be the element limiting primary production on early Earth, nitrogen generally limits primary production in the modern marine environment. We have little experimental basis for assessing the effects of variable nutrient levels (P or N) on net productivity, and net oxygen production, in systems relevant to Earth's early history.

We examined the response of a modern hypersaline microbial mat to elevated nitrogen and phosphorus loading in a long-term greenhouse (Bebout, et al., 2002) experiment. Additions of phosphorus, and nitrogen were adjusted weekly to maintain water column concentrations of 200 μM (for N we maintained 100 μM ammonium and 100 μM nitrate). After 6 months, both gross oxygenic photosynthesis and net oxygen production in the mat were stimulated nearly two fold with increased phosphorus loading, and by ca. fifty percent by nitrogen additions. The ratio of production to consumption of organic matter in these mats therefore appears to have been preserved at nutrient concentrations greatly elevated from ambient.

Biological nitrogen fixation in the mat was stimulated by the P treatment, and nearly eliminated in the N treatment. Analyses are currently underway to determine if the aggregate community response that we observed was due to a shift in community composition, or changes in the activities of the organisms present.

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Resumption of Photosynthesis After Prolonged Desiccation in an Intertidal Cyanobacterial Mat

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In the intertidal zone near Guerrero Negro, Baja California Sur, there exist extensive microbial mats dominated by cyanobacteria. These mats are desiccated for prolonged periods of time and are only hydrated during extremely high tides. When the tides recede and the remaining water evaporates, the mats can experience extreme osmotic and temperature stress as well as the ever-present stress of solar irradiation with ultraviolet radiation (UVR). These extreme conditions also prevent the existence of invertebrate grazers, allowing the mats to expand throughout much of the intertidal. We conducted experiments to determine how certain environmental factors (i.e. salinity, light intensity and UVR) affect the recovery of photosynthesis in desiccated cyanobacterial mats immediately after rehydration. Under optimal conditions, the mats recovered their photosynthetic ability within 30-60 minutes after rewetting. The cyanobacteria appeared to regenerate their photosystems in the dark, and thus were prepared for future light exposure. However, the onset of photosynthetic recovery was delayed under lower light intensity. UVR did not have an effect on photosynthetic recovery. This is probably because the cyanobacteria contained a large amount of the UVR blocking pigment scytonemin. The effect of salinity on recovery was more complex. Although very high salinity (i.e. 75-100ppt) seawater was detrimental to the cyanobacteria, optimal salinities for photosynthetic recovery appeared to be near that of seawater but absolute optima fluctuated from mat to mat. It is interesting that even though these mats spend the vast majority of their existence desiccated or in suboptimal conditions, they are not only able to maintain mat composition but grow and rapidly colonize exposed substrate.

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Lipid Biomarkers For A Hypersaline Microbial Mat Community

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The use of lipid biomarkers and their carbon isotopic compositions are valuable tools for establishing links to ancient microbial ecosystems. Various lipids associated with specific microbial groups can serve as biomarkers for establishing organism source and function in contemporary microbial ecosytems (membrane lipids), and by analogy, potential relevance to ancient organic-rich sedimentary rocks (geolipids).

As witnessed by the stromatolite record, benthic microbial mats grew in shallow water lagoonal environments. Our recent work has focused on lipid biomarker analysis of a potential analogue for such ancient mats growing in a set of hypersaline evaporation ponds at Guerrero Negro, Baja California Sur, Mexico. The aerobic, surface layer of this mat (0 to 1 mm) contained a variety of ester-bound fatty acids (FA) representing a diverse bacterial population including cyanobacteria, sulphate reducers (SRB) and heterotrophs. Biomarkers for microeukaryotes detected in this layer included sterols, C₂₀ polyunsaturated FA and a highly branched isoprenoid, diagnostic for diatoms. Cyanobacteria were also indicated by the presence of a diagnostic set of mid-chain methylalkanes. C₂₈ to C₃₄ wax esters (WXE) present in relatively small amounts in the upper 3 mm of the mat are considered biomarkers for green non-sulphur bacteria. Ether-bound isoprenoids were also identified although in considerably lower abundance than ester-bound FA (~1:10). These complex ether lipids included archaeol, hydroxyarchaeol and a C_{40} tetraether, all in small amounts. After ether cleavage with boron tribromide, the major recovered isoprenyl was a C₃₀: . This C₃₀₋₁yielded squalane after hydrogenation, a known geobiomarker for hypersaline environments in ancient oils and sediments. In this mat, it represents the dominant Archaeal population.

The carbon isotopic composition of biomarker lipids were generally depleted relative to the bulk organic material (δ^{13} C TOC -10‰). Most depleted were the cyanobacterial methylalkanes at -27‰ with FA such as the SRB biomarker, 10-methylC ₁₆, somewhat heavier at -16‰, and WXE at -17‰. The C₃₀₋₁ isoprenyl was most enriched with δ^{13} C in the -7 to -11‰ range, much too heavy to represent the methanogen population responsible for mat methane values measured at -60‰.

A Molecular View Into Hypersaline Microbial Mat Communities: Vast Diversity, Unexpected Composition, Discrete Structure

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The hypersaline microbial mats of Guerrero Negro, Baja California Sur, Mexico, are model ecosystems to understand the links between microbial community composition and biogeochemical cycles. As part of a large interdisciplinary study by the NASA NAI EcoGenomics Focus Group, we have described the microbial community composition of a hypersaline mat using a culture-independent molecular phylogenetic approach combined with fluorescent in situ hybridization (FISH), biomass and pigment analyses. We cloned and sequenced 2500 SSU rRNA genes, using "universal" and bacteria-specific primers, out of community DNA extracted from distinct layers to form a complete depth profile. Our survey revealed 1) Vast diversity: the majority of sequences are unique and previously unknown, with 24 bacterial phylogenetic divisions represented; 2) Unexpected composition: sequences belonging to the Green Non Sulfur (GNS) bacteria dominate (30-40% of clones) at all depths, and 3) Spatial organization throughout the mat: members of individual bacterial divisions and their subgroups show discrete depth distributions. Bacteriochlorophyll distibutions obtained by HPLC corroborate the rRNA spatial distributions. Members of the GNS were seen in very tight associations with the conspicuous "mat building" cyanobacterium Microcoleus by FISH and laser confocal microscopy. Ongoing research includes quantitation of specific groups by rRNA hybridization and real-time PCR. This extensive molecular survey of the microbial mat community offers an entirely new and unexpected view of the community and will inform our interpretations of biogeochemical data.

Diversity and dynamics of methanogenic Archaea within benthic cyanobacterial mats

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The evolution and dynamics of methane-producing microorganisms over Earth's history is thought to have significantly influenced the evolution of the Archean atmosphere and early Earth ecosystems. The study of modern day analogs of these ancient ecosystems can provide us with important insight into the biological and physico-chemical factors influencing biosignature formation (i.e. methane) in the rock record. Recent biogeochemical investigations of cyanobacterial mats, a prominent early Earth analog,

have demonstrated active methane production and unique methanogen community dynamics associated with benthic mats from hypersaline ponds in Guerrero Negro, Baja California Sur. These observations include concurrent methane generation and active sulfate reduction and active methanogenesis within and/or adjacent to the aerobic photosynthetic layers of the mat. These findings indicate that the generation of methane within these highly productive photosynthetic mats is complex, and introduces the potential for unique adaptive strategies by methanogens. Using a combination of 16S rRNA and methanogen-specific methyl-coenzyme M reductase (mcrA) gene surveys, fluorescent in situ hybridization assays, ¹³CH₄ analysis and characterization of ether-linked isoprenoids, we examined the diversity, spatial relationships and substrate utilization profiles of methane-producing Archaea in field-collected mats and in microcosm experiments using a range of competitive (H2, acetate, formate) and noncompetitive (trimethylamine) methanogenic precursors. Archaeal 16S rRNA and mcrA gene analysis demonstrated the presence of diverse methanogenic assemblages, representing at least three distinct genera grouping within the order Methanosarcinales, as well as an abundance of uncultured members of the Thermoplasmales and Crenarchaeota. Culture-independent diversity surveys indicate segregation of the different methanogen populations by depth and preliminary isotopic and geochemical evidence suggest different substrate utilisation patterns in the surface and deeper layers of the mat.

As The Salinity Cycle Turns: Methane Production In The Hypersaline Mats Of Combate, Puerto Rico

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Methane is a low molecular weight carbon compound with substantial potential for impacting atmospheric chemistry. As a biogenic signature, methane is important to interpretation of atmospheric data by remote observation, and on smaller scales, short-term fluctuations in methane concentrations may indicate changes in production rates.

Microbial mats present the modern analogue of the oldest ecosystems known on Earth. Fluctuations in physico-chemical parameters associated with mats across geographical and temporal scales make them ideal for studying fluxes of methane. Hypersaline mats epitomize systems with physical characteristics that may present additional stressors on constituent organisms. Research on hypersaline mats in the tropical system in Combate, Puerto Rico, has led to development of a conceptual model in which these mats undergo a salinity "cycle" described by dramatic changes in production and flux rates of methane.

The dynamics of methane production were studied across a salinity "cycle" [three stages: early (30ppt), middle (150ppt), late (350ppt)]. In situ studies with flux chambers show higher daytime than nighttime fluxes. At high salinity, the flux approaches zero [(-)0.005 – (-)0.22umol m²h¹], while at low salinity, the flux is approximately 1.5 – 2.7umol m²h¹. Slurry experiments were conducted with organic amendments and inhibitors; production and consumption data from these homogenized systems provided additional detail about methane dynamics. At high salinities, methane production ceases, although populations of methanogens persist. Methane consumption was not demonstrated in any sample. Mats appear capable of rapid recovery when the stress of hypersalinity is removed.

Results of this study provide insight into the life strategies microbes may have used in early Earth systems, which were likely characterized by dramatic environmental fluctuations. Ultimately, our results may assist in interpreting fluctuating methane concentrations as biogenic signatures in extra-planetary atmospheres.

Minerals As A Permanent Biogenic Record In Hypersaline Microbial Mats

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Cyanobacterial microbial mats typically display extremely high metabolic rates, which result in rapid element cycling. The carbon cycle plays a dominant role in energy transformations from phototrophs to heterotrophs through redox changes of C. These changes are facilitated by electron donors and acceptors, which, in hypersaline systems, are predomiantly O and S compounds. Despite a tight connection of element cycles, temporal and spatial decoupling of certain metabolic reactions (e.g., photosynthesis,

sulfate reduction) occurs. This results in the potential production of biogenic signatures, including gases and minerals. Such signatures may facilitate remote detection and interpretation of extraterrestrial life forms.

We investigated the distribution of carbonates in a variety of hypersaline mats (Cabo Rojo, Puerto Rico, Guerrero Negro, Mexico, Lagoa Vermelha, Brazil, Eleuthera, Bahamas) and modern marine stromatolites (Exumas, Bahamas). Direct microbial production (precipitation exceeding dissolution reactions) and indirect precipitation (through modification of the physicochemical environment) are key processes that facilitate carbonate precipitation. Moreover, a variety of minerals, ranging from aragonite to high-Mg calcite and dolomite, are produced, depending on local physicochemical and microbial characteritics. No single mechanism emerges, although characteristics of the exopolymeric substances (EPS) and the activity of sulfate reduction played a key role in all systems that were investigated. Geochemical alterations of microenvironments within the EPS matrix, notably by sulfate-reducing and sulfide-oxidizing bacteria, produce increased ion concentrations (Ca, Mg, carbonate) and facilitate pH changes that ultimately favor mineral precipitation. Although further diagenetic processes may alter these biogenic minerals, they can be preserved in the permanent rock record and possibly act as dipsticks for life, on Earth as well as on other planets.

Expression Profiling Of The Microbial Mat Organism: Microcoleus Chthonoplastes

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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. Assemblages of these microorganisms, which have demonstrated the ability to adapt to extreme conditions, are likely candidates in the search for life forms in habitable zones beyond Earth. While a number of studies have helped inventory the microbial diversity found in the Guerrero Negro mats, we have little understanding of the specific mechanisms enabling the organisms to function in their environment. To address this question at the genomic level, we have constructed a microarray-based system to study cyanobacterial expression patterns of *Microcoleus chthonoplastes*. Our array consists of 1090 unique *Microcoleus* cDNA clones and has been successful in monitoring cyanobacterial gene expression in response to a number of environmental conditions.

Salinity flux is a significant environmental stressor in microbial mat communities. *Microcoleus chthonoplastes* found in Guerrero Negro mats are regularly exposed to salinity values in excess of threefold as compared to open ocean. We employed our microarray to examine the ability of *Microcoleus* to adapt to salt shock. Cultures were placed in media either 200% normal salinity (70ppt) or 10% normal salinity (3.5ppt). We harvested cells at 1 hour and 3 hours after initial shock. Significant data (within 1 SD across multiple internal hybridization and flip-dye replicates) compiled from multiple reiterations resulted in a profile demonstrating changes in the expression of components from signal transduction pathways, heat and general shock response, and metabolism. While these experiments focus specifically on *Microcoleus*, ultimately we will apply this approach to examining global expression patterns of the entire interrelated mat community.

Mars

Public and media reactions to 2003/2004 Mars missions: A case for the Internet as the primary source of astrobiology-related news

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Public and media reaction to the Mars mission in December, 2003 and January, 2004 suggest that non-Internet based mass media was insufficient in quenching public demand for immediate information. A billions hits were recorded on NASA's web portal (Platt and Jacobs, 2004) in the four

days during the landing of the Mars Exploration Rover Spirit – equivalent to around four hits for every man, woman and child in the US. It perhaps reflects a growing trend in use of the Internet as an immediate news source and that the Web is emerging as a new mass medium for science news. This is in line with National Science Foundation findings that show a growing number of the public use the Internet as their primary source of science news (National Science Foundation, 2002). A similar picture exists in Europe (Eurobarometer 55.2, 2001). And in the UK, the major science communication report Who is Misunderstanding Whom? says the mass media should not be regarded as it is, but as it is becoming (Hargreaves, 2000). This paper examines the Internet communication strategies of NASA and ESA for the Mars missions compared to the response of Internet based news organisations such as CNN, space.com and spaceflightnow.com. What are the implications for the public communication of astrobiology if the opportunity exists for direct contact with a range of audiences far greater than is possible via the mass media - and without the process of interview and interpretation of science news by a science journalist?

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Survival of seven Bacillus spp. under simulated Mars UV irradiation suggests minimal forward contamination around landing sites

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Six Bacillus spp. recovered from the Odyssey spacecraft during prelaunch processing were used with a lab standard, Bacillus subtilis HA101, to develop kill curves of the spore-forming bacteria under Mars-normal UV irradiation. The Bacillus spp. used in these tests were: B. subtilis HA101, B. subtilis 42HS-1, B. pumilus SAFR-032, B. pumilus FO-36b, B. licheniformis KL-196, B. megaterium KL-197, and B. nealsonii FO-092. The bacteria were prepared as thin monolayers on aluminium coupons according to the procedures of Mancinelli and Klovstad (2000) and Schuerger et al. (2003). The Mars-UV irradiation model was based on the work of Schuerger et al. (2003) and delivered 9.78 W m⁻² (35.2 kJ m⁻² hr⁻¹) to bacterial monolayers simulating an optical depth (tau) of the Martian atmosphere of 0.5 at the equator. Dried endospores of each species were exposed to Mars UV irradiation for time-steps of 0, 0.25, 0.5, 1, 5, 15, 30, 60 or 120 min. The surviving endospores were then assayed with a most probable numbers (MPN) procedure adapted from Schuerger et al. (2003). Results indicated that B. pumilus SAFR-032 was the most resistant, and B. subtilis 42HS-1 and B. megaterium were the most sensitive of the seven strains exposed to simulations of Mars UV irradiation. Bacillus subtilis 42HS-1 and B. megaterium were inactivated after 30 min exposure to Mars UV, while B. pumilus SAFR-032 required >120 minutes for full inactivation. However, although the various Bacillus spp. exhibited diverse levels of UV resistance, none were immune to Mars UV simulations, and, thus, all species would be expected to be inactivated on sun-exposed spacecraft surfaces within a few tens of minutes to a few hours on Sol 1 after landing under clear-sky conditions in the equatorial regions of Mars.

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Subsurface Studies Of Mars-like Soils In The Atacama Desert, Chile

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In order to search for evidence of extinct or extant life on Mars, NASA is planning to send a smart Lander/rover capable of drilling and retrieving soil samples at depths of some centimeters to meters in 2009. We have recently described the existence of Mars-like soils in the extreme arid core of the Atacama Desert (Narvarro-González et al. 2003). These soils contain organic species at trace levels, extremely low levels of culturable bacteria; no recoverable DNA, and indications of the presence of as-yet-unidentified oxidant(s).

Studies reported to date have concentrated on the top surface layer of these soils. In order to examine the subsurface properties of these Marslike soils we constructed a soil pit approximately 1 meter deep within the core region previously studied. Samples were obtained at 10 cm intervals from 5 cm below the surface to a depth of 85 cm. The samples were tested for the presence of organic material and the total cfus for heterotrophic bacteria were determined. In the layers at 45 cm and below an increase in total organic material was observed using the oxidation titration method. These organics are currently being characterized using prolysis-GC-MS. No bacterial colonies were recovered from the majority of the layers plated on a variety of culture media. In some cases <10 bacterial colonies were recovered representing levels below the detection limit of the dilution plating method used. A number of organisms were recovered from liquid media enrichment cultures and have been shown to be similar to those reported previously from the surface layer (Narvarro-González et al. 2003). The presence of organic material in the lower layers may indicate the oxidant (s) do not penetrate to these lower levels. These data imply that the subsurfaces of Mars should be explored for evidence of life or past life forms.

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Dispersion of tracers in the Martian upper troposphere following large impact-cratering events

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Hypervelocity impacts on Mars inject particles of dust and water vapor into the upper troposphere/lower stratosphere, where the particles can be advected and mixed into complex dispersion patterns. By serving as condensation nuclei, the impact-generated particles could drive intense weather patterns far away from the impact site, and perhaps even trigger transient climate changes. Using a high-resolution, global shallow-water model which assimilates winds from a full Mars general circulation model, we investigate the dynamical mechanisms that control the dispersion of aerosols in the Martian upper troposphere/lower troposphere. In particular, we study the spreading rates, dispersal extent, and the potential for meteorological and climatological perturbations from medium to large sized (~10 to 100 km) impactors. We find that, because of the non uniformity of the resulting distribution pattern, a 1-D climatological response model is

somewhat appropriate only for the rare giant basin forming impacts, which load the atmosphere globally on impact. For smaller impacts, concentrated local regions of particles form in the impacted hemisphere, persisting over weather timescales (~1 week); these regions may mark areas of precipitation.

An Impact-Triggered Runaway Greenhouse on Mars

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The principle of the "runaway greenhouse" has been studied for many years. If the incident solar flux to a planet increases, and water is no longer stable on the planet's surface, the water will evaporate into the atmosphere. The added greenhouse from the water vapor will increase the surface temperature, which will in turn evaporate more water into the atmosphere. This of course increases the optical depth of the atmosphere, permitting less radiation to escape to space, until all of the planet's liquid water is in the atmosphere, and none remains on the surface. At this point, the planet has "run away." Analytical solutions to the equations discussed by Nakajima et al. (1992) show that there is a region in flux and temperature space where there are actually two stable solutions. One solution corresponds to a planet in the runaway state (warm) and the other solution corresponds to a planet in a stable state with respect to water vapor (cool). Both are stable and correct. The warm solution can only be reached if there is a significant temperature perturbation to the system. One way a planet can experience this perturbation is if it is struck by a large asteroid or comet. Large impact events are capable of raising a planet's surface temperature by 1000s of degrees and melting and evaporating surface and subsurface water (Segura et al. 2002). If the water released by such an event can be evaporated to the atmosphere quickly enough, the planet might run away. This research explores the different regions of phase space and speculates on how large an impact would be required for a given planet such as Mars. If this speculation is correct, any terrestrial planet could experience a runaway if struck by a large asteroid or comet.

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Air Blasts Provide A Feasible Method Of Clearing Rock Cuttings From Holes On Mars.

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Future Martian missions call for subsurface sampling, probably by mechanical core drilling. Drilling consists of two steps namely, rock breaking and the removal of cuttings. If the cuttings are not cleared quickly, they will be ground down, reducing drilling efficiency and causing excessive drill bit wear or bit stalling in an extreme case. Although the efficiency of rock removal is fairly constant, the power needed for cuttings removal will increase with hole depth and so an efficient cuttings removal system is essential for drilling success.

On Earth, rock cuttings are removed via circulating water, mud or compressed air. On Mars, no fluids can be used due to weight constraints and due to extreme temperature and pressure conditions. Compressing the thin Martian atmosphere to useful pressure levels for continuous air circulation may be prohibitive. However, periodical blasts of air could be effective in clearing the cuttings. This was proposed by others (Blacic et al. 2000) but never tested. This paper reports that tests conducted under Martian conditions proved that one litre of gas at differential pressures of up to ten times the Martian pressure could clear at least 30 grams of cuttings

from depths of 25 cm or more. This could be adequate for a wireline drilling arrangement. The experiments also showed the existence of a threshold pressure below which no cuttings were cleared and above which the majority of cuttings were removed. This threshold pressure depended on the initial quantity and on the size distribution of the cuttings.

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Water And Salts On Mars: Proof In The Martian Meteorites

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Data from the Mars Rover 'Spirit' [1], along with recent orbital data [2], indicate the presence of carbonates and possibly other salts. Previous studies have shown a definite martian origin for some carbonates (along with other salts and secondary phases) in certain Mars meteorites [3-5]. Several types of evidence have been used; our ongoing studies are based on SEM petrology. This work yielded the first unambiguous proof of carbonates (also Ca-sulfates) on Mars; i.e., impact-generated glass, which could not have formed after the meteorite (EETA79001) was ejected from Mars, contained micrometer-scale inclusions of these phases [3]. Subsequent studies of several Mars meteorites by our group and others [e.g., 4, 5] have continued to show evidence for aqueous alteration and salt deposition on Mars. In addition to proven martian phases, others (e.g., halite) may also be martian but current data are ambiguous [4]. Mars meteorites, including SEM-scale information, will continue to provide a critical contribution to understanding the near-surface environment on Mars.

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Examination Of Martian Subsurface Microenvironments Via Meteorite Studies: Suitable For Microbial Lifeforms?

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Much uncertainty surrounds questions concerning the size, disposition, and duration of water reservoirs at the surface of Mars. Scientists continue to focus their attention on these issues because of their implications for the shaping of the martian surface and the possibility for development (and subsequent evolution?) of simple extraterrestrial lifeforms in waterbearing regions of the planet's crust. Because of the extreme technical challenges posed by martian exploration, sample return missions have not yet been realized; as a result, the most detailed and first-hand information available regarding the martian hydrosphere is contained in preterrestrial aqueous precipitates in martian meteorites (Gooding et al., 1991; Treiman, 1993). We have employed electron- and ion-imaging and microanalytical techniques to gain an understanding of water-rock interactions beneath Mars. The information derived from such investigations of secondary minerals in nahklite meteorites can be used to constrain the type, nature, and sequence of the rock altering fluids and therefore, the suitability for those fluids to have supported microbes.

Alteration veinlets in olivines within the Lafayette meteorite retain evidence for an early fluid-rock reaction that resulted in the low temperature deposition of Fe²⁺- and Ca-rich carbonate (Vicenzi et al., 1997). A more oxidizing silicate-bearing fluid subsequently caused the partial dissolution of carbonate and precipitated amorphous Fe-and Si-rich silicates. In a final phase of secondary mineralization, Fe³⁺-rich clay minerals crystallized as a result of a reaction among the earlier formed amorphous phases.

The overall stability of these materials, their microstructure, and their mineral chemistries, require that these secondary materials formed in a low temperature (<100°C) aqueous environment which is consistent with earlier studies (Romanek et al., 1998; Treiman, 1993). Importantly, the veinlets containing alteration products contain Fe in multiple redox states, in addition to S released from the breakdown of Fe-sulfides, that could serve as suitable energy sources for hungry microbial lifeforms.

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We would like to acknowledge the enthusiasm and creativity Rob Hargraves expressed for Mars science. He is responsible for engaging us in deciphering the Martian meteorite record, and his passing in 2003 means our community will be poorer for the loss.

Lethality Of Martian Exposure Of Organisms To Large Solar Flares

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A Monte Carlo code for calculating the transport of high-energy irradiation of planetary atmospheres has been used to study the radiative transfer and surface biological dose spectra on contemporary Mars due to solar flares. The flares are parameterized by their total energy and the peak of their X-ray spectrum. We find that most of the energy reaches the surface as X-rays due to photoabsorption and Compton scattering, with a characteristic spectrum that is essentially independent of atmospheric composition. We calculate the biological dose per unit flare energy for water absorption of the ionizing radiation, and we estimate the frequency of biologically significant flares from the Sun at Mars as a function of time using present-day flare statistics and studies of solar proxies of various ages. Although intermittent, during flare outbreaks the calculated doses are orders of magnitude larger than for Galactic or Solar cosmic rays, especially if the peak in the flare spectrum is larger than about 10 keV. The sterilization of exposed organisms at the Martian surface is discussed using lethal dose data for a large number of prokaryotic and eukaryotic terrestrial organisms.

Chemical Characterizations Of Atacama Desert Soils: An Analog Of Martian Surface Chemistry

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Proton-Induced X-Ray Emission (PIXE) and Cyclic Voltammetry (CV) studies have been carried out on soil samples collected along a north-south transect (~70° W longitude) in the Atacama Desert, which is located along the northern Chilean pacific coast (from 30°S to 20°S latitude). Soils collected from the driest regions (24°S) of the Atacama were reported to be essentially free of organic matter based on flash pyrolysis GCMS analysis (Navarro-González et al. 2003). This condition of organic-depleted and nearly sterile soil is a remarkable Earth analog of the martian surface material. Micro-PIXE was used to create 2-D elemental maps, with 2.5 micron resolution, of the soils collected along the transect. In conjunction with the elemental information provided by the PIXE studies, we have characterized the redox behaviour of the same soils using cyclic voltammetry.

The motivation for this work is to perform quantitative site characterizations of soil chemical processes to allow further development and field validation of the Mars Oxidant Instrument (MOI) and the Mars Atmospheric Oxidant Sensor (MAOS). MOI and MAOS are in situ survey instruments designed to establish the presence of reactive chemical species in the martian soil, dust, or atmosphere, and to provide detailed reaction model system measurements to enable comprehensive Earth-based study. Functioning as survey instruments, MOI and MAOS test the broad range of hypotheses explaining the reactivity of the martian surface material that have been put forth since the Viking experiments.

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Exploring Martian Subsurface

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Due to Martian surface temperature range and low atmospheric pressure, surface liquid water is not stable. Extant life should be strongly dependent on the presence of stable liquid water and, energy sources available. The existence of Martian subterranean biomass, shielded from the UV radiation, protected by the depth from the strong oxidants probably present on the surface and in the first layers of the reolith, is supported by the Whitman, Coleman & Wiebe (1998) suggestion: the terrestrial subterranean biomass may be equal or greater than the surface one.

Subsurface Martian organisms should have an abundant flux of energy generated by a significant source: the oxidation of CO and $\rm H_2$ (both photochemically produced in the atmosphere), able to penetrate 100- to 1,000-m deep, where most $\rm H_2O$ is probably frozen except near hydrothermal systems; the availability of stable liquid water may be the main limiting factor of the biological activity (Weiss, Yung & Nealson 2000).

The concentriion peeks of Martian subterranean life (pockets of life) are sinks of atmospheric photochemical produced CO, $\rm H_2$ and sources of CO $_2$, $\rm H_2$ 0. A careful observation of the atmospheric mixing ratios deviations (local scale) from the equilibrium values computed by the Nair model (Nair, Allen, Anbar, Yung & Clancy 1994) is a step in the pockets of life detection (Weiss, Yung & Nealson, 2000). The first step is the careful examination of thermal, geological and water data to localize areas where subsurface liquid water should be avaiable. The method can be extended or adapted to other gases.

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Can Microbes Live Beneath The Surface Of Mars? Clues From The Meteorites.

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<For subsurface life to exist on Mars, either now or in the past, several requirements must be met by the subsurface environment: a] the presence of H₂O, b] a temperature range allowing the H₂O to be liquid at least part of the time in favourable subsurface environments, c] a suitable physical volume or space allowing growth of microbes and movement of nutrients and metabolic products, d] the presence of organic compounds or the building blocks to make them, and e] the presence of an energy source suitable for

use by the microbes to drive metabolism and growth. Evidence from the martian meteorites shows that these conditions were met within the martian subsurface at multiple places and over much of martian geologic time.

<This evidence consists of cracks and pore space in many of the meteorites that have been filled with a wide variety of secondary minerals precipitated from liquid water [meeting requirements a, b, and c]. This secondary filling of cracks has been well documented to have occurred on Mars before the meteorites were blasted off into space and landed on Earth (1,2,3). In addition, most of the analyzed martian meteorites contain organic compounds indigenous to Mars.[meeting requirement d] and the multiple redox states of iron and sulfur within and among the secondary minerals (Fe sulfides, Fe and Ca sulfates, magnetite, hematite, smectite, carbonate, etc.) show that redox energy was available for microbial metabolism [meeting requirement e]. Several possible terrestrial analogs exist for such subsurface environments.</p>

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Dating Method Of The Martian Permafrost Using Isotopic Ratios Of The Dissolved Gases

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We propose a new method to determine the timing when the water on Mars was frozen. The method is based on measurements of isotopic ratios of gases dissolved and (trapped) in ice.

Mars-Odyssey mission discovered ice and/or permafrost with high ice content under Martian surface. During water-freezing events dissolved atmospheric gases could be "trapped" in ice. Abundance of the dissolved gases depend on their chemical composition and atmospheric partial pressure. However, the composition of the Martian atmosphere was changing in time. Therefore, by measuring dissolved gases we can reconstruct the age and conditions when the freezing took place.

The most promising ratios to measure are $^{15}N/^{14}N$, $^{36}Ar/^{38}Ar$, $^{40}Ar/^{36}Ar$. They do not depend on chemical processes on the planetary surface. These ratios are set by the rate of non-thermal escape and the rate of outgassing . At present, isotopic ratios of $^{15}N/^{14}N$, $^{36}Ar/^{38}Ar$ in the Martian atmosphere are 1.6 and 1.3 times higher than the terrestrial ones although the isotopic compositions of sources of these gases should have been similar on both planets. Our estimations show that we can determine the age of the last contact of the liquid water with the Martian atmosphere with the accuracy of $10{-}100~Myr$.

³He accumulated in the Martian ice is another potential candidate for the age determination of the freezing events. ³He is produced by the intensive flux of the cosmic rays at the Martian surface. To implement this tracer in the Martian missions we propose an effective method of gas-extraction from ice (including selective extraction of He) followed by mass-spectrometric analysis. We estimate the range of ³He dating method as 10⁵-10⁸ yr

Using the proposed method, we can also reveal the imprints of ancient biological activity by measuring biogenic gases like $\mathrm{NH_3}$, $\mathrm{CH_4}$, $\mathrm{H_2S}$, which are virtually absent in the modern Martian atmosphere. Those gases are subject to quick oxidation in the Martian soil. However, ice and permafrost are good environments for the preservation of these gases.

Exploring Martian Subsurface

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existence of Martian subterranean biomass, shielded from the UV radiation, protected by the depth from the strong oxidants probably present on the surface and in the first layers of the reolith, is supported by the Whitman, Coleman & Wiebe (1998) suggestion: the terrestrial subterranean biomass may be equal or greater than the surface one.

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Analytical Protocols For Analysis Of Organic Molecules In Mars Analog Materials

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A range of analytical techniques and protocols that might be applied to in situ investigations of martian fines, ices, and rock samples are evaluated by analysis of organic molecules in Mars analogues. These simulants from terrestrial (i.e. tephra from Hawaii) or extraterrestrial (meteoritic) samples [1,2] are examined by pyrolysis gas chromatograph mass spectrometry (GCMS), organic extraction followed by chemical derivatization GCMS, and laser desorption mass spectrometry (LDMS). The combination of techniques imparts analysis breadth since each technique provides a unique analysis capability for certain classes of organic molecules.

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Chemical Evolution On An Early Mars: Implications For Mission Planning

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Due to the universality of chemical physics, the geophysical/chemical processes most likely to have supported chemical evolution on the early Earth are equally likely to have been found on a wet early Mars; and to accompany any more recent Martian hydrological episodes (Lerman

2004). The key to this is the bubble-aerosol-droplet supercycle (Lerman 1992). Based on physical chemical phenomena it requires only an airwater interface disturbed by a turbulent transport of energy from waves, meteorites, or geophysically active regions. Indeed, lacking a robust tectonic history, on Mars this supercycle is the only likely provider of the functional requirements in support of prebiotic chemical evolution. (Lerman 2004b).

Natural consequences of the terrestrial bubble-aerosol (bubblesol) supercycle are objects with morphologies and gross compositions fascinatingly akin to the so-named 'nanobacteria' of ALH 84001. These properties include the basic morphology (spheres and sausages), gross chemistry (suites of organics along with metals), and size distributions (nanometers to microns). Whether of biological or bubblesol origin, these striking similarities are due to the universality of the chemical physics involved in the interactions of charge-polarized organic amphiphiles at an air-water interface, coupled to the ubiquity of such scalable macroscopic physical phenomena as the Rayleigh-Taylor instability (Lerman 2002a,b).

With respect to the scientific concerns of mission planning for Mars the following points thus become critical:

- 1) The finding of bubblesol-generated objects (of Martian origin) in Martian meteorites or on Mars itself is by itself strong evidence for the existence of a complex Martian hydrology cycle capable of gathering, concentrating, and transporting organics.
- 2) The presence of such bubblesol objects in (or from) an extraterrestrial location would demonstrate that substantial environmental opportunities have existed for the support of prebiotic chemical evolution.
- 3) Specifically, on the tectonically simple early Mars (one having liquid water intermittently on its surface), such a complex hydrology cycle may well have been the only initiator and supporter of the rapid cycles of concentration, hydration, and dehydration necessary for organic polymerization in 'bulk' quantities.
- 4) Given the likely limited time scales of free surface water on Mars (days to years), the time scales of the bubblesol processes are likely to be the only ones capable of supporting the iterative cycles of concentration and selection necessary for chemical evolution.
- 5) Thus if chemical self-organization occurred on Mars it was likely to be a consequence of a bubble-aerosol cycle analogous to the terrestrial.
- 6) Therefore any life-searching Mars missions (or interpretations of Martian objects having made their way to Earth) must discriminate between the fossils of living systems at the nanobacterial scale and potential artifacts of the bubble-aerosol cycle necessarily found on any planet, planetoid, or satellite having both liquid water and amphiphiles (Lerman 2004a).

Additionally, IF bacteria (with surface active membrane elements) have existed on Mars, and were in any way tied to a surface liquid water environment then these same bubblesol processes could have been a prime mode of concentration and aerial transport. In analogy to current terrestrial processes the larger of these bubblesol-generated objects (in their hydrated state) could easily have transported such bacteria across a mostly arid planetary surface. This would have been useful for 'colonization', and could also explain the deposition and subsequent fossilization of "micro-clumps" of such bacteria in environments much removed from their origin.

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Identification Of Martian Biota Using Their Radioresistance Ability And Specific Isotopic Composition.

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Because of a thin atmosphere and weak magnetic field, Martian surface is a subject to high levels of ionizing radiation. On the other hand, variations in Martian obliquity produce the global climate oscillations (with the main period ~120000 years) of the great magnitude. 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. Therefore, all types of hypothetical Martian microorganisms living in subsurface layers of soil have to posses very high radiation tolerance.

In our experiments, we find that "ordinary" bacteria (scherichia coli and two species of Bacillus) can develop radioresistance ability after a number of 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. On the other hand, high radiation tolerance is hardly necessary for the survival in any natural environment on Earth.

A few number of terrestrial microorganisms (radioresistant bacteria) posses this peculiar ability (Deinococus radiodurance, Rubrobacter radiotolerance, Rubrobacter xylanophilus). The radiation background on Earth, including vicinity of natural nuclear reactor Oklo is many orders of magnitude lower than the lethal dose for these microorganisms. We show that such radioresistance can be "trained" only in the Martian conditions. Therefore, we propose that Earth has been infected several times by the Martian biota on Martian meteorites.

We propose that high radioresistance could be a strong sign of the Martian origin for potential microorganisms acquired in the sample return missions.

Another way to identify "Martian" microorganisms and exclude contamination in returned samples involves analysis of the radionuclides abundance (being produced by the high energy cosmic rays in the Martian soil). We show that these radionuclides (³H, ¹⁴C, ³²Si, ³⁶Cl, ⁴¹Ca) should have higher concentration in the hypothetical Martian microorganisms comparing to any terrestrial analogues. We propose a set of measurements of such "isotopic imprints" with accelerator mass spectrometry.

We also show that unusually high ratios of stable isotopes ¹⁵N/¹⁴N and D/H in the Martian atmosphere can be used for identification of Martian microorganisms because those ratios would be incorporated into the Martian biota.

Extent Of The Of Mars-like Soils In The Atacama Desert, Chile

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The Atacama Desert is a coastal desert that stretches from 17°S to 28°S in the area between 69°W and 71°W. The core hyper-arid region around at 24°S and 69°W has been shown to comprise soils with extremely low levels of culturable herterotrophic bacteria and organic material. These soils have been considered Mars-like in their various properties. The discovery of these soils is important for testing of new techniques and development of instruments to be used in the search for life on Mars. It is therefore important for us to know the extent of these Mars-like soils for future studies.

In order to explore the extent of this hyper-arid region we have sampled more extensively in the core region and also along transects to the east and to the west. The samples were tested for the presence of organic material and the total cfus for heterotrophic bacteria were determined. In the core region within an area of 18 km² we found similar conditions in the 12 of the 16 sites samples. The four sites that differed had elevated levels of heterotrophic bacteria and in some cases high content of organic material was detected by pyr-GC-MS. These levels of bacteria and organics were still lower than those found further south in the precipitation gradient (Navarro-Gonzalez et al. 2003). Samples were collected at 25 km intervals to the East and West. Along the transect to the West there is an observed increase in organic material and bacterial numbers approaching the coast. To the East there is some degree of patchiness indicating the possible influence of microclimates. This study provided an insight into the extent of the Mars-like soils in the Atacama Desert that will allow us to develop a protocol for the establishment of areas for scientific use and/or preservation in this region.

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Spatially Resolved Martian Water Vapor: Sources Beyond The Poles?

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Confirmation of water vapor sublimation from both the Martian Northern and Southern polar caps into the atmosphere by the TES instrument onboard MGS many years ago was a big step in beginning to accurately model the current water vapor cycle on this desert planet. These large polar plumes are efficiently studied using time-variable latitude data – that is, data that has been globally averaged over longitude (Smith 2001). However, this averaging makes more localized patterns impossible to isolate.

The discovery of significant near-subsurface water-ice by the Neutron Spectroscopy team (Mitrofanov 2002) as well as recent image analysis that seem to show very near-surface ice- or snow-packs (Christensen 2003), suggest that there may be a local component to the global water-vapor cycle that is not being accounted for by concentrating only on the seasonal polar plumes. Conversely, the identification of local pockets of water vapor that are not sourced from the poles could indicate places to search for very near-surface deposits. Understanding of these deposits may be critical to the investigation of such Martian mysteries as the geologically-recent water gullies observed along crater walls, and overall the history of water, and by extension life, on Mars.

To that end, we first produced and examined spatially-resolved water vapor maps (using Smith 2001). Subsequently, local patterns which seem unmatched or out-of-phase with the overall seasonal polar cycles were examined in more detail, in order to determine their most likely source. These examinations include time-variable vertical temperature profiling of the locale and surrounding region, surface temperature and thermal inertial analysis, and correlation with the presence of high-atmosphere water-ice clouds.

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Evidence For Subsurface Water Ice In Korolev Crater, Mars

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Following the work of Kieffer and Titus (2001), we present results of thermal infrared observations of Korolev crater, located at ~73 degrees latitude in the Martian northern polar region. Similar to Titus et al. (2002), we use thermal infrared images from the THEMIS instrument aboard Mars Odyssey to identify several units within the crater basin with distinct thermal properties. The THEMIS results show these regions exhibit both temperature and albedo variations, spatially within the crater and throughout the Martian year. In addition to the variations identified in the THEMIS observations, Mars Global Surveyor Thermal Emission Spectrometer (TES) observations show differences in albedo and temperature of these units on both daily and seasonal cycles. Modelling annual temperature variations of the surface we use TES observations to examine the thermal properties of these units. This analysis reveals the units are likely thick layers (several meters) of water ice, or extremely water-rich material, overlaid by a thin layer (several mm) of dust. Variations of the physical properties of these units are likely due to topography, variable dust content (caused by erosion and deposition patterns within the crater), and possibly variations in the subsurface material itself. As the polar CO₂ ice migrates to lower latitudes during times of increased obliquity, this layering process of water ice and dust may follow at the edges of the advancing polar caps. This may suggest a method for depositing layered sedimentary deposits in equatorial craters observed with MGS by Malin and Edgett (2000).

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Mars Ground Ice: Stability At The Present Epoch At Low And Mid Latitudes And Implications For Astrobiology

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Theoretical calculations combined with observations from the Mars Odyssey NS/GRS suggest that ground ice is stable in the top meter of regolith poleward of about ± 60° latitude (Mellon et al., 2004). At lower latitudes, inferred hydrogen abundances are greater than can easily be accounted for by chemically or physically bound water, but may be consistent with the presence of small amounts of ground ice. Ice is not stable with respect to sublimation and diffusion into the atmosphere at these latitudes, however, due to the relatively warm temperatures and low humidity of the atmosphere. Ice could be stable there at the present epoch if the atmospheric water content increased by only a factor of several. Such an increase could occur if the south polar cap lost its residual summertime covering of CO, ice; this would expose any underlying water-ice cap, which would heat up to temperatures warm enough to allow substantial sublimation into the atmosphere. Given the potential for the south cap to lose its CO, covering over timescales of only years (Jakosky and Haberle, 1990), ice could have condensed within the regolith within the last hundreds to thousands of years even though it has not been stable in the last two decades; the average behavior on this timescale is not known. If ice had been deposited on these timescales, it could still be present today as a result of low loss rates due to, for example, low soil diffusivity.

Ice within the regolith is an important astrobiology target. It holds the potential to have liquid water under certain conditions, either as thin films or if bulk or partial melting occurs. Its potential widespread occurrence may have geological implications for the structure of the surface at the millimeter scale, for the occurrence of water-related geochemical weathering, or for the potential for prebiotic or biotic activity.

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Martian Gully Features In Various Geologic Settings And Implications For Formation Processes

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Gullies on Mars were first discovered by Malin and Edgett (2000) using the narrow angle Mars Orbiter Camera (MOC) aboard the Mars Global Surveyor (MGS) spacecraft. These features are most likely formed by liquid water activity (Christensen 2003, Costard et al. 2002, Gaidos 2001, Gilmore and Phillips 2002, Hartmann 2001, Heldmann and Mellon 2003, Malin and Edgett 2000, Mellon and Phillips 2001). One possible source of this water is a subsurface aquifer (Heldmann and Mellon 2003, Malin and Edgett 2000, Mellon and Phillips 2001). However, "gullies" found on sand dunes and central peaks have been used to argue against a subsurface water source because the isolated nature of these features precludes the presence of an extensive subsurface aquifer (Christensen 2003, Costard et al. 2002, Mangold et al. 2003, Treiman 2003). The "gullies" located on such isolated structures are a separate class of features, though, and these geomorphic differences are most likely related to their process of formation.

In this paper we examine the variations in morphology among "gully" features found on various geologic terrains. The various classes of gully features are divided into three types, Type I, II, and III gullies, based on location. Type I gullies are those found on valley walls, crater walls, scarps, mesas, graben, and polar pits. These features represent those features first reported by Malin and Edgett (2000). Type II gullies are those specifically located on sand dunes, and Type III gullies are those specifically located on crater central peaks. The differences in morphology among Type I, II, and III features are then examined and used to hypothesize possible mechanisms of formation for each gully type. Gully features on sand dunes may be derived from seasonal deposition and removal of water ice whereas gullies on crater central peaks may tap into a deeper aquifer or may be the remnants of crater formation.

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Ultramafic Terranes As Habitats For Life On Mars And Early Earth

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For organisms to derive metabolic energy from their environment (Martian or terrestrial), thermodynamic disequilibrium must exist. The most widespread environment of chemical disequilibrium on Earth results from the juxtaposition of mafic and ultramafic rocks of the ocean crust with liquid water. Such environments were even more pervasive and important on the Archean Earth due to the near absence of continental crust.1

The composition of the lower crust and upper mantle of the Earth is similar to that of Mars. Indeed; all of the Mars meteorites reported to date are mafic or ultramafic in composition. Olivine, a common mineral in ultramafic rocks, has been identified in outcrop over much of the Mars surface2 and in rocks analyzed by the Mars Exploration Rover Spirit.

Potential habitats for chemosynthetic ecosystems in ultramafic rocks have been reported in off-axis hydrothermal zones and slow spreading centers along the mid-ocean ridge system.3-5 In some tectonic regimes, oceanic crust and mantle are exposed on land as "ophiolite suites." These ultramafic terranes offer an accessible field laboratory for studying water/rock interactions and the ecosystems that may be supported by the resulting geochemical energy. Our analyses of rocks from such terranes show that low-temperature olivine-water reactions result in microscale retention of phases and textures. Our goal is to identify and characterize microbial biosignatures in such terranes that could be useful in the robotic search for evidence of life on Mars.

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Acknowledgements

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Astrobiolab: A Mobile In Situ Subsurface Biotic And Soil Reactivity Analytical Laboratory

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AstroBioLab is a mobile astrobiology laboratory designed for field campaigns at terrestrial sites that have chemical and environmental characteristics similar to those of the Martian surface (1). The laboratory uses a complementary suite of in situ instruments that focus on state-ofthe-art organic compound detection coupled with determinations of the oxidation chemistry. This allows us to assess the interplay of organic compounds, inorganic oxidants and water in Martian-like terrestrial environments. The AstroBioLab is designed around the Mars Organic Detector (MOD) instrument in combination with a micro-chip capillary electrophoresis (μCE) system for enhanced analytical capacity. The target compounds are amino acids (the most abundant component of bacterial cells on a dry weight basis) and polycyclic aromatic hydrocarbons (the most abundant class of molecules in carbonaceous chondrites). If amino acids are detected with the basic MOD instrument, then the μCE system is used to assess whether they are biotic or abiotic in origin. The instrument package also includes the Mars Oxidant Instrument (MOI) that provides a complementary set of oxidant data. By deploying the AstroBioLab in field campaigns in the Mojave and Atacama deserts we will carry out experiments under flight-like conditions and thus demonstrate the feasibility of using this instrumentation to explore for signs of organic compounds during future landed missions to Mars. Preliminary results indicate that at Atacama sites where high levels of oxidants are present amino acids are at or below detection limits (< 0.1 ppb). In contrast, when oxidant levels are low, 0.5 to 1 ppm concentrations of amino acids were detected. This demonstrates the critical interplay of oxidants and the preservation of key biomarkers such as amino acids. Analyses carried out on Mars using a similar suite of instruments could enhance the chances of detecting organic compounds including those possibly derived from life.

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The Mars Microbeam Raman Spectrometer (MMRS) For Characterization Of Minerals, Water, And Carbon

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A key priority for on-surface astrobiological exploration of Mars is definitive identification and characterization of surface materials that help us assess whether life might have formed on Mars. These materials include minerals that are indicators of past climates and environments, mineral forms of the biologically important elements P, S, and Fe, minerals that contain water or required water for their genesis, and the inorganic and organic forms of carbon. The record of alteration of surface rocks is expected to reach back in time from relatively recent alteration of rock surfaces, to past stream and lake environments, to hydrothermal settings in the upper martian crust, to late-stage aqueous effects on the planet's early igneous rocks. To identify and characterize these materials, we have developed the Mars Microbeam Raman Spectrometer (MMRS). In addition to minerals, carbonate minerals, graphitic carbon, and organic C-C, C-H, C-O, C-N, bonds are readily detected. For example, we detected ≤50 ppm of partially graphitized, reduced carbon in a 3.35 Ga chert from South Africa using the MMRS brassboard [1]. In a study of a weathered basalt cobble, we encountered a crustose lichen whose protective wax coating yielded strong Raman peaks [2].

The MMRS Advanced Brassboard covers the necessary spectral range for characterization of all the materials listed above with adequate spectral resolution to enable mineral cation ratios to be determined to ~0.1 unit. It has a detection sensitivity ~40% that of our state-of-the-art laboratory Raman system, a good Raman-to-photoluminescence S/N ratio, and a good depth-of-sampling field. We recently conducted a successful whole-

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Magnetite Crystal Chains: Bacterial Fossils Of Unique Documentary Value On Earth And On Mars

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As soft-bodied bacteria rarely leave behind good fossils, the probability of finding conclusive fossil evidence of ancient bacterial life on Mars is rather slim. Magnetotactic bacteria constitute an exception: they produce permanent and morphologically distinct, fossilizable inner structures, chains of magnetite crystals. Single crystals may provide a good indication of biolological origin, but such claims remain contested and it seems unlikely that the question of biological origin of Martian magnetite will be settled based on this evidence alone. Crystal chains are a different matter: Recent studies (1) indicate that they are veritable cell organelles, complex systems that can only be produced by a sequence of chemical and physical processes and feedback loops. Their fossil remnants show morphological features uniquely characteristic of life and hence their documentary value is comparable to animal skeletons on a microscopic scale. On Earth, magnetotactic bacteria are ubiquitous in aquatic habitats and their presence in similar Martian paleoenvironments is quite likely. The site of most immediate interest may be the presumed fossil lakebed in Gusev crater.

Until now, magnetite chains could not be demonstrated in hard specimens of terrestrial magnetofossils as the method of preparation (acid cleaning) destroyed the chains. We are now able to show such chains in hard terrestrial magnetofossils in situ by backscattered scanning electron microscopy (SEM-BSE), the same method we used (2) to study such structures in the Martian meteorite ALH84001. As we show here, terrestrial and Martian magnetite crystal chains viewed with the same microscopic technique are similar to a remarkable degree. Further more, we suggest that this technique can be adapted for robotic operation on fossil Martian lakebeds.

The disadvantage of SEM-BSE is its limited resolution, which results in blurred images of the small, single-domain sized magnetite crystals. Final confirmation of results obtained by this method could be achieved by excising selected magnetite chains, using the focused ion-beam (FIB) technique, for high-angle annular dark-field (HAADF) electron tomography.

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Abiotic Formation Of Magnetite-pyrrhotite Assemblages In Martian Meteorite ALH84001.

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Although magnetite crystals in ALH84001 have received considerable attention in the literature as a potential biomarker, the sulfide component is important because the coexistence of magnetite and sulfides has also been suggested as a marker for past biogenic activity (McKay et al., 1996). An alternative hypothesis to the biogenic origin for the carbonate-magnetite-sulfide assemblage in ALH84001 is the inorganic formation of this mineral

assemblage by aqueous or hydrothermal precipitation of carbonate globules with Fe-sulfides followed by a heat pulse that was sufficient to decompose siderite to magnetite and pyrite to pyrrhotite (Golden et al., 2001; Allen, 2003). We experimentally demonstrate the feasibility of such a process by heating siderite and pyrite at 475 and 550°C in a closed system environment. The resultant products were unreacted siderite, magnetite and pyrrhotite. Pyrrhotite was found to form directly from pyrite and also as a product of S vapor interaction with siderite. The magnetite and pyrrhotite crystals are sub-micron in size and form an assemblage similar to magnetite-pyrrhotite assemblage in the black rims of Martian meteorite ALH84001 carbonate globules. Inorganic processes can exclusively account for the magnetitesulfide-carbonate assemblage in the meteorite. The laboratory experiments also provide an inorganic process analogue for formation of this mineral assemblage, i.e., precipitation of Fe-rich carbonates from circulating hydrothermal and carbonate-rich solutions and their subsequent thermal decomposition. Decomposition could have been induced by heating associated with meteoritic impact or volcanic processes, to form the magnetite-sulfide-carbonate assemblage in the meteorite.

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Tumbleweed: Wind-driven Sampling On The Surface Of Mars

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Seasonally receding frost at Mar's higher latitudes has been shown to provide sites with shortly-lived liquid water on the surface and longer-lived liquid water below the surface. Given the availability of sunlight and evaporitic dust, this constitutes a clear prospect of a surficial habitat, even if only seasonally, although a near-subsurface habitat may be supportive of life for a longer time. This surficial habitat can be thought of as extending over a large area, perhaps from 50 degrees to the poles themselves, and this in turn suggests the significant value of a long-range survey for habitat and "desert varnish" (surface oxide coatings) in the high latitudes. Site types that could be particularly suitable to this survey include desert surfaces, duricrusts, pavements, ice surfaces, and large flat-bottomed canyons.

Such a survey could be readily accomplished with a group of Tumbleweed rovers - wind-driven vehicles capable of using the readily available Martian wind to make their way across the Martian surface with minimal power, while optimizing their capabilities to perform a variety of measurements over relatively large swaths of terrain. The Tumbleweeds would need to be suitably instrumented for surface and near-surface interrogation and released, possibly on the residual cap, to roam for the duration of a season or even longer. Instruments could include miniature X-Ray Fluorescence (XRF), Raman and other spectroscopic techniques, gas-sensing ion selective electrodes, temperature sensors (e.g., thermocouples), as well as exciting new technologies such as lab-on-a-chip chemical sensing and quantum dots. Specific instrument selection would be tailored to the exact scientific goals of a particular mission scenario. Analyses comparing the quality, quantity, and coverage of data produced by this type of survey strategy compared to a more conventional coordinate grid sampling strategy are underway.

On Earth, a straightforward test of this approach could be conducted through Tumbleweed deployments in a number of arid polar and midlatitude sites. Test sites that incorporate both icy surfaces and dry desert are present in the high latitudes and more accessible hot deserts at mid to low latitudes. We present here an overview of the instrument selection options and the primary scientific objectives of both a Mars Tumbleweed and prototype Earth Tumbleweed.

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Spectroscopic Analysis Of Fe- And S-bearing Materials For Remote Sensing Of Biomarkers On Mars

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The BioMars project includes a broad range of astrobiological studies aimed at detection of current or past life on Mars1. We are particularly interested in developing techniques to characterize and identify Fe and S-bearing minerals that are associated with organisms. We are analyzing the evolution of the martian hydrosphere and surface to identify habitat types with the highest potential for sustaining extant or extinct life, and we are studying analogous Earth environments and conducting experiments to determine the form that a record of the past or current life might take. Visible and infrared spectroscopy provide a link between the geologic and biologic components of the BioMars project and remote sensing on Mars. The spectroscopy component of the BioMars team will be measuring spectra in the field and in the lab, and correlating these data with spectra from current and upcoming missions. In particular, we will evaluate the effects of iron oxide/oxyhydroxide/sulfate particle size, surface environment, and aggregation state on the spectral properties.

The BioMars team will be identifying minerals in rocks at selected field sites that are good indicators of aqueous processes, temperature, pH, etc. that provide information about conditions at the time of mineral formation. The spectral parameters of these minerals will be characterized as in a recent study2 in order to enable us to predict the spectra of key rocks and minerals associated with habitable conditions on Mars if they are observed by any of the martian spacecraft. The spectral properties of several Fe,S-rich materials have been measured and analyzed including a precipitate from the Iron Mountain site.

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Organic Contamination On Martian Landers: Astrobiology Implications And Mitigation Strategies

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The exploration of the possible emergence and duration of life on Mars from landed platforms requires attention to the quality of measurements that address these objectives. In particular, the potential impact of terrestrial contamination on the measurement of reduced carbon with sensitive in situ instruments must be addressed in order to reach definitive conclusions regarding the source of organic molecules. Following the recommendation

of the Mars Exploration Program Analysis Group (MEPAG) at its September 2003 meeting, the Mars Program Office at NASA Headquarters chartered the Organic Contamination Science Steering Group (OCSSG) to address this issue. The initial report of the six week study of the OCSSG can be found on the MEPAG web site. The study was intended to define the contamination problem and to begin to suggest solutions that could provide direction to the engineering teams that design and produce the Mars landed systems. Comments from the astrobiology community on this analysis are solicited, and will be used in preparing a revised report, which will be used in forward planning of the Mars exploration program.

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Pico De Orizaba – Insights Into The Limits Of Life And Implications For The Terraformation Of Mars

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There is evidence that the Martian environmental conditions were more clement in the past; the estimated global temperature was near 0°C and was higher during certain seasons and at certain regions specifically near the equatorial zone. Here on Earth, we find equatorial regions where the temperature oscillates near 0°C at high altitudes; these are the tropical alpine environments. As altitude increases in these zones environmental conditions such as temperature and pressure rapidly decrease and so organisms must adapt. At some point they will reach their physiological tolerance limits, e.g., treeline at thermal gradients which represents an abrupt transition in life form dominance. However, the physiological and developmental mechanisms responsible for treeline position worldwide are unclear. The limits of microbial growth and function are considered to play a role in treeline formation and this might have implications for the future terraformation of Mars.

In order to explore the role of microorganisms in treeline formation we carried out a sampling program inside and outside the treeline of the south face of Pico de Orizaba, Mexico. Samples were examined using chemical and microbiological techniques. The soils inside and outside the treeline were found have pH values in the range 5 and 6. The nature of the organic compounds detected was the same inside and outside the treeline. However, the organic content in the soil was highest inside the treeline, decreased towards the edge of the treeline and fell rapidly once outside the treeline. Colony forming units per gram of soil of heterotrophic bacteria were highest (1 x 107) inside the treeline and lowest (5 x 104) at the highest altitude outside the treeline. 16S rRNA gene sequence analysis showed these isolates to decrease in diversity as you move from the treeline and that a wide range of taxonomic groups are represented. Culture independent approaches demonstrated a similar trend in diversity but in addition revealed that certain taxonomic groups are more prominent either inside or outside the treeline. The data currently available indicate that there is a correlation between treeline and microbial composition of the soil. Current studies are aimed at the investigation of the function of these microbial communities in the delineation of treelines at high altitude. The understanding of this interaction between trees and microorganisms may provide important insights for the colonization of Mars.

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Searching For Biomarkers In Valleys, Canyons And Craters On Mars Using Tumbleweed Rovers

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Unique gully features have been observed on the slopes of Martian valleys, canyons, and craters in photos taken by the Mars Global Surveyor. These gullies typically occur on the cold face of slopes, primarily at mid-latitude, and possibly were formed by the recent flow of water from melting snow packs or subsurface aquifers. The current strategy in the search for life on Mars is to "follow the water" and thus these areas are of primary interest for conducting in situ investigations. A majority of these scientifically interesting sites, however, are not accessible by current conventional robotic systems due to the terrain and high winds typically associated with these areas. However, access to these sites may be possible using a new, unconventional rover known as a Tumbleweed. Designed to derive mobility through use of the surface winds on Mars, Tumbleweed rovers would be lightweight and relatively inexpensive, allowing multiple rovers to be deployed in a single mission to particular regions of interest. They would complement currently planned missions by serving as scouts, pinpointing particular locations of interest for detailed follow-on investigations by rovers, landers, or perhaps human explorers.

In order to investigate the gullies, Tumbleweed rovers could be deployed at the entrance to a valley or canyon, identified as having these features, and allowed to be driven by the wind into the region. Alternatively, Tumbleweeds could be deployed near the top of a valley, canyon, or crater and be blown by the wind down the slopes into the area of interest. The Tumbleweed would serve as a scout in these areas, searching for traces of water vapor and biogenic gases using an instrument such as a lightweight "mini" gas chromatograph / mass spectrometer system. This mission would address the proposed MEPAG investigation to "carry out in situ exploration of areas suspected of harboring liquid water," by conducting "in situ geophysical and chemical (e.g. "sniffers") searches for subsurface water and other volatiles."

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Habitability In Martian Polar Environments: Fundaments Based In Ice Screening Of UV Radiation

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The ultraviolet environment of Mars has already been widely investigated (Cockell et al, 2000; Patel et al., 2002; Córdoba-Jabonero et al., 2003) through the use of different radiative transfer models, and in general the results are similar. Among these, the ultraviolet (UV) solar radiation at wavelengths less than 200 nm is totally removed due to the high absorption of CO₂ (major component of the Martian atmosphere), but solar UV radiation (200 – 400 nm) does reach the surface. Major molecular absorbers in the UV range are O₂, O₃ and SO₂, but their mixing ratio in the present Martian atmosphere is very small (in the case of SO, is almost negligible) offering little protection from the biologically harmful solar UV radiation (UV-C and UV-B range) experienced on Mars. Therefore, under these extreme UV radiation and other environmental conditions, Mars is a planet without extant life on the surface. But this hard conclusion cannot be applied to the subsurface where habitability could be possible, but unfortunately little is known about the physical-chemical conditions available for survival of the microorganisms in the Martian subsurface environment.

In order to search for an environment on Mars which would be suitable for habitability from a radiative point of view, we pay attention to the subsurface polar environments due to two special environmental conditions: 1) their high latitude (surface UV levels are much lower due to higher zenith angles, and possible O₃ partial protection in winter/spring), and 2) they are snow-ice covered (high attenuation by CO₂ and H₂O ice of UV radiation). Thus, high latitude snow-ice covered environments are prime candidates to shelter biological matter. We present a study of the solar UV radiation in Martian high latitude environments covered by ice, where the UV propagation through the polar cover depends on the ice radiative properties (H₂O or CO₂ ice). But also we investigate the changes in the subsurface UV levels induced by the seasonal variations of solar UV flux on the surface, as well as by the seasonal freezing-thawing and related CO₂ sublimation

processes. The biological dose relative to DNA-damage is also estimated for biological implication assessments.

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Other

Bicontinuous Structures As Interesting Evolutionary Adaptations

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Formal bicontinuous structures are characterized by mutually interpenetrating labyrinths containing a hyperbolically curved interface¹. The partitioning surface generally divides regions of space of contrasting chemical, physical or biological properties. These structures are known to occur at many scales from the atomic – (e.g., zeolites), through molecular (cubic liquid crystals, block copolymers, microemulsions) to membranous (e.g., endoplasmic reticulum, mitochondria and other organelles)¹.². Bicontinuous structures are also recognized at larger scales – for example in the arrangement of biominerals in sea urchins tests, and vertebrate bones, and in the nest structures of mound building termites¹.².³. Arguably, bicontinuous structures may exist in the architectures of symbiotic relationships and amongst populations of organisms.

Aspects of the emergence of bicontinuity in nature, and the selective advantage it bestows upon organisms and populations, at the various scales, are presented. Bicontinuous membrane morphologies as primordial cellular structures are also discussed.

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A Study Of Some Meteorological Variables Around The Treeline Of Pico De Orizaba.

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As discussed elsewhere by some of us (Pérez-Chavez et al., 2000), Pico de Orizaba, Mexico (19° N) is an important example of a tropical alpine environment, which can be used as a plausible terrestrial analogue of martian environments near the equator. Because of it, during the past few years we have been monitoring the mountain around its treeline using meteorological, microbiological and organic chemistry approaches. Several locations in the mountain were selected above, below and within the treeline of Pico de Orizaba (Cruz-Kuri et al., 2001). In each station, we register some meteorological variables such as relative humidity, air temperature, etc., as well as soil temperatures at various depths (up to 40 cm). In this report we present some results up to date related to the continuing analyses performed to these variables, and discuss their relevance to astrobiology.

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Astrobiology And Scientific Proof

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Astrobiology theories are often inspiring but necessarily speculative. The accepted criterion for scientific theories is that they can be falsified by experiment (Popper 1935, 1959). It is of interest to examine some common astrobiology statements in this respect.

- 1. "Process X contributed to the origins of life". Cannot be falsified. We cannot return in time and test the actual mechanism of biogenesis.
- 2. "Process X could have contributed to the origins of life". Cannot be falsified. The chemistry of biogenesis is complex and it is unlikely that a unique mechanism for the origins of life can be proven.
- 3. "There exists extraterrestrial life". Cannot be falsified in practice. We cannot examine every potential habitat in the universe.
- 4. "There does not exist extraterrestrial life". Can be falsified by a single observation.
- 5. "The universe will remain habitable indefinitely". Cannot be falsified experimentally. If the statement is false, there cannot be observers to prove this
- 6. "The universe will become uninhabitable after a long time." Can be falsified in principle by the presence of observers, but cannot be falsified experimentally in advance or in practice. The observable past of the universe may be too short to predict its future with certainty.

The experimental verifiability of astrobiology theories requires careful examination (Mautner 2000). A debate within the astrobiology community about scientific proof could be valuable. For long-term scientific credibility, it seems appropriate to communicate the nature of astrobiology theories accurately both within the scientific community and to the public.

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Evidence Of Degradation Of Cometary Meteoroids In The Interplanetary Medium

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The range of masses of cometary meteoroids varies from several kilograms which can produce fireballs, (Ceplecha et al., 1998), to 10⁻¹⁷g detected by spacecraft in comet 1P/Halley, (Jessberger et al., 1988). The fluffy nature of cometary material facilitates the degradation of these particles in the interplanetary medium. Once ejected from their parent bodies, they are fully exposed to different erosion processes such as solar wind heating and collisions with interplanetary dust (Hughes, 1993). From the astrobiological point of view, one important question remains unanswered: Is the chemical composition of meteoroids affected during long exposure heating in the interplanetary medium? Depending on the degree of alteration, the subsistence of water and other organic compounds during typical residence times of thousand of years (Hughes, 1993) would be problematic. In order to gain insight into the significance of meteoroid streams on the origin of life (Jenniskens et al., 2000), we need to determine the importance of these degradation processes. Our approach in this work is based on recent meteor

spectroscopy results.

We used the Borovika (1993) model to determine the relative chemical abundances of ten cometary meteoroids by analyzing their fireball paths (Trigo-Rodriguez et al., 2003). We have observed that sodium may be associated with volatile phases in these meteoroids (Trigo-Rodriguez et al., 2004), as was also suggested from video spectroscopy (Borovi ka et al., 1999). The importance of the presence of Na in comets is underscored by the discovery of a sodium tail in Hale-Bopp that could be produced by direct cometary degassing or via the break-up of Na-bearing molecules, ions or dust particles (Cremonese et al., 1997). Sodium is also present in Interplanetary Dust Particles (IDPs), presumably the survival counterpart of low-velocity cometary (and asteroidal) meteoroids, that contain layered silicates and salt minerals produced by hydro-cryogenic alteration (Rietmeijer, 2002). These minerals would be easily eroded by solar radiation; consequently, the study of the abundance of Na in meteor spectra provides interesting clues on the role that such processes may have played in the delivery of volatiles to the Earth from cometary meteoroid streams. Our observations are in agreement with theoretical studies that show that long stays in the interplanetary medium affect sodium and other alkali volatile elements such as potassium (Young, 2000). Meteor spectroscopy can provide new ideas on the survival of volatile compounds of astrobiological significance.

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Outreach/Education

Connecting With Public Audiences: A Short Workshop

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A group of experts from all areas of science communication has come together to form a founding team to propose a science communication focus group to the NASA Astrobiology Institute. These experts include science journalists, successful scientist communicators and science communication specialists in education, museums, Internet, risk communication and in understanding the nature of science communication.

National Science Foundation figures suggest that while nine out of ten American adults claim to have an interest in science, three out of four are scientifically illiterate. While the mass media is often considered as a mass tool to increase the public understanding of science, most science journalists say their work is aimed at informing public audiences, not educating them. The science communication focus group founding team offers a workshop aimed at helping astrobiologists understand how to communicate their science effectively to public audiences given these challenges.

Format of the workshop: Members of a panel formed from members of the science communication focus group founding team – mostly the science journalists - will each give a short statement on the content of the workshop and then open the floor to questions. The flow of audience participation will be guided into specific focus areas by the chair and co-chair of the panel, Dr Seth Shostak and Prof Paul Davies, both experienced scientist communicators. The aim is two-way communication between panelists and participants with the objective of closely addressing the needs of the participants in understanding how to connect and communicate with public audiences.

Content: There will be discussion and questions on what to, when to, where to, who to and, most importantly, how to effectively communicate astrobiology to public audiences. Participants in the workshop should feel better able to undertake this task.

Duration: 1.5 hours.

Principles Of Communicating Research To A Multidisciplinary Audience

Sullivan, Woodruff (Ástronomy Dept. & Astrobiology Program, Univ. of Washington)

Dodson, K. Estelle (NASA Astrobiology Institute, Lockheed Martin Engineering and Sciences)

Question: What is the difference between a parsec and a light-year? Answer: a simple factor of 3.26, but astronomers insist on using parsecs for their distance unit, seriously impeding communication with non-astronomers. In science as with any language, if you do not understand the words, you are limited in your ability to understand and correctly interpret the concepts. Yet it is vital for the field of Astrobiology to understand research and new concepts in fields outside of your specialty, thus fostering valuable insights, new directions in research, and increased collaboration across disciplines. In addition to using a more accessible vocabulary, there are other approaches

and techniques that will be discussed in this session to effectively communicate your research to colleagues outside your discipline.

In this session, speakers will share experience and techniques that have proven successful in addressing multidisciplinary audiences. In addition, we will illustrate how high-level concepts can be communicated to a multidisciplinary audience without alienating participants. A 5-minute talk will be given twice, covering the same material first as if presented to a specialized audience, and then as it should be done to a multidisciplinary audience. The session will conclude with 15 minutes of discussion during which audience participation is encouraged.

Nai Insight Courses: Addressing The Challenge Of Interdisciplinary Collaboration

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A needs assessment survey of astrobiologists conducted by the NASA Astrobiology Institute (NAI) identifies language as a significant barrier to interdisciplinary collaboration. The difficulties posed by language differences - the same term having different meanings in different disciplines, for example - and the use of discipline specific jargon are two of the challenges identified in the survey. In addition, the ability to understand how the research of a specific discipline is relevant to the questions of astrobiology was cited as a further obstacle in communicating across disciplines. That is, those who do not understand the particular field will not be able to assume the astrobiology context for any given research.

While the astrobiology community must seek all means for resolving these problems, one solution for issues of communication has been to provide opportunities for cross-disciplinary education. By learning the concepts and language of another field, scientists can build bridges between disciplines. The NAI offers Insight Courses for astrobiologists who want to learn the basics of a field outside of their primary area of expertise. Through a mixture of classroom and field activities, these 5-day intensive courses immerse scientists in learning the essential elements and terminology of another field. The Insight Courses are an experiment in the facilitation of interdisciplinary science through professional education for researchers. Information from Insight Courses held in 2003 and plans for courses to be held in 2004 will be presented.

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The Impact Of Cognitive Science And Science Education Research On The Teaching And Learning Of Astrobiology

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The Conceptual Physics and Astronomy Education Research (CAPER) Team at the University of Arizona is focusing on combining the results of cognitive science and science education research in an effort to create instructional materials that intellectually engage students. The goal is to guide students to develop rich mental models on the central ideas in Astrobiology. Research illustrates that even though students may patiently listen to lectures, copy detailed notes, observe demonstrations, carry out the necessary experimental exercises, perform the required calculations with formulae, and reach predetermined conclusions, they all too often emerge from science courses (including astrobiology) without becoming intellectually engaged at a level sufficient to obtain a fundamental understanding. If we want our students to develop an interest in science and to emerge with a conceptually rich understanding of science concepts, it is necessary to treat the teaching and learning of science as a complex and interconnected process rather than a one-way transfer of knowledge between the scientific community and students. In particular, we must work to create more engaging and effective instructional environments that take

into account the needs of students and in particular their pre-instruction conceptual and reasoning difficulties. This work has been supported in part by NASA HQ #NAG5-4576 and the NASA EPO Programs for SIRTF, SOFIA, and NAI-Central.

Training The "Next Generation" Of Astrobiologists: An Undergraduate Astrobiology Course For Science Majors

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Within the last decade, astrobiology has become a unifying theme in scientific research. As a result of the truly interdisciplinary nature of the field, colleges and universities across the nation are beginning to look at astrobiology as an innovative alternative to traditional biology, chemistry, geology, and astronomy courses for fulfilling science elective requirements (Offerdahl, Prather, & Slater, 2002; Sauterer, 2000; Staley, 2003). As a first response, we have developed astrobiology courses for non-science majors that are enjoying considerable success. As a next step, we have focused on the development, implementation, and assessment of a new elective course aimed at enhancing the undergraduate education of science majors specifically. As a result, we have uncovered many unique and perhaps unexpected challenges not often faced by faculty working on traditional undergraduate courses. Our experience is that science majors from various disciplines have come to expect different things from their coursework. As a unifying theme, we developed an underlying philosophical goal of assisting science majors from different scientific backgrounds to communicate effectively across disciplines. This goal is relatively uncommon in undergraduate science majors' curricula. Consequently, our project involved (1) the development of an elective astrobiology survey course for students majoring in science and (2) the evaluation of the effectiveness of this astrobiology course in terms of student achievement, student attitudes, and ability to communicate interdisciplinary science results. Our assessment demonstrates that the course was successful in meeting its goals and is informing revisions to additional offerings of the course and can serve as a model for similar courses. This work was supported in part by a grant to the University of Arizona from the Howard Hughes Medical Institute.

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The First Generation Of "Native" Astrobiologists: The Graduate Astrobiology Conference, 2004

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As Astrobiology at the NASA Astrobiology Institute opens its sixth year, participating scientists continue to pursue ways of insuring the long-term success of this exciting scientific discipline. In a truly groundbreaking effort to foster cross-disciplinary collaboration and training for the next generation of astrobiologists, the first Graduate Astrobiology Conference took place January 7-10, 2004. Hosted by the University of Arizona LAPLACE Astrobiology Center, this conference welcomed 75 graduate students from around the world. Here we present details of the conference, including invited speakers, a summary of graduate issues, participant comments, and ideas for future ABGradCon events. The conference received overwhelmingly positive reviews, and with a price tag of \$30,000 we consider it to be money extremely well spent in support of the future of Astrobiology. We recommend that the Astrobiology Graduate Conference be specifically included in the NAI budget as a bi-annual event.

Nevada Observatory Establishes Student Quests In Astrobiology

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The new Jack C. Davis Observatory acts as an educational and developmental laboratory for introducing astrobiology to students, science teachers and the public at large. The Mars apparition of August 2003 drew over 3000 people to the Observatory that gathered "First Light" in May 2003. Three optical telescopes, a solar telescope and a radio telescope are being operated by Western Nevada Community College faculty and students in a quest to search out stars associated with extrasolar planets and nebulosity that contains prebiotic molecular signatures.

Under the auspices of Nevada's NASA Experimental Program to Stimulate Competitive Research (NASA EPSCoR), effort among scientists from the University and Community College System of Nevada, private industry and NASA field offices has resulted in the initial bread-board testing of a UVR spectrometer for a future mission to the regolith of Mars. The spectrometer is being developed to characterize the atmosphere and cloud structure of Mars between vacuum ultraviolet to visible light (190nm-575nm). More testing is planned within simulated atmospheres in upcoming months.

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An Integrated Approach To Astrobiology Education

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Astrobiology has always been an interdisciplinary field. With the collaboration of international partners, it is likely that all future astrobiology missions will be international and interdisciplinary. As a result of international collaboration, the project team will often be intercultural as well. Culture factors play a significant role in team actions and contributions and should be considered as a valuable part of any international team. Traditional graduate educational institutions do not take into account the international and intercultural aspects of space projects. This lack of educational diversity can lead to unsuccessful team interactions. In this paper we will show an innovative successful example of integrating astrobiology curriculum into an interdisciplinary, international, and intercultural educational environment.

Microbiology/astrobiology Outreach Education In Yellowstone National Park

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A comprehensive program is being developed to exploit Yellowstone's colorful and charismatic extremophile microorganisms to change the way up to 3 million annual visitors think about these tiny life forms. Though small, microorganisms that are nonetheless extremely important to the astrobiology story. A partnership involving the NASA AMES Astrobiology team, Lockheed-Martin Corp. and the Yellowstone Division of Interpretation has been formed to (i) develop a new chapter for the Yellowstone Resources and Issues Manual (the primary resource used to train interpretive rangers and park managers), (ii) develop new interpretive signs to be strategically placed along boardwalks, and (iii) revise trail guides to coordinate with new signs and provide another layer of learning. A partnership involving the Montana State University Thermal Biology Institute, the Yellowstone Division of Interpretation and the Yellowstone Park Foundation has been formed to (i) develop an electronic field trip and (ii) develop curricula for

four K-12 formal education programs already in place in Yellowstone. Microbiology/astrobiology interpretation is also one of the main themes of a new Old Faithful Visitor Education Center being planned by the Yellowstone Division of Interpretation.

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MIAC, the First "Virtual Collaboration" Of Minority Institutions Focused On Astrobiology

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During the Astrobiology Science 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 underrepresented 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 and for faculty members at minority institutions (MIs); (3) creating a forum for student presentations and publications in astrobiology; (4) creating an infrastructure in which to become a NASA Astrobiology Institute (NAI) Lead Team, and (5) building a successful model for collaborations among scientists and educators at minority institutions (MIs) that results in funding peerreviewed publications and shared resources which benefit minority students. Here we describe the success of MIAC in reaching these goals.

Implementing An Astrobiology Course For Teachers Using NASA EPO Grants

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Astrobiology: Voyages Through Time is a current course offering at Rice University. The departments of Astronomy and Physics and Statistics jointly offer the course, designed as graduate level course for Masters in Education students, as well as for teachers seeking professional development. The twelve-week, three-hour course is taught by local scientists and principal investigators actively involved in astrobiology and exobiology research. Dr. Siefert's NASA Exobiology grant was supplemented to fund the project. Grant funding enabled research scientists, both established and new to the field, to lecture during the course, and general audience events. The successful format of the course and the funding method can be replicated at other institutions.

The course is web cast and archived through collaboration with the Center for Learning Technology in Teaching and Learning, Rice University. Voyages Through Time, (VTT) curriculum materials, developed by the SETI Institute, with NASA and NSF funding, reinforces lecture content and provides solid classroom pedagological practices for enrolled teachers. VTT was developed with the over arching theme of evolution, and is comprised of six modules delivered on CD's: Cosmic Evolution, Planetary Evolution,

Origin of Life, Evolution of Life, Hominid Evolution, and Evolution of Technology. The curriculum is aligned with National Science Education Standards and is inquiry based, emphasizing evidence and the nature of science. Astrobiology, the consideration of the question, "Is there life beyond Earth?" stimulates teachers and their students.

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Acknowledgements

We wish to the Virtual Planet Laboratory, NASA Astrobiology Institute; Center for Technology in Teaching and Learning, Rice University

Space Science Programs And Events For Latinos In Urban And Rural Environments

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Texas has established a new testing mechanism that will emphasize math and science literacy. The state could be facing a crisis in preparing students from underrepresented and underserved populations to pass this test, particularly in Latino groups as educational attainment surveys indicate that they lag behind Anglos, African Americans, and Asian groups. This discrepancy is greatest among non-U.S. born Latinos. The goals of our program is to develop programs and events that will reach out and enrich the space science knowledge of Latinos in the greater Houston and south Texas areas, encourage and support their continuing education, including completion of baccalaureate degrees. Our methods for reaching out to this group are multi-pronged and include formal and informal education programs. Our formal activities include in-service workshops for teachers, space science-related courses for college students, faculty/student research internships. Informal activities include training high school and college students as Space Science Student Ambassadors to interact with community groups at predominantly Latino schools, children's shelters, and interacting with parents and their children at science family nights and summer science enrichment programs. Our group, by partnering with other organizations, including Passport to Knowledge, has developed larger outreach events that are advertised on Spanish speaking radio stations and local newspapers.

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Life: Origins And Extinctions

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In the last fifty years revolutionary discoveries in science has taught us that origin of life has precedents that stretch back to the beginning of the Universe. Likewise the extinction of life involves processes beyond our jurisdiction and some on the edge of our comprehension. Consequently the topic "Life: Origins and Extinctions" makes a marvellous vehicle at the freshman and sophomore level for describing and explaining a whole set of modern scientific discoveries at the core of which is the origins of life and its possible existence elsewhere in the Universe. During the third and fourth quarters 2002 this theme was the basis of a general education module (GEM) consisting of thirteen weekly two hour lectures given at the National University of Singapore. Amongst the topics covered were: string theory, nucleo-synthesis, theories of biological origins starting with Aristotle, oldest fossil controversies, bolides impacts and the KT event, rocks from Mars, New England game hens, red giants, supernovae, etc.

There were about two hundred and forty students from all disciplines (science, business, arts, engineering, etc.). Assessment was via four quizzes, one mid term, one final exam and about eight one hour tutorials. Students weak in science concepts were provided extra voluntary tutorials. Staff support consisted of two M.Sc. teaching assistants and five Ph.D. volunteer tutors from a variety of science disciplines who were just plain interested. There were additional explanatory materials (dictionary, profiles of scientists, basic introductions in science (chemistry, physics, molecular biology, geology)) available on the Universities IVLE (interactive learning) facility. All the lectures were web cast.

The poster will provide more details on course structure, tutorial

topics, exam questions and grading, as well as feedback (criticisms and improvements) provided by the students.

Micro*scope – A Developing On-line Resource For Microbial Diversity, Ecology And Evolution

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micro*scope (http://www.mbl.edu/microscope) provides educational resources about diversity, evolution and ecology of free-living microbes. It uses the TNS system of the uBio project (http://www.ubio.org) which embeds the power of taxonomy within the web site. A hierarchical classification with 20,000 microbial names indexes the resources available locally and allows for taxon-specific links to be made to remote sites and databases. Micro*scope contains about 6500 images and 5000 descriptions of taxa. Resources are collected into hierarchical clusters, and navigational pathways provide access to local collections, collections in sister sites, and information resources at remote sites. micro*scope is associated with the NSF NSDL DERMEED project (Digital Education Resources for Microbial Ecology, Evolution and Diversity) - and this will provide access to the collections of 'learning objects' held locally and remotely as well as create better bridges between the research and educational communities. Services to improve the utility of the resources are being developed, such as 'link*in' which scrutinises documents and inserts hyperlinks from taxon names to the relevant resources in micro*scope. As a community venture, micro*scope welcomes collaborations and suggestions for new services.

Training Opportunities In 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, advanced graduate students, postdoctoral scientists and researchers in areas related to Astrobiology. Teacher enhancement workshops expose middle and high school teachers to current astrobiology research presented first- hand by scientists. Significant laboratory time allows hands-on experience with essential lab and teaching techniques, and available classroom activities. Workshop opportunities 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 featuring activities in planetary protection, astrobiology and space life sciences concepts; and a 1.5 day workshop devoted to an astrobiology topic. Past offerings have included "Living Sands: Mapping Time and Space with Forams". This year's Astrobiology Workshop will focus on microbial mats.

Two advanced training opportunities are available to researchers who want to use comparative molecular and genomic approaches to address questions of phylogeny, molecular evolution, or ecology. The Workshop on Molecular Evolution brings together faculty skilled in the most current methods of molecular phylogenetic analyses and features a well-equipped computer laboratory with Linux and Unix workstations and servers for using computer programs such as Clustal W and Clustal X, FASTA, GCG, LAMARC, MrBayes, PAML, PAUP*, and PHYLIP. 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). Further information regarding these courses can be found at http://www.mbl.edu/education

The First Generation Of "Native" Astrobiologists: The Graduate Astrobiology Conference, 2004

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As Astrobiology at the NASA Astrobiology Institute opens its sixth year, participating scientists continue to pursue ways of insuring the long-term success of this exciting scientific discipline. In a truly groundbreaking effort to foster cross-disciplinary collaboration and training for the next generation of astrobiologists, the first Graduate Astrobiology Conference took place January 7-10, 2004. Hosted by the University of Arizona LAPLACE Astrobiology Center, this conference welcomed 75 graduate students from around the world. Here we present details of the conference, including invited speakers, a summary of graduate issues, participant comments, and ideas for future ABGradCon events. The conference

received overwhelmingly positive reviews, and with a price tag of \$30,000 we consider it to be money extremely well spent in support of the future of Astrobiology. We recommend that the Astrobiology Graduate Conference be specifically included in the NAI budget as a bi-annual event.

A Simulation Of The Viking Labelled Release Experiment For A Non-majors Astronomy Course

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One of the major challenges in designing astrobiology experiments for the undergraduate teaching laboratory is to provide an experience for the student that is authentic and meaningful, that conveys one or more basic principles of astrobiology, but that is relatively straightforward in implementation. This is particularly difficult in the case of introductory astronomy courses for non-science majors. In these courses, the students often have little or no science education beyond the secondary level. To compound the problem, most instructors in such courses are (naturally) astronomers, whose grounding in astrobiologically-related fields such as chemistry and biology may be minimal.

This paper describes an adaptation of a laboratory exercise (Corton et al. 2002) that demonstrates some of the principles behind the Viking Labelled Release experiment. The modified experiment involves the use of an indicator dye to detect carbon dioxide production by microorganisms or chemical reactions in a simulated "Martian soil". The difficulties involved in designing an exercise that accurately conveys the basic principles of the Viking biology experiments, and can still be performed in a classroom setting without significant facility needs, will be discussed.

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Educating And Informing The Public In Astrobiology Through Educating And Informing Science Journalists

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More than 85 % of the general public relies on daily and weekly news media for their science and technology news and information. The media represent a previously untapped mechanism for educating and informing the public. In astrobiology, this can be done through professional development workshops for space science journalists. Traditionally, interactions with the media have been done through media relations departments, via press conferences and press releases. There is a difference, however, between news briefings with the media and professional development experiences for journalists. The goal with the latter is to provide a deep and meaningful understanding of a particular topic, in order to give them the deep background necessary to properly cover a breaking story; if effective, such efforts have the potential to reach a tremendous number of people through media reports.

We designed and carried out a test of this approach by convening a twoday workshop for science journalists who were planning to cover the Mars Exploration Rover and Beagle II missions. These missions have compelling astrobiology connections, and the results are expected to be important in the astrobiology programs both in this country and abroad. The workshop was held in mid-December, two weeks prior to the first encounter. Sixteen journalists participated, and were given a series of detailed, hour-long briefings on the spacecraft, their missions, the landing sites, the instruments and the expected science outcomes, and how they fit within the broader picture of astrobiology, planetary science, and space exploration. The scientists who participated were a combination of those intimately involved with the missions and independent scientists who were experts in various aspects of Mars. In addition, forums allowed participants an opportunity to discuss the role of journalism in science education. The workshop received strongly positive reviews from the participating journalists, but it will take a detailed follow-up over the next six months to determine the real impact that it had.

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Digital Narratives In Astrobiology

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The widespread availability of digital multimedia has revolutionized the way in which space sciences content can be shared with informal science education audiences. At the Denver Museum of Nature and Science (DMNS), content for the new Space Odyssey exhibit is kept updated and relevant by developing and disseminating digital narratives on timely scientific topics. New content is produced daily in the DMNS Space Sciences Newsroom by scientists, educators, volunteers, and students working together.

For example, in order to share the science goals of NASA's MER missions, digital narratives aimed at public audiences were constructed to describe some of the basic scientific goals and principles of those missions: Why is water important to life? What evidence is there that water once existed on the surface of Mars? In January, the Stardust fly-by allowed the celebration of another successful NASA science mission while educating the public about basic astrobiological concepts such as the primitive solar system and the chemical origins of life in the Solar System.

Producing digital multimedia content for Museum programs also provides a unique educational experience for undergraduate students. A partnership between the University of Denver (DU) and the Denver Museum of Nature & Science provided opportunities for undergraduate students to participate in DMNS Space Science programs both behind the scenes and in direct contact with the public. Through this experience, students not only learn basic concepts in astrobiology, but they also develop skills in oral and visual presentation while providing a valued community service.

Examples of the work produced will be presented by undergraduate students involved in the DU/DMNS partnership. Lessons learned will be discussed as well as recommendations for implementing similar partnerships that strengthen university-community bonds while serving the goals of each institution.

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Doing Outreach In Other Languages

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It's important for science to reach the great public, since as important as the discovery itself is to encourage the imagination of the new generation of youths, in order to assure a new link in the long chain of human advances, a link that must comprise people from all around the world in the new age of International cooperation. Besides, public demands usually earn government funds.

Astroseti is a group of volunteers doing translations into spanish for free in their spare time. Currently translating for NASA Astrobiology Institute, Kepler Mission, Science@Nasa, among others, Astroseti volunteers benefit of learning while translating, and at the sime time, the different projects spread their science to a wider audience.

Astroseti model of volunteers, translating into other languages would be useful at rising the public interest in astrobiology all over the world.

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Postcard Earth

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I have argued [1] that message design for communication with extraterrestrial intelligences (CETI) should focus on images. The argument is based on simple semiotic analysis of cognitive principles which shows that the essential arbitrariness of symbol use renders the notion of linguistic exchange infeasible. By contrast, images are plausible content matter, and known to be so by both communicants. The concern in this paper is briefly to rehearse these arguments but essentially to take the point further in connection with outreach and education.

In many 'western' societies the education of children is failing to excite interest in science and technology (and possibly other subjects requiring the acquisition of basic skills and knowledge prior to the application of those skills in new settings – which is where it gets interesting!).

CETI could serve as an enormously attractive framework within which to locate educational efforts in science and technology with many rewarding secondary outcomes. This will be explained in the delivered paper: the core idea is to establish an international competition for the development of "Postcard Earth" – image content created with a view to transmitting from Earth. At Astrobiology conferences every two years the children/schools judged most enterprising will visit to present their work, and receive prizes. Clearly much needs to be done to establish such a scheme, but the rewards are likely to repay the effort many times over. The paper will set out the goals for such a scheme, and sketch out some structural/organizational issues.

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Twenty-First Century Space Science In The Urban High School Setting: The NASA/John Dewey High School Educational Outreach Partnership

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A unique and innovative partnership has recently developed between NASA and John Dewey High School, infusing the study of Space Science into the curriculum. As an outgrowth of the success and popularity of our Remote Sensing Research Program, sponsored by the New York State Committee for the Advancement of Technology Education (NYSCATE) and the National Science Foundation, our science department has established a Space Science Academy. John Dewey High School, located in Brooklyn, New York, is an innovative inner city school with students of a diverse multi-ethnic population and a variety of economic backgrounds. Students were recruited from this broad spectrum, which covers the range of learning styles and academic achievement. This collaboration includes students of high, average, and below average academic levels, strongly emphasizing participation of students with learning disabilities through inclusion teaching methods. In this 'classroom without walls', students apply the strategies and methodologies of problem-based learning in solving complicated tasks. The collaborative learning approach simulates the NASA method of problem solving, as students work in teams, share research and results. Students have the opportunity to apply inquiry-based learning strategies using 'real-time'

Space exploration has its own unique needs and its own dynamics. Students learn to recognize the complexity of certain tasks as they apply geosciences, mathematics, physics, technology and engineering designs. Their path follows the NASA model as they design, test and construct various devices. Our Space Science curriculum consists of a minimum of a one-year sequence of elective classes taken in conjunction with Regents-level science classes. This sequence consists of Remote Sensing, Comparative Planetology, Mission to Mars (NASA sponsored research program), and Astrobiology. Our 'ground-breaking' course of study in Astrobiology integrates biological and physical sciences through the study of planetary science using a series of inquiry-based activities. Students explore these scientific concepts and the course offers them a venue for investigating the same fundamental ideas and concepts that scientists and researchers use in their professions. Teachers attend professional development training sessions, workshops and lectures and are working with curriculum specialists (TERC) to provide us with resource guides and support. Our staff learn about the latest research and apply the necessary pedagogical skills to foster a deepened understanding in this highly advanced specialty area.

Support of partnerships is critical to the success of this program. NASA/MUSPIN (Minority University Space Interdisciplinary Network) sponsored field trips to the Goddard Institute for Space Studies, the American Museum of Natural History and Rose Space Center at the Hayden Planetarium, as well as a firm alliance between John Dewey High School and Medgar Evers College. Our curriculum has recently been enriched through coordinated efforts with Passport To Knowledge (P2K) as we hosted Mars-related

activities in the community and in the schools (including a visit by the M-team during their Marsapalooza Tour), coinciding with the launch and successful landings of Spirit and Opportunity over these past several months. John Dewey High School was also featured in P2K's video production of Space Day 2003.

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Undergraduate Educational Opportunities In Astrobiology

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Undergraduate astrobiology courses have begun to take form at many different colleges and universities. We conducted a web-based search of these courses to determine the subject matter being taught. From the posted course outlines and the contents of newly published astrobiology texts, it is possible to suggest a standard framework for an introductory course in astrobiology.

Overall, 1364 prospective departments were sent an email inquiry, yielding detailed information on 42 courses on "life in the universe". These are offered by departments of physics/astronomy, biology, or geology in the ratio 8:2:1. We found that that 76% of the astrobiology courses are for non-science majors and 67% require no prerequisite. These 42 courses used a remarkable 39 different texts, highlighting the diversity of course offering. From these 2002-3 data, *The Search for Life in the Universe* by Donald Goldsmith and Tobias Owen is the most popular text, although *Life in the Universe* by Bennett, Shostak, and Jakosky is a close second and is a new book that has had less time for exposure. The majority of these courses are large-scale lecture courses with enrollments of 60 or more students.

From the posted syllabus for these courses, we can suggest a standard example of astrobiology course content for non-science majors. The course is organized into 11 broad topics as follows: History of the Universe; Formation and History of the Earth; the Nature of Life; Evolution of Life; Extraterrestrial Life; Life in Extreme Environments; Life in Our Solar System (Mars); Life in Our Solar System (Europa); Aliens, Science Fiction, and Society; SETI; The Future of Humankind in the Universe. Notable by its absence is the topic of habitable planets in other planetary systems, but this may reflect the newness of the subject of extrasolar planets.

'Family Guides' To Topics Related To Astrobiology

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We have undertaken the development, field testing, and dissemination of a new series of "Family Guides" on hot topics in space science and astronomy. Each Guide includes an innovative collection of puzzles, pictures, poetry, and projects, all designed to stimulate enjoyable co-learning, inquiry-based experiences between kids aged 6-12 and the caring adults in their lives.

The Guides endeavor to be accessible to those who are not familiar with astronomy. They coach adults how to lead inquiry with kids without knowing all the answers. They provide background on questions commonly asked by children and they challenge common misconceptions.

The Guides also provide leads to more information or useful products related to family learning.

Guide content is related to national science education standards and valuable to home-schooled students as well as museum educators who run family education programs or after-school programs. Although primarily intended for use in informal educational settings, many classroom teachers have expressed interest in the Guide's activities as engagement pieces for more formal lessons.

We released the field test version of the Family Guide to the Sun in late summer 2003. In January 2004 we released the field test version of the Family Guide to Mars in time for use with educational programs associated with the Mars Exploration Rover landings. A Family Guide to the Search for Life Elsewhere is currently in development, and we will report progress. We will also provide details of the Guides' contents and results from field testing in various educational settings.

References

Please see http://marsquestonline.org/resources/familyguide

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Experiences Teaching "Life In The Universe: A Cosmic Perspective" As A Liberal Arts Core Curriculum Course

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A survey course in astrobiology, titled "Life in the Universe: A Cosmic Perspective," has been taught during the past two decades at Colgate University. This course is offered in the Scientific Perspectives on the World component of the college's Liberal Arts Core Curriculum. SP courses are "designed to introduce students to topics of current interest and to examine the historical and contemporary influence of science on the individual and society." This course is taught in a seminar, as opposed to lecture, format to small classes of about twenty students. In this poster, I describe the course syllabus, the assignments and the topics of classroom discussions.

The catalogue description outlines the course's content and focus: "This course examines the historical debate on the concept of whether extraterrestrial life exists. We examine what astronomy and physics tell us about the origin and evolution of the Universe, the production of elements that make up living matter on the Earth, the evolution of stars like the Sun, and the formation of solar systems. We examine the astronomical, geological, chemical, and biological conditions that were responsible for the origin and evolution of life on the Earth, and speculate about the possibility of life on other planets in our solar system or on planets around other stars. How would we detect the presence of simple life forms on other planets in our solar system or intelligent life elsewhere in our galaxy. The development of intelligent life and the possibility of contact between civilizations will be examined."

Readings include Dick's Life on Other Worlds: The Twentieth Century Extraterrestrial Life Debate, Dick's Many Worlds: The New Universe, Extraterrestrial Life & the Theological Implications, the textbook Life in the Universe by Bennett, Shostak & Jakosky, and two classic science fiction novels – Wells' War of the Worlds and Sagan's Contact.

Astrobiology Student Experiments In Microgravity

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The emergence of sample return missions and the search for life theme in the astrobiology program have created many microgravity research needs. Some of these questions can be answered by simple student experiments. Both the European Space Agency and NASA offer flight opportunities aboard a modified Airbus-300 and KC-135 respectively. In this paper I will suggest some experiment options, explain the application process, and describe our experiment of Drilling in Microgravity. The purpose of this poster is to help further graduate and undergraduate studies in astrobiology and promote education.

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, Earth's structure, human health and systems theory. With an understanding of the "whats" and the "whys" students then engage in a mission module 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". By meeting education standards, teachers can easily integrate this product into their classroom curriculum.

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Astrobiology In Museums

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Science communication to the public is important for many reasons not the least is the desirability of the public to understand science to appreciate the expenditure of public money on science. This is especially true for astrobiology, which partly involves the exploration of space for habitats that could support life. Science-centers play an important role in presenting and interpreting science for the public and inspiring the next generation of scientists who may carry out the missions being planned today. Science centers are a major element in our armamentarium for informing and inspiring the public about science. We know a lot about why visitors come to science centers. They come for a myriad of reasons some of which are: to be entertained as well as to be educated; hey respect science centers to give unbiased presentations in a non confrontational manner; to learn about current, and even controversial, science. And they come in large numbers. These all work in our favour and this panel will highlight some of our efforts to engage the public in the quest for understanding of the formation and evolution of our universe, the search for habitats that could support life (past and present) and ultimately life itself.

There are 337 science centers and science and natural history museums in the United States and it is estimated that yearly attendance is approximately 70 million. Wendy Pollock, Director, Research, Publications and Exhibitions, Association of Science-Technology Centers, Wash, DC.

Scientists And Museum's Working Together

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Science communication to the public is important for many reasons not the least is the desirability of the public to understand science to appreciate the expenditure of public money on science. This is especially true for astrobiology, which involves the exploration of space for habitats that could support life. Science-centers play an important role in presenting and interpreting science for their visitors and to inspire the next generation of scientists who may carry out the missions being planned today. While museum personnel are experts in developing programs and exhibitions, science-centers often do not have astrobiology content experts on staff. They rely on scientists to help with science content interpretation. It is the partnership between scientists and science-center personnel that lead to exciting and stimulating experience for visitors. Sometimes it is difficult for scientists (not all by any means) to leave their labs to work with science enters on exhibitions and programs due to a lack of experience and an understanding to the role between content expertise and exhibition and program development.

This workshop is designed to take advantage of the presence of astrobiologists and to team them with experienced museum program developers. in an astrobiology exhibit charette. This will provide scientists with insight and experience working with museum professionals. We are inviting museum professionals (exhibit developers, designers and evaluators) from local science enters (The Tech Museum of Innovation in San Jose, The California Academy of Sciences and The Exploratorium

both in San Francisco) to participate. We will setup small groups containing scientists and science-center personnel. The teams will be charged with developing several different exhibits, which will be chosen to explore particular problems in exhibit development and content interpretation in astrobiology. Finally, the groups will present to the entire workshop for positive critiquing.

Acknowledgement

We would like to thank NAI Headquarters for funding the participation of museum professionals and the AbSciCon organizing committee for support of this workshop.

Prebiotic Chemistry & The Origin Of Life

The Importance Of Silica In The Preservation Of Labile Amino Acids In Rock Coatings

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We have found silica in desert varnish and its presence provides an explanation for the preservation of labile amino acids. Silicic acid can form a variety of complexes with ions and organic molecules, including mucopolysaccharides, glycoproteins that are enriched in hydroxyl amino acids (serine and threonine), glycine, aspartic and glutamic acids. These amino acids have been found in significant quantities in desert varnish coatings from the Mojave and Sonoran deserts (Perry, Engel et al. 2003). It is the ability of these amino acids to form complexes with the hydroxyl groups of silicic acid that may provide an explanation for their presence. This is true particularly for serine and threonine, since they are generally unstable in the desert environment. Arid conditions along with high UV fluxes and hot temperatures often reaching ~ 60° C, combined with organic acids on black desert varnish surfaces, make for a particularly unsuitable environment for the preservation of these labile amino acids. Racemization might provide an alternative explanation, however under the harsh desert conditions it is not understood. The relatively high abundance of labile amino acids serine and threonine, along with the lack of D-alloisoleucine suggests that the amino acids in desert varnish might be less than 200y old if the amino acids are homogeneous throughout the varnish rather than on or near the surface (Perry, Engel et al. 2003). The amino acids also might comprise a peptide that plays a role in the stabilization of desert varnish. In this regard it is noteworthy that the carboxylated amino acids, glutamic and aspartic acids, along with the hydoxyl amino acids, serine and threonine, may comprise part of a peptide that forms stable complexes with oxide/ hyroxide and/or clay minerals in the varnish coatings. Our finding of the presence of silica, found by TEM-EDS analysis and opal A and CT found by XRD analysis, suggests a more viable explanation for the preservation of serine and threonine. Silicic acid, Si(OH)4, and its mono silicate ion, Si(OH)3O-, condense in a process in which the silicate oxyanion acts as a nucleophile—Si from silicic acid acts as an electrophile, and one of its OH groups acts as a leaving group(Zubay 2000). Other oxyanions may react in principle, for example an alkoxide, which is derived from an alcohol. In such cases an organosilicate should be formed as a product.

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Zubay, G. (2000). Origins of life on the Earth and in the cosmos. San Diego, Academic Press. Steen Rasmussen¹, Liaohai Chen², Martin Nilsson³, and Shigeaki Abe⁴ ¹Self-Organizing Systems, Earth and Environmental Sciences, Los Alamos National Laboratory, MS-T003, Los Alamos NM 87545 USA, steen@lanl.gov; 2Bioscience Division, Argonne National Laboratory, Argonne IL60439 USA; lhchen@anl.gov; 3NORDITA Blegdamsvej 17, DK-2100 Copenhagen, Denmark, mnilsson@nordita.dk; ⁴Division of Biological Sciences, Hokkaido University, Japan.

Using a thermodynamic design principle we present a simple step-bystep route to assemble a very simple proto-organism ~5 nm in diameter, weighing about $4x10^{-20}$ g and thus $\sim 10^8$ times smaller than the smallest bacterium. Many pictures have been proposed to describe the origins of life within the astrobiology and artificial life communities and more recently alternative pictures are emerging from advances in nanoscience and biotechnology [1-10]. We propose a concrete rational design of a very simple physicochemical system that integrates the key functionalities in a thermodynamically favorable manner as a lipid aggregate integrates protogenes and a proto-metabolism. Under external pumping of free energy (light), the metabolic processes produce the required building blocks, and only specific gene sequences enhance the metabolic kinetics sufficiently for the whole system to survive. Our design is based on hydrophobic genes and metabolic complexes that operate at the external interface of a lipid aggregate and not at inside of a container (e.g. a vesicle). This design bypasses a number of difficulties with transport across membranes and allows us to use very small lipid aggregates.

We present our experimental results [7-9], together with relevant results produced by other experimental groups, and we specify what is still missing experimentally. Using a photo fragmentation process that breaks an ester bond we demonstrate the system's ability to produce simple lipids (carboxyl acid). We derive the kinetic and thermodynamic conditions of each of the proto-organism subsystems together with relevant theoretical and computational results about these subsystems. For example we can show that depending on the sequence of the lipophilic PNA (peptide nucleic acid) gene, different metabolic efficiencies are obtained due to the sequence's electron relay properties. We present and discuss detailed 3-D simulations of the lipid aggregation processes. From the reaction kinetics we derive analytical aggregate size distributions, and derive key properties of the metabolic efficiency and stability. Thermodynamic and kinetic issues with the ligation directed self-replication of the proto-genes are discussed, and we summarize the full life-cycle of the proto-organism by comparing size, metabolic effect (~5x10⁻²² W) and energy to biomass efficiency (~1,200 J/g) of contemporary unicells [11].

By assembling one possible bridge between nonliving and living matter we hope to provide a brick in the ancient puzzle about who we are and from where we come.

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Mechanistical Studies On The Formation Of Sugars And Amino Acids In Extraterrestrial Ices

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Ever since the detection of the first carbon-bearing molecules in interstellar

space almost 60 years ago, physical and chemical processes leading to the formation of molecules under the harsh, cosmic radiation field has been a stunning target of extensive research. Very recently, particular attention has been devoted to the question of how precursors to biologically important molecules such as sugars and amino acids—the basic ingredients of life as we know it-were formed in outer space and in our solar system. Here, a detailed understanding of the synthesis of C₂H₄O₂ isomers, acetic acid (CH3COOH), methyl formate (HCOOCH3), and glycolaldehyde (HCOCH,OH) and of the simplest amino acid glycine (H,NCH,COOH) is of particular pertinence to test chemical models of molecular clouds and hot cores and also of the astrobiological evolution of the interstellar medium.

In our lab, we carried out simulation experiments on the galactic cosmic ray particle processing of low temperature, carbon rich ices (10 K) as condensed on interstellar grains in cold molecular clouds. These studies investigate under-well defined physico-chemical conditions synthetic routes how the simplest carbon hydrate—glycolaldehyde—and the simplest amino acid—glycine—together with their isomers can be formed. We identified various mechanisms which are initiated by an energy transfer of the cosmic ray particle to the electronic system of the target molecules. This leads preferentially to a X-H (X=C, N, O) bond rupture and the formation of suprathermal hydrogen atoms. The latter add to C=O π bonds forming, for instance, HOCO and HCO radicals. If the reaction takes place in a matrix cage, the neighboring radicals react with CH2NH2 and CH2OH to form, for instance, glycine and glycolaldehyde, respectively. Our studies provide for the very first time well-defined mechanisms how astrobiologically important species are formed on the molecular level.

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On The Detection Of Polycyclic Aromatic Hydrocarbons In Interstellar Dense Molecular Clouds

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Polycyclic aromatic hydrocarbons (PAHs) are ubiquitous in space (Allamandola et al. 1999) and should be present in interstellar dense molecular clouds. PAHs in clouds should be detectable through their infrared spectral absorption features. Weak features attributed to PAHs have been observed in the spectra of a few objects embedded in dense clouds (Sellgren et al. 1995; Brooke et al. 1999; Bregman, et al. 2000), but it has been difficult to interpret them because of their low spectral contrast and a lack of relevant laboratory spectra.

We present laboratory IR spectra of the PAH naphthalene (C10H8) frozen in a variety of matrices at various concentrations and temperatures. The positions, widths, and strengths of the absorption bands of naphthalene are significantly altered from the gas phase when it is placed in a matrix. Gas phase naphthalene shows P, Q, and R branches characteristic of ro-vibrational transitions, while naphthalene in condensed forms does not. The IR features of naphthalene in inert matrices (e.g., Ar or N2) are narrow (generally FWHM < 2 cm-1) and may show multiple components associated with different matrix sites. In more interactive matrices (e.g. pure naphthalene and H2O), the bands become broader (factors of 3-10), show small band position shifts (0-10 cm-1 in either direction), and show variable changes in relative band strengths (typically factors of 1-3). The bands are relatively insensitive to concentration and temperature in H2O-rich ices, but show dramatic changes when amorphous H2O ice crystallizes.

A more detailed description of this work and its astrobiological implications can be found in Sandford et al. (2004).

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What Can Complete Genomes Tell Us About Early Animal Evolution?

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Complete genome sequences are now available for several vertebrate (human, mouse, rat, fish) and invertebrate (fruit fly, mosquito, worm, tunicate) animals, as well as from fungi and plants. The number of genes in each genome ranges from 6,000 to more than 20,000, with each gene coding for a protein with typical length of 300-400 amino acids. This represents several orders of magnitude more data for evolutionary research than previously available. Potentially, these valuable new data will accelerate our understanding of early life. However, at the same time they create analytical challenges and the need for more sophisticated methods. Distinguishing gene duplication from speciation events and accommodating rate variation are two of the most difficult issues and they will be addressed here. With some new bioinformatic approaches we have conducted complete genome sequence analyses and our results bear on the early evolution of animals and the rise in complex life on Early Earth.

A theoretical study of ice-bound photoionization and chemistry of polycyclic aromatic hydrocarbons in the interstellar medium

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Polycyclic aromatic hydrocarbon (PAH) species are the largest known interstellar molecules identified to date and are also found in carbonaceous chondrites. To complement recent experimental work by Gudipati & Allamandola (2003), we have used density functional theory calculations to characterize the photoionization behavior, electronic excitation spectra, and chemistry of benzene, naphthalene, anthracene, and pyrene in UVphotoprocessed interstellar ices. We found that PAH ionization energies are significantly reduced when the molecules are embedded in a water ice matrix. Our calculations also indicate that the resulting cations are long-lived likely due to the trapping of electrons at OH or other radical sites produced by photolysis of water. In spite of the large changes that ice induces in ionization energies and electron affinities, electronic excitation energies were found to be remarkably unaffected, which is consistent with experimental observation. Finally, long-lived PAH cations are more vulnerable to attack by radicals, leading to substituted PAH species that may be prebiotic precursors that contributed to the origin of life (Bernstein et al. 1999).

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Comparison Between The Organics Found In Interplanetary Dust Particles And Those Made By Experimental Simulations Of Ice Processing In The Interstellar Medium

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Interplanetary dust particles (IDP's), with typical sizes of a few micron, are collected in the stratosphere. Many of them show very high isotopic abundances, indicating an interstellar origin. It was suggested that IDP's provided a significant amount of prebiotic organic matter to the surface of the early Earth, contributing to the development of life (Anders 1989). IDP's have an average carbon content of 10%-12 % (Schramm 1989), of which 1-2 % are organics (Flynn et al. 2003). The detection of two bands in the infrared, the 3.4 micron (CH stretch of aliphatics) and a band around 1700 cm⁻¹ (C=O stretch of a carbonyl) in IDP's (Flynn et al. 2003) is evidence for organics in IDP's with incorporated oxygen.

We have performed micro-FTIR analysis on 8 IDP's, provided by NASA. By means of a novel technique, we succeeded in removing the silicate fraction of these particles, which allowed a better detection and quantification of the organic features. Next to the previously reported 3.4 micron and 1700 cm⁻¹ bands, we found a broad feature centered at 3250 cm⁻¹, characteristic of the OH stretch vibration in carboxylic acids.Our esultare being compared to the spectra of samples made by UV-irradiation of interstellar ice analogs in our laboratory, in order to elucidate its formation. The fact that organics in IDP's contain oxygen indicates that these species could be formed by photoprocessing of ice mantles in interstellar/circumstellar environments.

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The Solid-State CP/MAS 13C NMR Analyses Of Macromolecular Material In The Antarctic Carbonaceous Chondrites For Evaluation Of The Meteoritic Alteration Level

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Most of organic matter in carbonaceous chondrites is present as insoluble macromolecular material, with a minor part as soluble organic compounds. It has been supposed that the formation of macromolecular material was probably related to thermal alteration in the solar nebula or the meteorite parent body. Recently, quantitative structural analyses of the macromolecular material have been done for Murchison meteorite by solid-state CP/MAS 13C NMR (Gardinier, et al., 2000; Cody, et al., 2002). In the present study, aromatic (Aro) and aliphatic carbons (Ali) in macromolecular material were identified by CP/MAS 13C NMR and the ratios between these two groups (Aro/Ali) were estimated for various Antarctic carbonaceous chondrites and Murchison meteorite, to evaluate the alteration level of each meteorite.

Each powdered meteorite sample, from which soluble organic components were removed, was repeatedly treated by 6N HCl and 8N HF/3N HCl. The macromolecular material was finally obtained by washing with methanol and dichloromethane. All 13C NMR analyses were performed at 75MHz (JEOL CMX300) and used the variable-amplitude CP (VACP) method with a spinning rate of 10kHz, recycle time of 4s, and contact time of 1ms. The spectra were the sum of 21600 acquisitions.

When the Aro/Ali ratio was plotted to the H/C ratio obtained by the elemental analysis, the classification was observed. The more altered chondrites showed higher Aro/Ali and lower H/C, and the less altered ones showed lower Aro/Ali and higher H/C. It was shown that chemical structures of the macromolecular material in meteorites reflected the meteoritic alteration level.

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Structure And Bonding Of Kerogen In The Apex Chert: Distinguishing Biogenic Carbon From Fischertropsch-type Carbon Using Energy Loss Spectroscopy

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In recent years, a more rigorous standard has been required for the identification of typical terrestrial biomarkers. Preserved biogenic carbon, or kerogen, can no longer be identified with optical microscopy. Laser-Raman spectroscopy has been applied to investigate the biogenicity of "microfossils" in the Apex Chert, presumably the oldest fossils on Earth, with mixed results^{1,2}. This ambiguity is due to the relative insensitivity of laser-Raman spectroscopy on disordered carbon³. Two additional techniques, electron energy-loss spectroscopy (EELS) and x-ray absorption near-edge spectroscopy (XANES) may prove useful to distinguish true kerogen from abiotic carbon.

We will compare the EELS spectrum of Apex Chert residual carbon with that of abiotic Fischer-Tropsch-type (FTT) carbon synthesized via hydrothermal methods⁴. The residual carbon is not associated with any microbial morphologies, but it would have undergone a similar geologic history and should share similar spectral features with the proposed microfossils. Spectral features of interest are the π^* peak at 285 eV, indicating sp² bonding, the σ^* peak at 291 eV, which is very sensitive to graphitization, and the carbonyl (C=O) peak at 288.5 eV.

We will also show the usefulness of XANES for the identification of biogenic materials. This technique provides an order of magnitude better energy resolution than EELS. Using XANES, the less intense carbonyl peak can be easily observed in spectra of Apex Chert residual carbon. The presence of carbon-oxygen double bonds suggests that this material does not simply consist of hydrocarbons or amorphous elemental carbon.

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The Hydrothermal Stability Of A-alanine And Related Amino Acids.

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The stability of the structurally simple amino acids α -alanine, glycine, and α -alanine were investigated experimentally under non-enzymatic, aqueous hydrothermal conditions at 120-185°C and 20 bar. An inert gold-lined spectrophotometric reaction cell was specially designed and built for this purpose, and permitted observations of the system in situ at temperature and pressure. There was strong evidence that these amino acids can preferentially undergo polymerization reaction pathways under certain conditions.

Previous studies of this system have generally observed α -alanine to decarboxylate, and glycine to either decarboxylate or polymerize. Differences between the currently available data may be attributable to variability in experimental conditions and in particular to the nature of the reactor surfaces exposed to the analyte solutions.

A postulated reaction scheme involving polymerization will be

presented, along with the resulting rate constants derived mathematically from the experimental data using a factor analysis-based method. Additional information resulting from the model, including calculated concentration profiles and individual molar absorptivities, will also be discussed.

Glycine Ablation During Comet/meteoroid Impact

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Amino acids and other organic compounds important to the chemistry of life are thought to have been delivered to early Earth by asteroids and comets. The survivability of such compounds upon high speed entry is not well understood. If molecular processing occurs during entry, the nature of the new molecules produced by such processing is also an open question. To address this question, we have initiated a study of the ablation of glycine, the simplest amino acid, upon the high speed entry of a comet or meteoroid into an atmosphere.

The study assumes glycine is distributed on the surface of the comet/ meteoroid. The high speed impact creates electrons, ions, and radicals in the atmosphere that react with the surface and either desorb glycine or break it up. The ablation process is studied as a function of entry speed and atmospheric composition. The AURORA code from the commercially available software package CHEMKIN is used in the study.

References

CHEMKIN is a software package available from Reaction Design (2000).

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Enantimeric Separation Of Complex Organic Molecules From Irradiation Of Interstellar/circumstellar Ice Analogs

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Our laboratory group aims at studying the photo- and thermochemical evolution of dirty ice mixtures (containing $\rm H_2O$, $\rm CO$, $\rm CH_4$, $\rm CH_3OH$, $\rm NH_3$, etc.) known to be present on the surface of interstellar grains observed in molecular clouds around protostars and also found in comets.

The first step was to determine the chemical composition of these ices by comparison of interstellar ice infrared spectra from the European Infrared Space Observatory (ISO) with the spectra obtained in laboratory experiments. That work allowed us to identify and quantify the abundance of simple molecules such as H₂O, CO, CO₂ and CH₄, as well as to understand the shapes of some infrared features (shifts, band widths, splittings) resulting from interactions within the ice structure due to molecular complexes.

The irradiation of these ices with UV light at low temperatures down to 10 K leads to the formation of species such as $\rm H_2CO, NH_4^+$ and OCN', which have been already identified in astrophysical sources. If the irradiation is continued, more complex molecules, stable at room temperature, are formed. The refractory residue obtained by warming up the sample to room temperature can be analyzed by chemical techniques such as gas chromatography coupled with mass spectrometry (GCMS). A lot of complex molecules such as glycine, alanine or glycerol are detected, among them amino acids, known to play an important role in prebiotic chemistry.

The extension of this experiment, called Chiral MICMOC (for Matière Interstellaire et Cométaire, Molécules Organiques Complexes, i.e. Interstellar and Cometary Matter, Complex Organic Molecules, repeating the same experiment using circularly polarized UV light has been performed with the synchrotron light of the SU5 beam in LURE. The purpose is to reveal and study the possible apparition of an enantiomeric excess on amino acids formed in such experiments.

Our preliminary analyses results show that a possible enantiomeric excess would be small. A careful data reduction is then required to quantify this effect. These results could be then compared to the excess supposed to appear in the organic matter of some primitive meteorites.

Selective Derivatization And Sequestration Of Ribose From A Prebiotic Mix

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Models simulating a prebiotic synthesis of nucleic acids from simple starting materials are plagued by multiple problems of stereo- and regiochemistry, chemical selectivity, and relative rates of formation and degradation. For example, ribose, the sugar component of nucleic acids, would have been a small component of a highly complex mix of sugars resulting from the condensation of formaldehyde in a prebiotic world. Selective utilization of ribose would have been further complicated by its rate of degradation, which exceeds those of many other monosaccharides.

In this work, attempts have been made to sequester ribose from other sugars by taking advantage of its higher reactivity. In the presence of cyanamide (NH,CN), ribose underwent an efficient reaction to form a bicyclic product, with cyanamide joined at both the 2'-hydroxyl and the anomeric carbon (Sanchez, 1970). This product, ribose-cyanamide, exhibited extraordinary stability and contained ribose in the furanosyl form. Furthermore, upon formation, ribose-cyanamide crystallized out of solution, forming homochiral domains within large, enantiomorphouslytwinned crystals. Ribose was the only sugar of those tested whose complex crystallized spontaneously in aqueous solution.

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Astrobiology And The Origin Of Life On Earth

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Thanks to the combined effort of researchers from a wide range of scientific fields and the development of the new field of Astrobiology, current approaches to understanding how life began on Earth have changed dramatically. In spite of many unanswered questions, nowdays neither the formation of Sun-like stars and planetary systems or the appearance of life itself are seen as the results of miracles or inescrutable random events, but rather as the natural outcomes of evolutionary events.

Although the recognition of the oldest traces of biological activity on Earth is a contentious issue, it is generally agreed that life emerged very rapidly and quickly took hold succesfully establishing itself in a wide range of environments. Although I will argue that astronomical evidence, laboratory simulations and or other of evidence strongly support the idea that the origin of life occurred from a primordial soup formed by organic compounds of both terrestrial and extraterrestrial origins, it must be underlined that others adhere to different schemes. However, it must be underlined that acknowledgment of such differences in opinion have been recognized by the scientific comunity as intellectual challenges that have in most cases led to fruitful clarifying debates.

Bioorganic Molecules In Astrochemistry: Challenges For The Laboratory And For Radio Astronomy

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One of the more interesting classes of species studied recently in interstellar space are large organic molecules of biological interest. These molecules pose potential difficulties for both laboratory spectroscopists and radio astronomers. From the viewpoint of rotational spectroscopy, such compounds are problematic to get into the gas phase and have many low energy conformers (structural isomers), each which exhibit complex patterns. Such spectra are hard to accurately identify in interstellar gas because of the possibility of many chance coincidences. Wide frequency ranges must be searched and a considerable number of transitions detected to establish an accurate identification. Recent confirming observations have been conducted for two organic molecules possessing biologically important functional groups, glycolaldehyde and vinyl alcohol, using the ARO $\dot{K}P12m$ telescope. To date, 24 convincing transitions of glycolaldehyde have been measured in the Sagittarius B2(N) region arising from the Ka = 0, 1 and 2 ladders. For vinyl alcohol, 15 credible transitions thus far have been detected in SgrB2(N). Owing to a high line density in this source, contaminating

features have complicated the identification of these species and others. Our current and future astronomical observations pertaining to the identification of these molecules will be discussed. Recently, the detection of the amino acid glycine has been claimed via its rotational spectrum in the same SgrB2(N) region of the galactic center (Kuan et al. 2003). The claim, although convincing, has met a significant opposition, partly because it was based on predicted frequencies instead of direct laboratory measurements. Experiments are planned to settle this issue.

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Experimental Study Of Potential Abiotic Sources Of Organic Carbon In Rocks From The Early Earth

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The majority of astrobiologists have come to believe that life on Earth had become widespread well before 3.4 billion years (Ga) ago. This belief is largely based on observations that many of the oldest rocks on Earth contain reduced carbon compounds (kerogen and graphite) that are depleted in 13C to a degree typically associated with biological carbon fixation. However, recent reassessments of the geologic context of several ancient rock strata have suggested that the reduced carbon compounds they contain may instead result from abiotic organic synthesis. Chemical pathways that have suggested as sources of organic matter include Fischer-Tropsch-type synthesis within hydrothermal systems and decomposition of siderite (Fecarbonate) during metamorphism. It remains uncertain, however, whether these processes are consistent with the conditions implied by the geologic context or if they are capable of generating the abundance and isotopic composition observed in rock samples from the early Earth.

I will discuss both proposed pathways for abiotic organic compound formation using results of recent experimental studies as a point of reference. Siderite decomposition and Fischer-Tropsch synthesis both generate organic compounds with high potential for preservation in ancient rocks, but they require significantly different conditions to proceed and generate distinctly different products. Studies to evaluate the isotopic fractionation of these synthesis pathways are currently underway. Initial Fischer-Tropsch synthesis experiments resulted in organic compounds that are depleted in ¹³C by about 36% relative to dissolved CO₂, which is consistent with the isotope fractionations observed in ancient rocks.

Concretions: A New Archean Biomarker

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The environmental setting in which life first emerged on earth appears to have been dominated by hydrothermal processes (Brasier et al., 2002) that, because of their unusual chemistry, had the potential to emulate and perhaps synthesize life itself. These hydrothermal systems potentially overwhelm any biospheric geochemical signal and may therefore be the most difficult environments in which to draw the prebiotic-biotic boundary (Lindsay et al., 2003). One approach to solving this dilemma is to search for chemical signals produced by microbes (e.g. Archea) in less complex environments that lie beyond the zone of hydrothermal influence. An example of this approach is provided by diagenetic concretions we have studied in the c.3.1 Ga Paddy Market Formation of the Gorge Creek Group on the Pilbara of Western Australia. The formation consists of fine-grained, thinly bedded, silty sandstones and siltstones which were deposited in a turbidite setting. Graded bedding is common, as are simple sole markings. Synaeresis cracks are present locally.

Analysis of nodules from the Paddy Market Formation shows that most are clasts of well rounded chert or igneous rocks derived form an adjacent fluvial setting, or soft sediment rip-up clasts eroded by turbidity currents from the substrate, while still others are simply conchoidal fractures in fine sediments that emulate concretions. However, a small number of chert nodules are concretionary. Septarian cracks filled with later chert veins transect the nodules. Remnant carbonate rhombic euhedra (70-160µm), now largely replaced by Fe oxides, suggest the chert has replaced a sideritic carbonate that was deposited displacively during diagenesis. Small

pseudomorphs (<10 μ m) of Fe oxides after pyrite occur scattered throughout the chert matrix whilst clusters of larger (30-50 μ m) well developed complex octagonal pseudomorphs of Fe-oxides after pyrite are present in the core of the concretion. The sedimentary interval and the nodules are intensely weathered and, while much work remains to be done, the concretions seem set to provide some of the earliest evidence for life on Earth.

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Reactivity Of Simple Nitriles In Laboratory Simulations Of Titan And Interstellar Ices.

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Dust grains in dense molecular clouds of the interstellar medium acquire icy mantles, and can be subsequently incorporated into comets. Both interstellar and cometary ices are processed by several energy sources to generate a variety of molecules, some of which are likely complex organics. These molecules may have been delivered to the bodies in the early Solar System, including the ancient Earth, serving as an important early source of organic materials.

In the Cosmic Ice Laboratory at NASA's Goddard Space Flight Center we have carried out proton irradiations of samples containing water-ice and simple organic molecules. Experiments were conducted by forming mixed-molecular ices at ~15 K under high vacuum, irradiating them with 0.8 MeV protons, to simulate cosmic-ray bombardment, and monitoring the reactions via IR spectroscopy.

We also have adjusted our experimental conditions to simulate processing of ices on Titan. This is of particular relevance since Titan can be viewed as an astrobiological laboratory. Our results also may be applicable to analysis of data to be returned by the Cassini-Huygens probe.

Residues that remained after warming processed ices to room temperature were analyzed chromatographically to check for the formation of compounds of possible prebiotic significance, as well as to study the thermal and radiation stability of the starting materials. In our presentation, we will focus on ices containing various simple nitriles, such as those found on Titan, in cometary comae, and in the interstellar medium.

Influence Of Limonite And Basalt On Photochemical Processes Related To Early Forms Of Life: Implications For A Martian Medium

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A commonly accepted view is that biomarkers are likely to be present in upper layer of Martian surface. This would imply the presence of natural minerals such as limonite and basalt as protective shield for biomolecules defending chemical substances from destructive Martian environment. We have investigated two processes relevant to the origin of life - solid phase synthesis of polypeptides and nucleotides and their stability in Martian radiation environment - and established that both are adversely affected by presence of mineral components in experimental samples. Since the research task was to find out whether main organic substances (aminoacids and nucleosides) are able to survive and to form more complicated ones in the absence of water, our experimental dry films were exposed to the UVC radiation with 254 nm wavelength abundant on Mars. In particular, mineral beds, which are plausible models of primitive Martian surface, are able to protect impregnated biological molecules from destruction in Martian surrounding and to provide higher reaction yields, as compared to pure molecular samples. Limonite was taken as the analogous material obtaining parameters similar to those of Martian soil. Experimental samples were placed into an isolated chamber containing two types of gases – CO, and N, - to figure out more favorable environment for organic processes. CO,

atmosphere was found to be the most suitable both for the survival of initial molecules and for the formation of new ones. Further calculation made to extrapolate experimental results to more extended time period showed that organic molecules could possibly survive long - duration exposure to cosmic UV radiation. These results coincide with our previous experiments representing the system where minerals of extraterrestrial origin such as meteorites Allende, Murchison and lunar soil were tested with respect to their influence over decay and biological synthesis in similar conditions (Gontareva & Kuzicheva 2001, Kuzicheva & Gontareva 2003). Hence it seems quite plausible that organic molecules are stable enough to survive in Martian conditions and thus might be found in Martian surface. Since organic molecules are much more resistant than bacteria in strong radiation conditions, future missions to explore exobiology sites of interest can be also targeted in order to reveal possible biomarkers such as aminoacids and nucleosides.

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Transformation From Chemical To Biotic Planet

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Science recognizes two great scientific mysteries remaining to be solved. The first and seemingly simplest in terms of basic knowledge is the origin of biology (life) on planet Earth. In this research project fundamental issues concerning the origin of life are being addressed using advanced theoretical materials surface science theory. In this project we use molecular dynamics, solid state electron structure calculations and the quantum chemistry Gaussian computation package to study the adsorption of water, ions and simple organic molecules on transition metal sulphide mineral surfaces. The current work includes:

- 1. Physisorption and chemisorption
- 2. Diffusion and mineral growth mechanisms
- 3. Bulk terminated surface models of minerals
- 4. Chemical reactions leading to a $\{C_1\}$ organic manifold.

To proceed beyond part 4 we are using the Gaussian computation package to identify low molecular weight organic molecules containing S and N atoms that could have been synthesized under hydrothermal conditions (<100atm, ~300–800K) likely existing four billion years ago. If $\{Cn\}$ is a manifold of organic species containing n carbon atoms say mostly in the form of chain molecules. Then the problem is to find the geochemical pathways involving mineral surfaces that connect these manifolds $\{C_1\} \rightarrow \{C_2\} \rightarrow \{C_3\} ... \rightarrow \{Cn\}$ etc. Scenarios for reduction reactions on the mineral pyrite FeS2 have been developed and the results will be described with three dimensional ball and stick models of reactants on low index crystal surfaces.

Three publications have been prepared. The first uses MD to describe the adsorption of water on well (001) pyrite FeS_2 surfaces has been published in J. Chem. Phys. (2004). Two other papers have been prepared that address specific issues in the electronic band structure of the semiconductor pyrite FeS_2 .

Additional Evidence 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. This polymer can be hydrolyzed to yield the amino acids glycine, glutamic acid, aspartic acid, and alanine. Matthews and Moser (1966) proposed that this chemistry could lead to the direct formation of "primordial" proteins from HCN and H₂O that would involve the formation of polyaminomalononitrile, a poly-α-cyanoglycineamidine,

as an intermediate. A. Eschenmoser suggested that this model would be supported if the base-catalyzed reaction of HCN polymer with acrylonitrile yielded increased amounts of glutamic acid arising from the Michael addition of the α -carbanions to acrylonitrile. Indeed, it was found that after hydrolysis of the reaction product, the amount of glutamic acid, as measured as its TBDMS derivative using GC-MS, increased by a factor of 1.2 to 132, depending upon the starting materials and reaction conditions. In the reaction of unlabeled acrylonitrile with 98% C-13 labeled HCN polymer in water, the glutamic acid was found to contain only two 13C labels, consistent with this hypothesis. In a second test, the amount of the amino acid serine detected in the polymer acid hydrolysis products increased over a hundred fold when formaldehyde was stirred with HCN polymer and a small amount of base, consistent with the addition of polyaminomalononitrile anions to formaldehyde. (Minard and McGowan, 2002). This work has now been expanded by studying the reaction of HCN polymer with acetaldehyde and thioformaldehyde (or formaldehyde and sulfide) to produce the amino acid α-groups of threonine and cysteine. The results of these studies will be reported.

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Constructing The First Theoretically Complete Metabolic Network

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An autotroph is an organism which can survive solely off of the inorganic world. It is therefore arguable that autotrophic organisms provide the best contemporary examples of early life – and perhaps even earlier. Harold Morowitz states, "the flow of carbon in the intermediary metabolic pathways of autotrophs recapitulates chemical evolution prior to the universal ancestor."

Autotrophic metabolism offers a unique opportunity to "complete" an entire metabolic system. By "complete" we mean that the metabolic network is biochemical logical: either a biosynthetic pathway or else a transporter exist to account for all metabolites in the organism. In the case of autotrophs, we hypothesize that the organism must synthesize all metabolites, and thus a metabolic pathway must exist from the carbon source to every metabolite in the organism.

Based on this hypothesis, we present a novel approach for the theoretical completion of autotrophic metabolic networks. To demonstrate the approach, we considered the annotation of M.jannaschii, the first autotroph to be genomically sequenced. The approach first constructs a list of all metabolites annotated to be in the organism (by way of enzyme annotation). This is our a priori metabolome. In M.jannaschii, this amounts to 356 metabolites

Next, using our pathway search engine, PathMiner, we systematically infer a biochemical pathway from carbon dioxide to each and every metabolite in the metabolic network. Metabolites with pathways that can be connected using the enzymes annotated in the organism are categorized as "endogenously" connected. We identify only 110 metabolites that can be so connected. PathMiner can also be allowed to consider enzymes not annotated to be in M.jannaschii. These metabolites are annotated as "exogenously" connected. There are an additional 194 metabolites that can be synthesized from carbon dioxide.

The remaining 52 of the metabolites for which PathMiner cannot identify a biosynthetic pathway remain unconnected. Based on our basic biological assumption regarding autotrophs, we believe there must exist metabolic pathways for generating these metabolites. However, the construction of these pathways is beyond the capabilities of PathMiner.

We will briefly discuss exciting future approaches for identifying these pathways using the EXZYME system now under development. EXZYME uses a similar heuristic algorithm as PathMiner, but allows for the inference of novel enzymes and metabolites in the pathway search. This new system will have the capability of delivering on the promise of the first theoretically complete metabolic network.

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Are Young Solar Nebulae Nurseries For Microorganisms?

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Early carbonaceous asteroids contained liquid solutions that we reconstructed for biological tests. The solutions contain the nutrients nitrate, phosphate and iron, also 10 g/L of organic compounds including amino acids and adenine, and high concentrations of Ca, Mg, Na, K, and sulphate. This environment can be suitable for early halophiles. The carbonaceous chondrites also contain about 2% solid organic polymer which may be nutrients for heterotrophs.

To examine microbial responses, we inoculated these solutions and wet carbonaceous chondrite meteorites with microorganisms. Several soil microorganism including Nocardia asteroides and Pseudomonas fluorescens, and algae and cyanobacteria grew to total populations up to 10⁷ CFU/ml, similar to soil solutions (Mautner 2002).

Possible indications of early life in asteroids: The relative amounts of the carbon, nitrogen, phosphorus and potassium in CM2 meteorites are similar to biological matter; amino acids, adenine and coal-like polymer are present; also putative structures resembling fossilized blue-green algae (Claus and Nagy, 1961; Urey, 1962).

Microorganisms may originate and multiply in the early asteroid solutions, and frequent collisions can disperse them throughout the asteroids where they can establish large total populations and reach planets. Many asteroids and comets are ejected from the nebula and can disperse microorganisms to other young solar systems where they can multiply and disperse space similarly (Mautner 1997, 2000). The chemical and biological results suggest that early solar systems may be efficient nurseries to multiply and vehicles to disperse microbial life through natural or directed panspermia.

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Interstellar Photochemistry As A Source Of Meteoritic Pre-biotic Organic Molecules.

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The many tons of organic material that came to Earth 4-5 Ga ago in meteorites and dust particles probably helped to make the Earth habitable, and possibly played a role in the origin of life. The organic compounds in these carbonaceous meteorites include amino acids (basic components of proteins), quinones (aids to electron transport), and a host of other complex organic molecules, including some that form vesicles (perhaps the earliest membranes)

The origin of many of these molecules remains mysterious, but in recent years we have performed experiments demonstrating that the energetic processing of interstellar ice analogs produces these same compounds: amphiphiles (Deamer et al., 2003; Dworkin et al., 2001), quinones and other substituted aromatics (Bernstein et al., 2003; 2002a), and amino acids (Bernstein et al., 2002b). Thus, low temperature ice photochemistry could account for the presence of many of these molecules in meteorites. This

is consistent with the deuterium enrichments of many of these meteoritic molecules. If many of these compounds formed from ice photolysis, rather than solely from aqueous alteration for example, then they might be more common than would otherwise be presumed. Wider distribution of prebiotic organic compounds may increase the number of environments where life arises.

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The Formation Of Glycerol Monodecanoate By A Dehydration/condensation Reaction: Increasing The Chemical Complexity Of Amphiphiles On The Early Earth.

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Dehydration/condensation reactions between organic molecules in the prebiotic environment increased the inventory and complexity of organic compounds available for self-assembly into protocellular structures. As a model of such reactions, we have investigated the esterification reaction between glycerol and decanoic acid that forms glycerol monodecanoate. This amphiphile enhances robustness of self-assembled membranous structures of carboxylic acids to the potentially disruptive effects of pH, divalent cation binding and osmotic stress. Experimental variables included temperature, water activity and hydrolysis of the resulting ester product, providing insights into the environmental conditions that would favour the formation and stability of this more evolved amphiphile.

At temperatures exceeding 50° C, the ester product formed even in the presence of bulk water, suggesting that the reaction occurs at the liquid interface of the two reactants and that the products segregate in the two immiscible layers, thereby reducing the rate of the hydrolytic back reaction. This suggests that esterification reactions were likely to commonly occur in the prebiotic environment as available reactants underwent cycles of wetting and drying on early landmasses at elevated temperatures.

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Downstream Elements Of The Protein Translation System; Key Mechanisms Necessary To Life As We Know It

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The upsteam portion of the translation system and its components, such as tRNAs, aminoacyl-tRNA synthetases, the genetic code, elongation

factors, release factors, and the ribosomal peptidyl transferase site itself, has been the object of many studies related to fundamental requirements of life and its possible evolution from an RNA world. However, key components of the downstream portion, such as the ribosome exit tunnel, the signal recognition particle, various chaperones, signal peptides (and their coding) and the translocon, are also universally present and evidently necessary for life as we know it.

This article reviews relevant facts about these downstream elements from the literature (including recent contributions which significantly revise some earlier accepted views), with emphasis on aspects likely to be important to early life, such as co-translational insertion into plasma membrane (or endoplasmic reticulum). The article concludes with some comments on the differences inherit in carrying out the upstream tasks in an RNA world, which mostly involve catalyzing reactions by ribozymes, etc, versus those of the downstream tasks, which are more mechanical in nature, and for which functions, for the most part, RNA based mechanisms have not as yet been demonstrated.

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Formation of prebiotic compartments on mineral surfaces

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The clay mineral montmorillonite can catalyze the synthesis of RNA from activated ribonucleotides; this and perhaps other mineral surfaces are therefore thought to have played a key role in the emergence of polymers capable of encoding heritable information (Ferris and Ertem, 1992; 1993). We have recently reported that montmorillonite greatly accelerates the spontaneous conversion of fatty acid micelles into vesicles (Hanczyc, Fujikawa, and Szostak, 2003). Clay particles often become encapsulated within the vesicles they have assembled, thus providing a potential pathway for the prebiotic encapsulation of catalytically active surfaces within membrane vesicles. In addition, we show that RNA bound to clay can be carried into vesicles, highlighting the unexpected ability of mineral surfaces to bring together the key components of primordial life. We have extended our analysis of vesicle catalysis to include other minerals and surfaces. Results show that while RNA polymerization on minerals may be restricted to the surface environment provided by montmorillonite, vesicle formation is enhanced in the presence of disparate types of mineral surfaces. Our work with synthetic surfaces is now providing clues to the mechanism of this amphiphile-surface interaction.

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The Role Of Small Molecules In The Origin Of Life

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One commonly accepted theory holds that life began with the spontaneous abiotic formation of RNA or a related macromolecule that exhibited both genetic and catalytic capabilities. Although this idea has intellectual elegance, its experimental support is drawn entirely from "prebiotic" syntheses. However these syntheses have required multiple steps, each of which has employed a very limited number of purified reagents. The reactions have been carried out with modern laboratory equipment under careful supervision. The probability that such a sequence of steps would take place in a natural setting on the early Earth is extremely small (Shapiro 2000). These points will be illustrated by an analysis of the well known oligomerization of activated RNA components by clay minerals (Ferris 2002).

The alternative to a macromolecular origin of life is one in which a collection of small organic molecules enhance their numbers through catalyzed reaction cycles, driven by a flow of available free energy (Morowitz, 1999). Heredity is stored as a compositional genome (Segré and Lancet 2000), and reproduction takes place by splitting of the ensemble into smaller fragments. Although a number of potential systems of this type have been suggested and individual reactions carried out (for examples, see Morowitz 1999 and Wächtershäuser 2000), no experimental demonstration has been made of the operation of such a self-enhancing reaction network. The requirements for a successful system of this type will be described, and a new suggestion will be made: a "driver" reaction is needed that directly couples the external energy source to the central metabolic cycle.

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Peptide Synthesis In Simulated Deep-sea Hydrothermal Environments

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The synthesis of oligomeric biomolecules such as peptides is the key step marking the evolution from prebiotic chemistry to biochemistry (Imai et al., 1999). While monomer synthesis has been demonstrated to proceed in high-energy impact shock, lightning, cavitation or UV-radiation dominated environments (Chyba and Sagan, 1992), monomer oligomerization requires lower energy yields (Kawamura, 2001), typically found in geological settings such as deep-sea hydrothermal environments (DSHE). In particular, increasing temperatures are predicted to shift the thermodynamic equilibrium between amino acids and product peptide as well as between precursor and successor peptide toward the product oligopeptide (Shock, 1992, Amend and Helgeson, 2001), however, this hypothesis has not been tested experimentally. Using hydrothermal gold cells we demonstrate the formation of short peptides from the amino acid glycine in the temperature range 160°C to 260°C and 200 bar, conditions typical of DSHE. We show that glycine and product peptides enter into equilibrium and demonstrate a lowering of the Gibbs energies of diglycine and diketopiperazine formation from glycine with increasing temperature. Our results confirm that the thermodynamic stability of the peptide bond in diglycine and diketopiperazine increases relative to the free acid with increasing temperature (Shock, 1992). They support a high temperature origin of life and the early emergence of peptides during chemical evolution.

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New Ionic Reactions, And Catalysis By Polycyclic Aromatics, As Pathways In Prebiotic Synthesis

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Prebiotic synthesis in planetary ionospheres and in interstellar clouds can contribute organics the origins of life. We observed new ion-molecule reactions for synthetic and dissociative processes in these ionizing environments.

- 1. Hydrogenation by reactions between hydrocarbons and formaldehyde. We observed hydrogen transfer reactions of the type $\rm H_2CO^+ + CH_3CCH$ -> $\rm C_3H_6^+ + CO$, and analogous reactions starting from ionized alkenes and alkynes and formaldehyde. The reactions can yield to saturated ions that associate with oxygen and nitrogen compounds to give more complex organic ions.
- 2. Exothermic reactions of $\mathrm{H_3}^+$ with alkanes, alkenes, alkynes, and aromatic hydrocarbons are mostly dissociative with the loss of $\mathrm{H_2}$ and methane. Nondissociative proton transfer is observed with benzene, pyridine, and larger aromatics (Milligan et al.. 2002). These reactions can contribute to the steady-state distribution of hydrocarbons and to the build-up of aromatics.
- 3. Concerted charge transfer/condensation on ionized aromatic and polycyclic hydrocarbons. We observed the reaction $C_6H_6^++2$ CH_3CHCH_2 -> $C_6H_{12}^++C_6H_6$ that involves charge transfer made exothermic by the concerted condensation reaction (Meot-Ner et al.. 1997, Pithawalla et al. 2001) The reaction has a significant negative temperatures coefficient can reach unit efficiency at interstellar temperatures. Similar processes may occur with polycyclic aromatics ions and we are investigating such reactions.

In summary, ion chemistry can contribute to the accumulation of hydrocarbons, especially aromatics and PAHs in interstellar clouds, both by synthesis and by their stability against dissociative processes. Their ions can in turn catalyze the accumulation of complex organics in prebiotic synthesis.

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Prebiotic Synthesis Of Autocatalytic Molecules And Microstructures

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Our research goal is to model the chemical processes on the primitive Earth that generated the first autocatalytic molecules and microstructures involved in the origin of life. Our approach involves investigation of a model origin-of-life process named the Sugar Model that is based on the reaction of formaldehyde-derived sugars (trioses and tetroses) with ammonia

(1,2). Recently, we demonstrated that under mild aqueous conditions the Sugar Model process yields autocatalytic products, and generates organic micropherules (2-20 μm dia.) that exhibit budding, size uniformity, and chain formation. We also discovered that the sugar substrates of the Sugar Model are capable of reducing nitrite to ammonia under mild aqueous conditions. In addition studies done in collaboration with Sandra Pizzarrello (Arizona State University) revealed that chiral amino acids (including meteoritic isovaline) catalyze both the synthesis and specific handedness of chiral sugars.

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Analysis Of Mixtures Of Amino Acid Enantiomers By IH NMR Spectroscopy Using Cobalt(III) and Rhodium(III) Chiroporphyrins As Chiral Shift Reagents

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We have designed a novel family of chiral shift reagents which bind analytes as axial ligands of a diamagnetic metal center embedded in a porphyrin with four chiral meso substituents in an α , β , α , β conformation. Chlorocobalt(III) tetramethylchiroporphyrin^[1-4] CoCl(TMCP) quantitative in situ derivatization of chiral amino compounds without any detectable kinetic resolution,[1] and it allows a qualitative and quantitative determination of their enantiomers in a mixture using 1H NMR spectroscopy. [2] The influences of the chiral cavity and of the ring current of the porphyrin on the signals of amino acid methyl esters L* can be seen in the upfield region of the ¹H NMR spectrum of the bis-adducts [Co(L*)2(TMCP)]+Cl-. The signatures of the (R) and (S) ligands are well resolved at 200 MHz, and their relative intensities can be readily determined by peak integration. We have a complete collection of spectral fingerprints for the adducts of the 20 biogenic amino acid methyl esters (R and S), which allows a safe assignment of each amino acid enantiomer. 1D 1H TOCSY experiments allow an unambiguous determination of the amino acid enantiomers which are present in a complex mixture. [3] The structural basis of the exceptionnally large diastereomer dispersion in these adducts has been investigated by X-ray crystallography.[4]

CoCl(TMCP) binds two amino acid ligands, and the formation of three diastereomeric species $Co^*(R)(R)$, $Co^*(R)(S)$, and $Co^*(S)(S)$ from a mixture of (R) and (S) amino esters can be a source of complexity in the analysis of unknown samples. In the iodorhodium(III) complex RhI(TMCP) a single axial coordination site is available for amino ester coordination, leading to only two mono-adducts Rh*(R) and Rh*(S), which greatly simplifies the enantiomeric analysis of amino acid mixtures.

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Boron, Ribose, And A Martian Origin For Terrestrial Life

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The recent discovery of an efficient inorganic pathway for the synthesis of ribose (1) is a major advance in the understanding of the origin of life. For the first time, the there is a pathway that leads to copious quantities of this biologically critical sugar that avoids its condensation into brownish, tar-like residues. However, the critical requirements – locally high concentrations of chemically available boron and calcium ions in an alkaline environment – may have been more likely to have been present on the early Martian surface than on the early Earth.

Boron is a soluble trace element in most continental rocks, which is freed upon surface weathering and usually finds its way into the oceans. Deposits of economic borate minerals like colemanite and ulexite are formed exclusively by evaporative concentration in playa lake deposits that drain large areas of igneous rock, such as those in California (2), Turkey, China, and the Andes. This requires extensive areas of subaerial exposure, coupled with an active hydrological cycle.

The discovery that rocks ejected from Mars by impacts can be transferred to Earth without being heat sterilized (3), that living organisms can withstand space travel for many years (4, 5), and laboratory studies indicating that bacteria can withstand the acceleration forces produced during the ejection and re-entry processes (6) have made it clear that both the surface of Mars and Earth are both potential candidates for the cradle of Terrestrial life (7). However, the Hadean and early Archean Earth was most likely a 'water-world', in which sedimentary transport systems were short. In contract, Noachian Mars probably had a wet interval during the major eruptive phase of Tharsis (8), with rivers draining through long distances. Hence, the discovery of this borate-dependent ribose synthesis pathway strengthens the hypothesis that we were all originally Martians (7).

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The Real Rates Of Rna Evolution Under Selection

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With the exception of limited viral and bacteriophage sequence data reconstructed phylogenies for nucleic acid evolution have been dependent upon extant sequence information. However, in vitro evolved ribozymes (RNA molecules which are autocatalytic) provide a unique and unprecedented view into RNA evolution. We report the phylogeny of independent lineages of in vitro evolved ribozymes where the rate of mutation, actual ancestral states, and the specific selection constraints are known. In doing so, we were able to evaluate the population structure of each generation. These metrics indicate the direct evolutionary response of a structural RNA to the selective pressures experimentally applied as related to linear time within the population. This analysis provides two metrics: 1) the amount of diversity (sequence space) that a particular RNA sequence that is catalytically active can transverse and 2) the actual rate of evolution in terms of accepted point mutations. These two values have direct relevance to the possible diversity and amount of time necessary to populate an RNA world with the requisite number of molecules at the boundary of a chemical/ pre-biological system.

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Lipid Catalysis Of Oligomerization Of Amino Thioacids And Thioesters

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The long term goal of research on the origin of cellular life is to better understand how polymerization reactions of biopolymers became associated with self-assembled membrane structures composed of amphiphilic molecules. One question which arises in this regard is: did lipid surfaces help organize polymerization reactions?

Maurel and Orgel (2000) recently reported that α -thio glutamic acid (GluSH) can be oligomerized in aqueous solution in the presence of bicarbonate and oxidant. Here we show that vesicles made from didode cyldimethylammonium bromide (DDAB), a positively charged synthetic amphiphile, strongly accelerate the oligomerization of GluSH and that oligomers are formed at much lower concentrations. Simultaneously with the formation of oligo-glutamates the vesicles aggregate visibly to large structures.

In a different approach micelles composed of 2-mercapto fatty acids were oxidized to the respective disulfides which form vesicles under basic conditions. In addition thioesters between glutamic acid and 2-mercapto fatty acids have been synthesized. They assemble into micelles and react to give oligoglutamates. Here we report on progress in redox-controlled micelle-to-vesicle transition, peptide formation and the coupling of these two processes.

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Spontaneous Chiral Enhancement In Racemic Mixtures Of Amino Acids

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We propose that physical asymmetries of D and L amino acid structures arising from parity violating energy differences can interact differentially with electronic or magnetic spin states of water of hydration. This interaction produces cooperative effects during nucleation that cause D and L enantiomers to crystallize into different polymorphic structures. Because polymorphs exhibit differential nucleation rates and solubilities, enantiomeric enhancement can occur during crystallization from racemic mixtures. Such an enhancement for DL tyrosine solutions was recently reported by Shinitzky et al. (2002). It is conceivable that polymorphic crystallization of enantiomers may also account for the L-enhancement of amino acids observed in the Murchison meteorite by Cronin and Pizzarello (1997).

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Habit and habitat of earliest life on Earth

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If we wish to determine whether life ever flourished on planets other than our own, it seems sensible to first study the rise of life as it is recorded in the geologic record of Earth. This will improve our ability to predict the types of geological settings in which life might arise on other planets and to recognize traces of microbial life in the geologic record of those planets.

The Strelley Pool Chert (Pilbara, Western Australia), with its extensive outcrops of putative microbially formed stromatolitic structures (Hoffman et al, 1999), is a prime natural laboratory for studying Earth's early biosphere. However, verifying a biological origin for the putative stromatolites and other microbial structures of the Pilbara, and the type of environment in which they formed, has been problematic (Brasier et al., 2002). The present study seeks an understanding of whether microbial life

existed 3.5 billion years ago during deposition of the Strelley Pool Chert, the type of environment in which the organisms may have flourished, and how they interacted with their environment. A summary of recent findings is presented herein.

The influence of microorganisms upon sedimentation during deposition of the Strelley Pool Chert is strongly supported by; (1) highly uneven spatial distribution of stromatolites, (2) complex conical morphology (+/- 2nd order sinuosity) that varies between adjacent stromatolites, (3) faithful inheritance of millimetre-scale laminae over heights of > 1 m, (4) consistent formation of acute angles between cone axes and the up dip side of a palaeoslope, and (5) retention of granular material on steep-sided cones. Many of these individual characteristics might be explained by either a biological or non-biological (for example; structural, mechanical or chemical) process. However, research suggests that there are no examples in the geologic record where such a unique group of characteristics are clearly produced by abiologic mechanisms, but biogenic examples are documented. Thus, a biologic input seems most probable.

A hydrothermal origin for the Strelley Pool Chert has been proposed (Van Kranendonk, in press), and recent mapping suggests there may have been local areas of hot fluid emplacement at or near the surface during some stages of deposition. A localised unit at the base of the Strelley Pool Chert comprises banded black and green chert crosscut by 5-30 cm-wide breccia dykes that extend up to lenticular green chert +/- breccia deposits. Cross cutting relationships and alteration around the tops of the dykes, but not in the overlying strata, indicate that successive breccia lenses were deposited atop one another at the palaeosurface. Upward flow of fluidized material through the dykes is suggested by puzzle-fit geometry of pieces spalled and lifted off the dyke walls and by flow banding in the matrix. The effects of heat are evident in patterns of thermal maturity in carbons and reaction rims on entrained detritus. Although indications of heat, upward flow of material and surface exhalation are present; the provenance, emplacement mechanisms and regional significance of this localized basal unit are not clear. Importantly, the basal unit forms part of a continuous depositional sequence with the overlying stromatolitic beds. Thus, questions arise regarding interrelationships between processes that formed the basal chert breccia/dyke deposits and those that formed stromatolites. On the one hand, emplacement of hot, fluidized material apparently preceded the onset of stromatolite formation, as evidenced by the superposition of stromatolitic layers above the green chert layers. This suggests that stromatolite formation and hot fluid emplacement processes were temporally dissociated. On the other hand, stromatolites in the vicinity of the basal green chert breccia/dyke system show greater morphological complexity compared to those elsewhere in the Strelley Pool Chert, suggesting a spatial (causal?) relationship, and possibly hydrothermal (?) 'nurturing'. The latter is consistent with popular models of the early terrestrial biosphere (Corliss et al., 1981), in which primitive microbial life flourished around hydrothermal vents and derived chemical and thermal energy from exhaled fluids. Testing that model will help validate, refute or refine its application for landing site selection and astrobiological exploration of other planets, particularly Mars.

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The Pilbara: One Billion Years Of The Early Evolution Of Earth's Surface Environments And Life

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The Pilbara contains the most complete sequence of 3.5 to 2.4 billion year old sedimentary and volcanic rocks. Because many of these rocks have experienced only low-grade metamorphism it is our best available natural

laboratory for studying the origins and early evolution of life on Earth (and other planets) and the environments it inhabited. Indeed discoveries of the oldest possible microfossils, stromatolites and molecular fossils, as well as key mineral, geochemical and isotopic evidence of surface environments and the biosphere have all been reported from Pilbara rocks. Unfortunately complex geology and deep weathering (since the Mesozoic) makes interpretation of some of this record ambiguous leading to heated debates over evidence for life and environmental conditions. It is not surprising then that the first stages of the Astrobiology Drilling Program are being drilled in the Pilbara to obtain samples of sedimentary rocks unaffected by modern weathering. These should provide the best evidence yet of when and how life evolved on Earth, the nature of the environments it inhabited and a template for evaluating possible evidence of life from Mars and other planets. This talk will briefly outline the evolution of the Pilbara as one of the Earth's first continents and the interpreted environmental settings of the range of sites being drilled by the Archean Biosphere and Deep Time Drilling Programs. These include 3.52 to 2.5 Ga submarine and lacustrine black shales, 3.45 Ga deep- and shallow-marine banded cherts, 2.72 Ga stromatolite reefs, an interpreted 2.76 Ga paleosol, and banded iron formations.

Homochiral Growth From Enantiomeric Crossinhibition

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The chirality of molecules in living organisms must have been fixed at an early stage in the development of life. All life that we know is based on RNA and DNA molecules with dextrarotatory sugars. The introduction of chiral molecules is assumed to have taken place at a stage when there was already growth and self-replication. It is therefore plausible to assume that the existence of chiral molecules has an autocatalytic effect in producing new chiral molecules of the same chirality. This is the basis of the recently proposed polymerization model of Sandars (2003). The purpose of the present paper is to reconsider this model (or a slightly modified version of it) and to analyze its stability behavior and conservation properties.

The achiral (racemic) solution is found to be linearly unstable once the relevant control parameter (here the fidelity of the catalyst) exceeds a critical value. The growth rate is calculated for different fidelity parameters and cross-inhibition rates. A truncated version of the model is used to derive a set of two ordinary differential equations and it is argued that these equations are significantly more realistic than those used in earlier models of that form. Finally, a chirality parameter is defined and shown to be conserved by the nonlinear terms of the model.

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Abiogenic Prebiotic Organic Compounds In Terrestrial Volcanic Gases.

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Terrestrial volcanic gases emitted at 360-440°C from Vulcano, Italy, were analysed for a wide range of organic compounds using a new method specially developed for this purpose. Among the compounds identified were simple nitriles, alcohols, halocarbons, alkyl thiols, and carboxylic acids (including formic and acetic).

Previous studies on the organic chemistry of volcanic gas emissions have focused on either hydrocarbon or halocarbon compounds and were hampered by analytical problems due to the sulphurous, hydrous and acidic matrix of volcanic gases. We successfully applied our newly developed approach to overcome these problems during both sampling and analysis. Sampling was performed by cryogenic separation of the target compounds from the gas stream, and analyses were accomplished using short-path thermal desorption solid-phase microextraction cryotrapping gas chromatographymass spectrometry (SPTD-SPME-CT-GC-MS). As a result of the increased sensitivity and selectivity of this method, we were able to determine a large

range of compounds using small sampling volumes (0.5 L dry gas) down to pptv levels of concentration. We found the identified organic compounds to be present at levels above all blank readings. Several blanks were used, including field blanks (ambient air at remote, near sampling and vegetated sites), laboratory air blanks and procedural blanks.

Our results support recent theoretical predictions on the abiogenic synthesis of prebiotic organic compounds in volcanic gases (Zolotov and Shock, 2000). Historically, simple hydrocarbons have been identified in volcanic emissions since the mid-nineteenth century on Italian volcanoes (Sainte-Claire Deville, 1856) and elsewhere.

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Relic Chemical Structures Left Over From The Prebiotic Era – Cluster Molecules Of Fe And S That Are Enzyme Cofactors In Extant Organisms And Their Connection To Sulphide Mineral Surfaces

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It has been repeated suggested that Fe-S enzyme cofactors may have evolved from Fe-S catalytic particles present on the Earth in a pre-biological phase of the origin of life. This presentation explores this connection. Semiconductor iron sulphide minerals are readily doped and would have provided an adaptable source of holes and electrons for low activation energy redox chemistry. This is a prime function of Fe-S clusters in enzyme cofactors.

We report the geometrical and electronic structure of a series of cluster molecules (including the biochemically important clusters ${\rm Fe}_4{\rm S}_4$ and ${\rm Fe}_8{\rm S}_9({\rm SH})_2$) for: different electronic charge & spin manifolds, endohedral cavity occupants, and different terminal iron atom coordinations. Some of these structures are strikingly evident in iron sulphides like greigite ${\rm Fe}_3{\rm S}_4$. The intent of this work is to explore the key physical and chemical aspects that alter the electronic and structural framework of these molecules, through which its main biochemical functions are activated. We also examine other aspects of the structure which also modify structure and properties and possibly reveal new functions.

The molecule $Fe_8S_9(SH)_2$, a component of many Fe-S coenzymes, consists of two directly facing Fe_4S_3 units held together by three μ_2 -S bridges. In the calculations reported here the two extreme ends are capped by $-SH_2$ groups. This structure is unique in enzymes in that the two ends are the only form of covalent bond attachment to rest of the protein. In contrast, the cuboidal Fe_4S_4 cluster is tethered by four covalent cysteine linkages on at each Fe atom site to its protein scaffold. In addition to the basic structure $Fe_8S_9(SH)_2$, we also report studies of changes induced when selected atoms, diatoms and triatomics are endohedrally included in the central cavity formed amongst the six trigonal prism iron atoms, and in addition describe the change in geometry accompanying the replacement of one the terminal Fe atoms by a different transition metal atom.

Prebiotic Methane Abundance In The Hydrogen/CO₂-rich Atmosphere. Methane Atmospheric Recycling And CO₂-Shielding.

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Decreased solar luminosity and multiple lines of geologic evidence in favor of a "liquid" ocean on the ancient Earth set a puzzle known as the "Faint Young Sun" paradox. For several decades, elevated atmospheric ${\rm CO_2}$ levels were considered to be the most self-consistent solution for the warm early Archean/Hadean climate (Kasting et al., 1993). However, to offset a ~25% decreased solar luminosity (at ~3.5 Gyr ago) and keep the mean global

surface temperature at ~288K, $\rm CO_2$ should have been at a steady-state concentration of about 0.3 bars. At such high levels, $\rm CO_2$ would condense in the Earth's polar regions (as it does on Mars today) and no longer could be considered as the only "stabilizer" of the early Archean/Hadean climate. Climate simulations (Pavlov et al., 2000) show that 100-1000 ppm of methane would be sufficient to maintain warm climate under decreased solar luminosity without invoking huge $\rm CO_2$ levels.

The major argument against methane in the prebiotic atmosphere is the lack of substantial methane volcanic flux even in the early Earth history because of the early mantle differentiation.

However, previous calculations assumed a high ("diffusion-limited") rate of hydrogen loss to space. If atmosphere was anoxic, hydrogen should have been lost at a much (~100 times) slower rate (Tian et al., 2004). In hydrogen-rich atmospheres $\mathrm{CH_4}$ molecules could have been effectively "recycled" after initial photolysis. Additionally, high $\mathrm{CO_2}$ levels (if present) would partially shield $\mathrm{CH_4}$ molecules from UV photolysis allowing further $\mathrm{CH_4}$ build up. Here we demonstrate that 100-1000 ppm could be maintained with a much smaller methane flux in the hydrogen/ $\mathrm{CO_2}$ -rich atmospheres.>

We conclude that methane should have been abundant even in the prebiotic environment and most likely was responsible for the lack of irreversible glaciations early in Earth history.

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Prebiotic molecules formed in the protosolar nebula and delivered to the primordial Earth are thought to have contributed to the origin of life. The recent discovery of glycine in the interstellar medium (Kuan et al 2003) is a milestone in the field of astrobiology. Laboratory experiments have demonstrated that energetic processing of astrophysical ice analogs produces prebiotic molecules, including glycine and other amino acids (Bernstein et al. 2002). A broad feature at 2165 $cm^{\text{--}1}$ observed in the infrared spectra of a number of protostellar objects is indicative of such processing. While this feature resisted definitive identification for many years, numerous experimental studies covering more than two decades provided enough evidences to support a good conjecture of OCN- in icy grain mantles for the carrier of this feature. We have thoroughly confirmed this with quantum chemical cluster calculations. We observed spontaneous formation of OCN-NH₄+ charge transfer complexes arising from HNCO or HOCN and NH, in a water ice environment. The frequencies of the asymmetric stretching mode of OCN including H, C, N, and O isotope shifts were computed at the B3LYP/6-31+G** level, as well as the frequencies of two other weak vibrational modes. As reported recently (Park & Woon 2004), the calculated values of all seven spectroscopic properties are in very good agreement with the laboratory data. The scaled harmonic frequency for the HNCO case where 12 explicit waters were included is 2181 cm⁻¹. We also explored OCN formation in pure water ice without a strong base such as ammonia present as well as OCN- completely isolated by solvent water molecules (Park & Woon, to be submitted).

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Ni-(Fe) Alloy And Sulfide Formation During Forsteritefayalite Dissolution At Hydrothermal Conditions: Importance For Prebiotic Synthesis

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Ni-Fe alloys (e.g., awaruite) and sulfides (e.g. heazelwoodite, pentlandite) are commonly present in serpentinized (ultra)mafic rocks of the ocean floor (e.g. Alt & Shanks, 1998). Recently, Horita & Berndt (1999) have shown that hydrothemally formed Ni-rich Ni-Fe alloys can catalyze the kinetically inhibited abiogenic reduction of bicarbonate to methane. Microscopic grains of Ni-Fe alloys on the surface of minerals could have served as primordial catalytic centers for reactions essential for prebiotic synthesis, such as CO₂ and N₂ reduction.

The objective is to evaluate how Ni-Fe alloys and sulfides form during forsterite-fayalite dissolution at hydrothermal conditions. Dissolution experiments with natural (<0.3 wt.% NiO) and Ni-doped (1 and 50 wt.% NiO) synthetic forsterites-fayalites and deionised, O₂-free water (R/W 0.07-0.14) were conducted in passivated titanium vessels (~3 mL volume) at 230 °C (duration 40 days). Characterization of samples prior to experiments confirmed the absence of Ni⁰-bearing phase (SEM). The surface nickel was found to be present in the oxidized state as Ni²⁺ (XPS). The XPS and SEM methods were also used to examine the reacted samples. The results indicate that Ni is mobilized during the dissolution process. The presence of sulfur in the system is important as the Ni-Fe (di)sulfide formation appears to be favoured over the formation of a iron-nickel alloy.

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Peptide Nucleic Acids Can Form Ordered Selfassembled Monolayers On Surfaces With Dna Recognition Capability

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Peptide nucleic acid (PNA) is an achiral and uncharged DNA mimic that exhibits high biological and chemical stability. From an evolutionary point of view, PNA has been proposed as a suitable candidate to have preceded RNA at the first stages of the evolution of genetic molecules, constituting a putative "pre-RNA world". Single stranded (ss) PNA hybridizes to complementary targets (RNA, DNA or PNA) according to Watson-Crick rules for base-pairing, and it shows higher affinity and specificity for complementary DNA than the corresponding ssDNA sequence.

The use of powerful label-free techniques for surface characterization such as synchrotron radiation based photoemission spectroscopy (XPS), X-ray absorption near-edge spectroscopy (XANES) and atomic force microscopy (AFM) allowed us to describe the formation of ordered selfassembled monolayers (SAMs) of ssPNA molecules on gold surfaces, with efficient capability for recognizing complementary ssDNA. In spite of their remarkably long length of 6 to 7 nm, cystein-containing ssPNA oligomers can assemble standing-up on the surface similarly to the SAMs of short alkanethiols. The equilibrium between lying and standing up molecules on the surface is a function of the molecular coverage, and it does not require the addition of spacer thiols or other adjuvant molecules that would lead to mixed monolayers, as previously reported for ssDNA. The specificity of SAMs of ssPNAs is such that they can discriminate even a point mutation in ssDNA target sequences. Therefore, ordered PNA arrangements on surfaces could have played a prominent role during the early evolution of genetic information.

Theoretical Study Of Effects Of Water Environment On Spectra Of Small Biological Molecules

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Effects of water environment on infrared spectra of several molecules of biological relevance (amino acids, nitriles, small peptides) are investigated using quantum chemistry techniques. In cases of amino acids and peptides, the effects of water on spectra were found to be very significant, leading to large red shifts of vibrational frequencies and significant increase of infrared intensities. In addition to these effects, it was also found that water environment (modeled in theoretical calculations by a cluster approach) also leads to the possibility of proton transfer reactions and stabilization of zwitterionic forms of amino acids and peptides. While the hydrogen bonding interactions with water lead to significant red shifts of carboxyl group vibrational frequencies of acids, C N stretches of nitriles (precursors of amino acids) shift to a much lesser extent and in the opposite direction (to the blue) upon complexation with water. The effects of complexation with water found in this study should be helpful in the interpretation of astronomically observed infrared spectra of organic molecules present in the outer solar system and in the interstellar medium.

Modeling The Simplest Generic Life: Spontaneous Emergence Of Selection From Molecular Self-Organization

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A generic molecular system is described showing how auto-catalysis can spontaneously develop towards a self-contained, self-representing, selfreplicating molecular system capable of undergoing natural selection in its simplest form. A three step proto-evolutionary sequence is described in which a spontaneously auto-catalytic set of molecules that produces a simple linear lipid as a byproduct will, with reasonable probability, tend to self-enclose in an aquatic environment so as to contain the essential elements of the autocatalytic set within a self-assembling lipid membrane and thus prevent dissipation when substrates become exhausted. Such molecular systems will have vastly greater probability of maintenance and reconstitution across disruptive conditions than other autocatalytic systems. Molecular systems of this form that additionally produce byproducts which selectively bind together the principle catalysts themselves will further be capable of self-similar reconstitution of multiple replicas despite physical disruption. They will additionally be subject to selection via the production and constitution of these replicas with respect to surrounding conditions because variants of such binding molecules will effectively re-present in their structure specific features of the reaction topology of the autocatalytic system that produced them. Many different kinds of molecular systems with these basic features may be able to form spontaneously depending on planetary conditions. Because of their self-maintaining autonomy, replicative potential, and capacity to evolve via selection such simple molecular systems should be considered a form of protolife.

The ancestor to all modern life on Earth lived in a hot environment

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In order to understand the environmental conditions necessary for life to evolve on other planets, it is first necessary to determine what conditions existed when life first emerged on Earth. Modern organisms have evolved to fill diverse environmental niches, and it is difficult to infer which of these represents an ancestral state. Different bacteria, for example, are capable of living in temeratures ranging from nearly freezing (Bowman et al., 1997) to well above 100 degrees Celsius (Kashefi & Lovley, 2003). By using maximum likelihood phylogenetic algorithms, it is possible to use the genetic sequences from existing organisms to reconstruct what the genes of ancient organisms might have looked like. This technique has been used to reconstruct genetic sequences from the common ancestor to all of modern life, and the resulting sequences have been analysed to determine whether they share more characteristics with modern thermophilic organisms or mesophilic organisms. So far, the results of these studies have been inconsistent (Galtier et al., 1999; De Giulio, 2000, 2003; Gaucher et al., 2003). However, this paper describes the largest study yet undertaken, and the results point unambiguously towards a thermophilic ancestor to modern

The proteins produced by thermophilic bacteria tend to have a unique amino acid composition in comparison to their mesophilic relatives, allowing the two groups to be distinguished using multivariate analytical methods (Kriel & Ouzounis, 2001; Singer & Hickey, 2003). In the present study, these methods have been applied to 34 proteins from 20 modern thermophilic and mesophilic bacteria, producing classifying functions that are capable of distinguishing mesophilic proteins from thermophilic proteins. These same modern protein sequences have been used to reconstruct the protein sequences at the basal node of their phylogenetic tree; i.e., those from the common ancestral organism. These reconstructed sequences were analysed with the classifying models, and with high posterior probability the results show that the origin of modern life was in a high-temperature environment.

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Chemical Evolution On An Early Mars: Existence Of A Planetary-scale Infrastructure

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Just as the biochemistry of contemporary organisms can be viewed as a 'fossil' record of biogenesis, so the geochemical physics of the contemporary earth as an indicator of the self-organizing dynamic processes underlying prebiotic chemistry on any terrestrial-like planetary body.

The most critical insights result from a return to the question of water: but water at the scale and perspective of its chemical physics in a locally non-equilibrium environment (this being the only realistic situation in a geological environment). The application of a mechanical disturbance results in the Rayleigh-Taylor instability, which in turn is driven by surface free energy considerations to be meta-stabilized by polar organic surfactants. This combination at the micro-level directly results in the creation of a complex planetary-scale hydrological cycle. It is in fact a generalization of the terrestrial bubble-aerosol-droplet cycle modulated by the geological boundary conditions of the extraterrestrial body in question.

Due to the universality of chemical physics, the geophysical/chemical processes likely to have supported chemical evolution are equally likely to have been found on an early Mars, and throughout any subsequent Martian hydrological episodes.

Also on Mars, due to the ubiquity of chemical physics, artifacts of these prebiotic processes have the potential to mimic, abiotically, fossilized evidence of life; while simultaneously preserving evidence of past conditions and dynamic processes almost certain to have supported the functional requirements of chemical evolution. These and other specific applications to Mars is discussed in the lead author's accompanying contribution to this conference, "Chemical Evolution on an Early Mars: Implications for Mars Mission Planning" (Lerman 2004b).

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Laboratory Simulations of Titan's Organic Haze and Condensation Clouds.

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Titan, the largest satellite of Saturn, has a thick atmosphere composed primarily of nitrogen and methane. Active organic chemistry occurring in the atmosphere leads to the formation of organic haze and condensation clouds, which eventually settle on the surface of Titan. Titan is especially important to understand in the context of the role of organic chemistry occurring on a planetary scale. Such abiotic organic processes may provide us with important clues for the origin of life on the early Earth. The Cassini/Huygens mission beginning in 2004 will obtain a great amount of information about the properties of Titan's atmosphere and its surface.

We have conducted comprehensive experimental simulations relevant to the formation of organic haze and condensation clouds in Titan's atmosphere and organic chemistry on its surface. In the process of the formation of haze, aromatic molecules are likely to be important intermediaries from simple gas molecules to the complex organic haze. Those aromatic molecules included in Titan's haze may dominate the thermal structure of the atmosphere via their optical properties. In the stratosphere, reactive gas species such as HCN, HC₃N, C₂H₂, and NH₄CN, may condense and accumulate on the surface of Titan. On the surface, the ice mixtures consisting of reactive species would be converted to the dark colored complex organic molecules efficiently, if they are heated by geologic processes, such as impact and volcanic activity.

In Titan's surface-atmosphere system, methane and nitrogen in the atmosphere are eventually transported to the surface as complex organic molecules. In the processes of forming complex organic molecules, reactive species possessing unsaturated multiple bonds play an important role. Thus, the behavior of hydrogen in the chemical reactions controls the organic chemistry of Titan.

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Mineral Generated H₂O₂ And The Loss Of RNA

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Prebiotic chemistry is heavily weighed toward syntheses. Minerals have been implicated in the sorption and aiding of reactions leading toward organics similar to those present in life. However, other than temperature alone, very few studies have shown the reverse pathway of destruction in the presence of minerals. Hydrogen peroxide (H2O2) has been detected from O2-free aqueous suspensions of the most common metal sulfide, pyrite (FeS2)1,2. Hydroxyl radical (•OH) generation through Fenton's reaction—Fe(II) + H2O2 = Fe(III) + •OH + -OH— with iron provides a hitherto unknown source of this highly reactive radical species. •OH is capable of oxidizing all biomolecules and has been shown to destroy RNA. RNA has also been shown to decompose in the presence of pyrite3. A full understanding of the H2O2 generation mechanism is unknown at this time. The goals of this contribution are several fold: 1) use RNA as a representative scavenger of •OH to spectroscopically (horizontal attenuated total reflectance Fourier transform infrared spectroscopy HATR-FTIR) determine its fate in the presence of minerals, 2) to investigate the formation

of H2O2 from pyrite and several other iron sulfides and common minerals, and 3) gain a better understanding of the H2O2 generation mechanism. The potential of H2O2 and •OH generation from mineral-aqueous reactions could have fundamental implications for the stability of prebiotic building blocks and biomolecules during the origin and evolution of life.

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Tholins As Coloring Agents On Solar System Bodies

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Most small, icy bodies in the Solar System, whether they have high or low surface reflectance (albedo), show a pronounced downward slope in reflectance at wavelengths shorter than ~1 μm . This increasing absorption of sunlight toward shorter wavelengths is characteristic of π -bonds in hydrocarbons having chains or rings of conjugated C atoms. Tholins, which contain polycyclic aromatic and aliphatic hydrocarbons, exhibit these color properties. Using the complex refractive indices of tholins in models of the reflectance spectra of icy bodies in the Solar System (Cruikshank et al. 2003), we find that these complex organic materials satisfactorily account for the coloration so widely observed.

The new results presented here show that the wide variety of colors of Kuiper Belt objects can be fit very well with tholins (Cruikshank and Dalle Ore 2003), as can the colors of Pluto and Triton (Cruikshank et al. 2004). The implications of these fits of Kuiper Belt objects is that complex organic material is created on their surfaces by energetic particle bombardment of native ices, and also may be accreted from external sources. In the cases of Pluto and Triton, photochemistry of their weak $\rm N_2 + CH_4 + CO$ atmospheres produces complex organic molecules that precipitate to the surface, providing local color.

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Radio Astronomy Searches For The Amino Acid Glycine In High-mass Star Formation Regions

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Amino acids are basic constituents of life, and recent laboratory experiments demonstrate they can be synthesized in the gaseous nebulae that are the birthplaces of stars. Amino acids and other complex organic molecules are formed in the laboratory when ice mixtures representative of interstellar grain mantles are subject to UV radiation similar to that produced by young stars. We describe sensitive searches with the Very Large Array radio telescope that did not detect the lowest energy form of glycine (conformer I) in two high-mass star formation regions, namely the Orion Molecular Cloud (OMC-1) and Sagittarius B2(N). If glycine exists in these regions, it is weaker than our detection limit, is distributed across a wider spatial region than other large molecules, or is primarily in its high-energy form (conformer II).

We also present Very Large Array observations of the organic molecules formic acid and methyl formate in OMC-1 and ethyl cyanide in Sagittarius B2(N). The motions of the latter molecule have revealed a rotating edge-on gaseous disk approximately 0.1pc in diameter.

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Experimental Study Of Potential Abiotic Sources Of Organic Carbon In Rocks From The Early Earth

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The majority of astrobiologists have come to believe that life on Earth had become widespread well before 3.4 billion years (Ga) ago. This belief is largely based on observations that many of the oldest rocks on Earth contain reduced carbon compounds (kerogen and graphite) that are depleted in 13C to a degree typically associated with biological carbon fixation. However, recent reassessments of the geologic context of several ancient rock strata have suggested that the reduced carbon compounds they contain may instead result from abiotic organic synthesis. Chemical pathways that have suggested as sources of organic matter include Fischer-Tropsch-type synthesis within hydrothermal systems and decomposition of siderite (Fecarbonate) during metamorphism. It remains uncertain, however, whether these processes are consistent with the conditions implied by the geologic context or if they are capable of generating the abundance and isotopic composition observed in rock samples from the early Earth.

I will discuss both proposed pathways for abiotic organic compound formation using results of recent experimental studies as a point of reference. Siderite decomposition and Fischer-Tropsch synthesis both generate organic compounds with high potential for preservation in ancient rocks, but they require significantly different conditions to proceed and generate distinctly different products. Studies to evaluate the isotopic fractionation of these synthesis pathways are currently underway. Initial Fischer-Tropsch synthesis experiments resulted in organic compounds that are depleted in 13C by about 36% relative to dissolved CO2, which is consistent with the isotope fractionations observed in ancient rocks.

Lightning-Induced Organic Chemistry In The Cometary Atmosphere

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At discussion about the possible role of comets in formation of biochemical compounds on the early Earth, it is necessary separately to consider the scenario of non-contact interaction with the Earth. In this version, the composition of cometary substance falling on the Earth is determined by the chemical composition of coma. The study of chemical composition of coma has shown, that is required the long-continued analysis of received results for understanding of processes in the cometary atmosphere, determining their chemical composition [1].

In supposed work is analyzed the possibility of formation of chemical composition the cometary's atmosphere under effect of electric discharges. Under certain conditions in the cometary atmosphere are possible the development of the electric discharges [2], which is similar to the discharges in high layers Earth's atmosphere (sprites). In this connection, it is interesting to note, that for an explanation of the chemical composition of the Jupiter and Titan atmospheres is attracted the supposition about formation of some chemical compounds (HCN and acetylene) under effect of electric discharges [3].

As against the lightning in dense atmospheres (Earth, Titan, Jupiter), the discharges in rarefied gas-dusty cometary atmosphere will have following specialties [4]:

- -presence of electrons of high energy (≥1eV)
- -presence charged micron-size particles with charge $\approx 10^3$ e
- -large volumes (≥10⁷m²).

These particularities give the additional capabilities for synthesis of the organic compounds observed in atmospheres of comets, and the increasing of the electrical activity at an approaching to the Sun can result in the growth of concentration of some organic compounds.

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Replicating Vesicles And The Origin Of Life

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Cellular life requires both a genetic polymer to encode heritable information, and compartment boundaries to enable Darwinian evolution by linking genotype to phenotype. However, the earliest genetic molecules and cell membranes must have been able to replicate solely in response to chemical and physical forces, because of the absence of any biochemical machinery. Darwinian evolution and life itself may be viewed as emergent properties of systems that combine self-replicating genetic polymers and compartment boundaries¹.

We have recently described a laboratory demonstration of the replication of membrane vesicles². Membrane growth was based upon the addition of alkaline fatty acid micelles to buffered vesicles, as originally described by Luisi and co-workers³. Extrusion through small pores resulted in vesicle division with minimal loss of contents. Repeated cycles of replication were carried out, with continuity of both membrane and contents from generation to generation. Our current work is aimed at finding more pre-biotically plausible scenarios for vesicle replication.

During the course of the above experiments, we observed that many mineral surfaces catalyze the assembly of micelles into membrane vesicles. We were able to show that RNA bound to the surface of particles of the clay mineral montmorillonite could become encapsulated within fatty acid vesicles assembled by the clay. Thus, the same mineral surface that has been shown to catalyze the synthesis of RNA can also act to bring together nucleic acids and vesicles, suggesting a possible role for this process in the assembly of early cell-like structures.

More recently we have shown that mixed vesicles consisting of fatty acids and fatty acid-glycerol esters are sufficiently stable in the presence of Mg²+ to allow encapsulated ribozymes to exhibit catalytic activity, suggesting that RNA replication inside such primitive vesicles may be possible. We have also demonstrated that vesicles containing high concentrations of RNA become osmotically swollen, and that this phenomenon provides a driving force for the uptake of additional membrane components. This observation suggests the possibility of a direct coupling, based on physical principles, between RNA replication and vesicle growth. Finally, we have observed that fatty acid vesicles have surprising permeability properties, including greater permeability to ribose than to other aldopentoses. We suggest that primitive membranes may have contributed, along with other mechanisms such as specific catalysis and product stabilization, to simplifying the chemical environment in which early metabolism arose.

In summary, simple pre-biotic membranes are likely to have contributed in many distinct ways to the organization of cellular life from simpler chemical systems.

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Structure, Function And Self-assembly Of Simple Membrane Proteins

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A viable protocell must have been able to transport material across membranous walls separating the cellular interior from the environment, capture and utilize energy and tranduce environmental signals. In modern organisms, these functions are carried out by membrane proteins. We make the parsimonious assumption that these functions were carried out by peptides in the protobiological milieu. While membrane proteins are large and complex, their building motifs are simple, with -helical structures being common. Under protobiological conditions, peptides could have spontaneously formed and organized into simple, functional structures that were ancestors of modern protein channels and receptors. While the insertion of an -helix into a membrane is generally unfavorable, some stability can be regained by the association of peptides into dimers and larger assemblies. This is also the first step in the formation of functional peptide assemblies. To help understand the factors affecting the stabilibly of transmembrane protein assemblies, we have investigated the peptide-peptide interactions in the formation of Glycophorin-A dimers, a system that has been well characterized experimentally. The stability of transmembrane aggregates of simple proteins is often only marginal and can therefore be regulated by environmental signals or small sequence modifications. This is important because a key step in the earliest evolution of membrane proteins was the emergence of selectivity for specific substrates. Many channels could become selective if a few properly chosen amino acids are properly placed along the channel, acting as filters or gates. This is a convenient evolutionary solution because it does not require imposing conditions on the whole sequence.

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In Search Of A Self-replicating Ribonucleic Acid.

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The long-term goal of the Szostak laboratory is the de novo synthesis of a protocell with the minimal characteristics of life (i.e., autonomous growth and division that allows for Darwinian evolution). Such a system would require replicable genetic information, and a lipid vesicle to separate it from its external environment (Szostak et al., 2001). The genetic information must replicate efficiently and reliably, using nucleotide monomers that could diffuse through the non-polar lipid protocell membrane. The simplest conceivable replicable genetic information is an RNA that can act as a polymerase to produce more replicating RNA molecules (ie, an RNA polymerase ribozyme). The choice of activated nucleotide the enzyme will use is paramount in developing the polymerase ribozyme. Highly activated nucleotide monomers are advantageous in that they are usually less polar than nucleotide triphosphates (NTP) thus facilitating their diffusion through lipid vesicles. Using these substrates will reduce the rate enhancement required of the ribozyme to efficiently polymerize the monomers, which should simplify it. These ribozymes may also be smaller and easier to replicate. The successful identification of a ribozyme with these properties will represent a step towards the evolution of an RNA replicase and an advance in the synthesis of artificial life. This work also will provide insights into how simple replicating systems could have lead to the emergence of life on earth.

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Analysis Of Unexpected Differences In Relative Solubility Of D- And L-tyrosine

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Most amino acids can have either L or D structures, yet living organisms incorporate only L-amino acids into proteins. It remains unclear how life

first began to use L-amino acids. The only physical differences between L and D forms should be in their ability to rotate polarized light, yet recent results have shown L-tyrosine to be more soluble than D-tyrosine, which crystallizes from supersaturated solutions more rapidly (1). This difference permits DL racemic mixtures to undergo enantiomeric enhancement during crystallization. Our hypothesis is that L- and D-tyrosine may have different hydration states in solution, which lead to different solubilities. We tested our hypothesis by examining the crystal structures and solubility of the amino acid serine to determine whether water of hydration varies between D and L forms. We also examined serine solubility in D₂O and H₂O. We predicted reduced differential solubility and crystallization rates of D- and L-amino acids in D₂O because of D₂O's weaker magnetic spin asymmetry.

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Alife In Hypothesis Construction For The Origin Of Life

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This paper explores what artificial life (alife) simulations can contribute to hypothesis construction on the origin of life. Because alife theorists use simulation, the pure process of synthesis, they can build hypotheses that they did not anticipate when they designed their simulation, hypotheses that emerged as the simulation played out.

Alife has been used to investigate a range of principles that may have played a role in the origin of life, such as adaptability, emergence, replication, variation, selection, evolution, differentiation, individuality and cooperation. These principles give rise to meta-principles, such as the evolution of evolvability and the plasticity of adaptation. For life to emerge and evolve requires a richly diverse environment. Alife theorist Norman Johnson characterized an environment rich enough to originate life as one that allows "loosely cooperative relationships" to form, driving an ecosystem toward maturity through their co-evolutionary interactions.

Alife may be the most powerful tool we now have to study emergence, offering new ways to investigate the question, Is there a boundary between non-life and life? Exploring how non-life "could live" in the digital domain, alife uncovers the principles that govern the emergence of life-like qualities, independent of life's material constituents. This paper will explore what alife offers to a key origin of life debate: Was evolution directed or openended? Are evolutionary outcomes defined by setting a goal, finding an empty niche, or adopting a set of operational heuristics (in order to make decisions in process)?

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Defining Life: Hypotheses On The Boundary Between Non-life And Life

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This paper surveys the many definitions of life, showing the exceptions to each definition. I clarify how the process of defining can enable or constrain problem-solving. Theorists thinking about the origin of life define its principles and processes differently. They disagree about what counts as evidence for the origin of life and what doesn't. To date all attempts to define life have not failed. But none have quite succeeded.

Before 1828 scientists thought there was material distinction, that the constituents of life could be distinguished from those of non-living things. Some still think there is a causal distinction, that first life was produced differently from non-life. Some think there might be a boundary, limits or some sort of interface that would separate non-life from life. But all these definitions focus on things, on the objects of life. If we focus instead on how life acts, distinguishing life from non-life by whether it acts "alive", we have

five more classes of definitions: physiological, energetic, informational, order vs. entropy, and autonomic. We find exceptions to all of these eight classes of definitions: Is life merely the sum of its properties, or is there some additional synergistic "quality of life" that does not lie in any of its properties, or even in their summation? I focus on the implications of the autonomic definition of life and argue that for problems like the origin of life, defining and problem-solving must co-evolve.

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Origin Of Life: Case Studies Of Of Hypothesis Construction

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In this paper I will contrast the approach of different theorists on the origin of life, e.g. Graham Cairns-Smith, David Deamer, Stuart Kauffman. I will contrast their methods, creative trajectories, and discuss the role of thought experiments in the construction of their hypotheses. I will show what case studies of the strategies that individual scientists use can reveal about the creative process in science. Origin of life theorists are exceptional case studies of hypothesis construction because of their reliance on thought experiments, analogs, and scenario-building to justify admitting proposed sources of evidence and because of the many instances where their "logical" reasoning produces conflicting results.

To date no one has been able to "repeat the experiment" — to recreate life ex nihilo. Nor can we test myriad competing, contradictory hypotheses about the origin of life, either to verify them or to prove them false. Many aspects of the origin of life lack the traditional cornerstones of scientific method: a single unknown variable, repeatable experiments, or falsifiable results. Because of its intractability, the origin of life is an ideal case study of "scientists as designers", showing how they generate hypotheses before they can apply more rigorous methods. Pressing the limits of traditional scientific method, the origin of life emerges, not just as an enigma, but as an anvil on which to forge new methods for solving cross-disciplinary problems.

This paper relates to my work for NASA Ames Research Center developing a program plan for a new program in astrobiology (website above), which is dedicated not just to training specialists but to metalevel reflection on the scientific process — how to support breakthrough scientific discoveries and technology innovation, and the nature of scientific collaboration across disciplines.

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Life Or Something Like It: The Practical Implications Of Defining "Life" For Astrobiology

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As we struggle to uncover life's origins here, search for life elsewhere, and even, perhaps, recreate life in the lab, one of the most pressing issues is to begin with an appropriate understanding of what we mean by "life." Traditionally, life is taken to be a quality: something is alive, just as something is blue or buoyant or made out of carbon. Possessing the quality

of being alive thus becomes a question of possessing other subordinate qualities that lead to life (e.g., the ability to replicate, having a metabolism, etc.) Perhaps, however, "life" is not best thought of as a noun or even an adjective. Perhaps "life" is more constructively thought of as a verb. Or even as something that cannot be captured accurately in a grammatical metaphor.

If "life" is a verb, then we might think of it as akin to "flying" rather than "flight." That is, how does an airplane fly? We might say that a plane does not possess the quality of flight, but rather that flying is what happens when the plane is pushed through the air. Flying—seen as an activity, as an event, as a verb—is something that denotes an interaction between the plane and the environment. As such, it could not properly be reduced to a description of qualities possessed by the airplane. We could then ask how the wings of the plane developed the order needed to be an airfoil, but this is a fundamentally different question from "How did the plane come to have the quality of flight?" Seeing "life" as an activity, an event, an interaction of organism and environment thus can have a practical impact on the design of experiments meant to search for life and for its origins. This paper traces some of those practical implications.

It is also the case that "life" might not be something capable of being captured grammatically. This is not to imply that life cannot be explained through physics, biology, and chemistry, but it is to open the door to the possibility that seeing something as alive is actually a way of experiencing something rather than a quality of the thing being experienced. If it is the case that life and nonlife form a continuum, then perhaps a "phenomenology of astrobiology" is in order—an investigation of how it is that we structure our experience and thus could re-structure our experiments as we investigate that brave new world-continuum and the creatures that live and don't live within it.

Search For Life Beyond Earth (Microbes to SETI)

Terrestrial Planet Formation Around Close-binary Star Systems

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More than half of all stars reside in multiple star systems; however, virtually all models of planet formation have assumed an isolated single star. Disk material has been indirectly observed around one or both components of young binary star systems. If terrestrial planets (which form by an accretion process from dust and gas in a disk) form at the right places, they can remain in stable orbits within binary star systems for eons.

We are simulating the late stages of terrestrial planet formation around close-binary stars, using a new, ultrafast, symplectic integrator that we have developed for this purpose. The initial circumbinary disk of planetary embryos is the same as that used for simulating the late stages of terrestrial planet growth around the Sun and around each component of the Alpha Centauri wide-binary star system. The sum of the masses of each binary system is one solar mass, and we vary the binary semimajor axis, eccentricity, and the inclination of the disk relative to the stellar orbit. Giant planets are included in these simulations, as they are in most terrestrial planet formation simulations of the Solar System. When the stars travel on a circular orbit with a semimajor axis of up to 0.1 AU about their mutual center of mass, the planetary embryos grow into a system of terrestrial planets that is statistically indistinguishable from those formed about single stars. A larger semimajor axis and/or a significantly eccentric binary orbit, however, can lead to a significantly more dynamically hot terrestrial planet system.

Organics And Life Detection On A Chip

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We have developed a thumbnail-sized, prototype life-detection "chip" or antibody microarray, using a method first used to investigate protein function (Macbeath and Schreiber 2000). Several different antibodies, specific to important biological markers, were printed on a 3mm2 glass surface, producing a 15 \times 12 grid of "features" or spots, each 200 μ m in diameter. Each chip was incubated with sample, washed, incubated with fluorescent-

tagged antibody mix, washed again, scanned and data retrieved. These microarrays can simultaneously detect DNA (pan-specific), L-glutamate, PAH, chaperonin 60, β -galactosidase, peptidoglycan, lippolysaccharide, scherichia coli and Mycoplasma, all at sub- μ M concentrations and using a few μ l of sample. Such a chip may be sent to Mars, incubated with hydrated regolith, washed, scanned and the data sent back to Earth.

Antibodies are well suited for a Mars mission: they are stable for several years (Kukis et al, 1999), less affected by radiation than DNA and the incubation/washing steps function well in 0.38g (Maule et al, 2004). This chip detects "broad" (e.g. DNA, all organisms known on Earth), "intermediate" (e.g. peptidoglycan, gram-positive bacteria only) and species-specific (e.g. E. coli) biomarkers. To address issues of contamination and planetary protection, chips include antibodies to contaminants (e.g. Mycoplasma or mammal-specific proteins) and could perform a test for life/organics in space during Earth-Mars transit as a negative control prior to Mars landing.

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Increasing Diversity In Interstellar Message Composition.

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To enhance the intelligibility and representativeness of any messages that might some day be transmitted in reply to a signal from extraterrestrial intelligence, Vakoch (1998) has advocated broad-based dialogue across cultures and disciplines. To increase the global and disciplinary diversity of interstellar message composition, a series of international workshops and seminars was held in Bremen, Paris, Toulouse, Washington (DC), and Zagreb (e.g., http://publish.seti.org/art_science/2003). Participants from thirteen countries represented fields in the arts, humanities, natural sciences, and social sciences. Workshop themes included the interface of art and science in interstellar message composition, the challenges of encoding concepts of altruism in interstellar messages, the potential universality of certain mathematical and scientific concepts, and strategic planning to institutionalize research on interstellar message design. By holding some of these meetings in conjunction with international conferences (International Astronautical Congresses, a Space and the Arts Workshop, and a World Archaeological Congress), but inviting some participants not attending the primary conferences, specialized topics could be addressed from multidisciplinary perspectives. Papers presented at these meetings are being published in full or as extended abstracts in an ongoing series in a peer-reviewed journal (e.g., Vakoch 2004) and in collections of essays (e.g., Vakoch in press). These meetings were sponsored by the SETI Institute; the International Society for the Arts, Sciences and Technology; the International Academy of Astronautics; and the John Templeton Foundation.

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An Experiment For Comparison Of Multivariate Statistical Techniques For Increasing Spectral Separation Of Organic Chemical Biosignature Data

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The rapid detection of chemical biosignatures indicating the presence of life in rocks and sediments may include the acquisition of diverse, often multispectral data sets. The complexity of this data may necessitate the use of multivariate analysis techniques in order to discriminate between abiotic chemical signatures and biochemical signatures.

Currently, there are several multivariate statistical techniques such as principal components analysis(PCA) and artificial neural networks(ANN) being used in an attempt to differentiate spectra(1-4). It has been shown that a stepwise combination of techniques can provide a higher degree of fidelity in the analysis of spectral data(3). This combination is typically used with a front end filter used to reduce the dimensionality of the data while retaining the variance prior to treatment with a second technique(3). We have investigated various combinations of the most commonly employed methods in order to determine which tools or combination of tools are the most efficient at identifying separations between groups of bioorganic compounds.

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Life Detection By Hopane Biomarkers: Analogue Studies On Bedrock To Ice In The Haughton Impact Structure

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Hopanes are the optimum choice as chemical biomarkers for the detection of life during planetary exploration because they are a product of simple, prokaryotic biology, they have high longevity, we have extensive experience in their interpretation from petroleum geochemistry, and they can be purchased in purified form for experimentation. In the search for biomolecular evidence of life, we might sample bedrock, surface sediment and surface fluids. On the present Martian surface, we cannot sample liquid water, but we could sample ice at relatively shallow depth or at the surface in polar regions, and the polar ice caps of Mars are strong candidates for the preservation of a biomolecular record.

In Mars analogue studies in the Haughton Impact Structure, Devon Island, Nunavut, Canada, hopanoid biomarkers are recorded in each of bedrock, sediment and ice samples. The dolomitic bedrock at Haughton has experienced oil generation-migration, so hopanes and other organic compounds are abundant in it. Surface detritus is derived by erosion of the bedrock, and ice deposits contain sandy-silty detritus incorporated from the wind and surface run-off. Where winds are strong, as is very evident on Mars, surface particulate matter will be blown across icy surfaces to become entrapped by adhesion, and is likely to be the major source of incorporating a biosignature into Martian ice. These biomarkers are present in concentrations far in excess of what we could expect on Mars, or elsewhere. However, this analogue study does show the potential for biosignatures to be transferred from bedrock to surface sediment and ice, which increases the chance of detecting the signature, given high-resolution measurement techniques.

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The Galactic Habitable Zone And The Age Distribution Of Complex Life In The Milky Way

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As we learn more about the Milky Way Galaxy, extrasolar planets, and the evolution of life on Earth, qualitative discussions of the prerequisites for life in a Galactic context can become more quantitative. We modeled the evolution of the Milky Way to trace the distribution in space and time of four prerequisites for complex life: the presence of a host star, enough heavy elements to form terrestrial planets, sufficient time for biological evolution, and an environment free of complex-life-extinguishing supernovae. We identified the Galactic habitable zone as an annular region between 7 and 9 kiloparsecs from the Galactic center that widens with time and is composed of stars that formed between 8 and 4 billion years ago. This Galactic habitable zone yields an age distribution for the complex life that may inhabit our Galaxy. We find that 75% of the stars in the Galactic habitable zone are older than the Sun.

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The Inner Planets Of The Solar System And Their Potential To Harbor Life

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Although the terrestrial planets originated from very similar material accreted in close regions of the planetary nebula, the worlds that developed after 4.6 billion years of Solar System history are not entirely similar. Mercury and the Moon are without dynamic activity, a protecting atmosphere, and significant amounts of liquid water. As these conditions have been prevailing since their origin, they are unlikely to have harbored life. The terrestrial planets Venus, Earth, and Mars, on the other hand, show many signs of dynamic activities both in the past and still occurring today. These planets likely had a similar atmosphere early in the history of the Solar System, derived by volcanic emissions containing mostly CO₂. The surfaces of all three planets might have been partially covered with oceans and/or lakes, and therefore provided suitable habitats for life at that time. This is no longer the case for both Venus and Mars. Surface conditions on Venus are extremely hot and desiccating, and on Mars very oxidizing and desiccating accompanied with high fluxes of UV radiation. If life ever gained a foothold on Mars and Venus as it did on Earth, subsequent climatic and geologic changes could have driven it into the subsurface of Mars and into the atmosphere of Venus. For Mars, subterranean voids may provide environments suitable for life to thrive until environmental conditions improve such as when nutrients and energy are injected into the system, e.g. by a pulse of magmatic activity (Dohm et al., 2001). On Venus, a case has been made that life may have adapted from living in surface water pools to utilizing the atmosphere as an ecological niche (Schulze-Makuch & Irwin, 2002). On Earth, life is known to exist in both subsurface and surface environments, and at least transiently in the atmosphere. The presence of life on Venus and Mars can be argued upon, however, it is certainly not as pervasive as it is on Earth. Therefore, future missions will have to be specifically designed to optimally search these potentially life-containing refuges on our neighboring terrestrial planets for possible microhabitats of life.

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Intentionality and targeted searching in SETI

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Edmondson and Stevens [1] propose a new strategy for SETI which is motivated by careful consideration of the shared presuppositions and intentions in and ETI community. The proposal identifies target stars from the Habstar list produce by Turnbull and Tarter [3]. The proposal will be reviewed in the presentation and the paper will go on to argue that consideration of intentionality in such communicative enterprises (cf. Janovic [2], Vakoch [4]) argues for the reappraisal of the value of targeted searches.

The paper will also suggest some criteria for evaluating SETI proposals in relation to intentionality and other related factors. A question to be considered is whether or not the strategy proposed by Edmondson and Stevens is perhaps only the first of a new category of targeted searches.>

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Circumstellar Material in Habitable Zones: Planetary Debris Disks and Candidate Partial Dyson Spheres

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Previous searches in astronomical databases from the IRAS, ISO and 2MASS infrared missions revealed a number of solar-type stars with circumstellar material at habitable-zone temperatures, 273 to 373 K. Such material has been associated with the remnants of planet formation, but with some restrictions could also be the signature of Partial Dyson Spheres (PDS), habitats of advanced civilizations. We will review and re-analyze two such published searches that started from catalogs of known stars and determined their infrared properties. We will report results of our own complementary search starting from a list of astronomical sources with temperatures in the liquid water range that we then associated with stellar catalogs. Although many of those sources are expanding dust envelopes around red giant stars, a few are found to be associated with solar-type stars. The latter include young stars with planet-forming debris disks. We examine how one would distinguish debris disks from PDS and the extent to which this has been done and might be done with existing astrophysical facilities.

Increasing diversity in interstellar message composition

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To enhance the intelligibility and representativeness of any messages that might some day be transmitted in reply to a signal from extraterrestrial intelligence, Vakoch (1998) has advocated broad-based dialogue across cultures and disciplines. To increase the global and disciplinary diversity of interstellar message composition, a series of international workshops and seminars was held in Bremen, Paris, Toulouse, Washington (DC), and Zagreb (e.g., http://publish.seti.org/art_science/2003). Participants from thirteen countries represented fields in the arts, humanities, natural sciences, and social sciences. Workshop themes included the interface of art and science in interstellar message composition, the challenges of encoding

concepts of altruism in interstellar messages, the potential universality of certain mathematical and scientific concepts, and strategic planning to institutionalize research on interstellar message design. By holding some of these meetings in conjunction with international conferences (International Astronautical Congresses, a Space and the Arts Workshop, and a World Archaeological Congress), but inviting some participants not attending the primary conferences, specialized topics could be addressed from multidisciplinary perspectives. Papers presented at these meetings are being published in full or as extended abstracts in an ongoing series in a peer-reviewed journal (e.g., Vakoch 2004) and in collections of essays (e.g., Vakoch in press). These meetings were sponsored by the SETI Institute; the International Society for the Arts, Sciences and Technology; the International Academy of Astronautics; and the John Templeton Foundation.

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Magnetite Crystals In Martian Meteorite ALH84001: Evidence Of MARTIAN Biogenic Activity

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The landmark paper by McKay et al. (1996) cited four lines of evidence associated with the Martian meteorite ALH84001 to support the hypothesis that life existed on Mars approximately 4 Ga ago. Now, more than five years later, attention has focused on the ALH84001 magnetite grains embedded within carbonate globules in the ALH84001 meteorite. We have suggested that up to ~25% of the ALH84001 magnetite crystals are products of biological activity (e.g., Thomas-Keprta et al., 2001, 2004). The remaining magnetites lack sufficient characteristics to constrain their origin.

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The papers of Thomas Keprta et al. were criticized arguing that the three dimensional structure of ALH84001 magnetite crystals can only be unambiguously determined using electron tomographic techniques. Clemett et al. (2002) confirmed that magnetites produced by magnetotactic bacteria strain MV-1 display a truncated hexa-octahedral geometry using electron tomography and validated the use of the multi-tilt classical transmission microscopy technique used by (Thomas-Keprta et al., 2001). Recently the geometry of the purported martian biogenic magnetites was shown be identical to that for MV-1 magnetites using electron tomography (Thomas-Keprta et al., 2004).

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Drilling In Ancient Permafrost On Mars For Signs Of Life. H. D. Smith¹ & C. P. McKay²

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Did life on Mars and Earth have the same origin, or was there a second genesis? In order to determine if life that might have existed on Mars was the same as Earth life or different we need to find preserved organisms. On Earth we find ancient dormant organisms in subsurface permafrost (Gilichinisky et al 1992). On Mars there is extensive permafrost at low temperature (-70°C). In order to collect subsurface samples a drill or other penetrating devices are needed. When drilling to search for life, it is necessary to take special precautions to avoid the possibility of introducing life, or chemical contamination into the sample. The very nature of drilling makes sterilizing the drill unpractical. It is clear that the exterior of the samples taken from aseptic drilling methods are contaminated by the drilling environment. However because of the impenetrability of frozen cores, it is likely that the inner core of the sample is sterile and uncontaminated by the drilling environment. Problems with current drilling methods, techniques to trace the cleanliness of samples collected, and complications with maintaining an aseptic environment are considered here. The three types of tracers, biological, chemical, and passive, are described, compared, and analyzed for each of their particular uses. Suggestions for future research on drilling methods and tracer technique developments are considered. Advances made on Earth in aseptic drilling will be applied to the development of a "Mars drill".

Policy and Societal Issues Associated with the Discovery of Extraterrestrial Life

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Although Astrobiology is a unifying theme scientifically, current searches for evidence of extraterrestrial life are quite different in their policy and practical implications. The various searches can be viewed in three general categories: 1) 'SETI' searches for messages from extraterrestrial civilizations, 2) exploration for extrasolar or habitable planets, and 3) searches within the solar system (planetary missions, meteorites, cosmochemistry). Each class looks in different locations, uses different scientific instruments and methods, and seeks different types of evidence and data. Moreover, the meaning and implications of a 'discovery' in each of the categories are different as well. From a policy perspective, searches within the solar system are complicated by practical, legal and societal considerations that represent potential impediments to research and missions. In addition, solar system searches have greater ethical complexity than search types outside the solar system In pondering the future directions of Astrobiology, we must seriously consider the policy, practical and societal contexts of the field to ensure continued public support for our efforts.

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A Model To Differentiate Aromatic Ring Structures Based On Uv Fluorescence Spectroscopy

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The in situ detection of organic material on an extraterrestrial surface requires effective means of searching a large surface area or volume and a more specific means of identifying abundance and type of compounds in

target samples. Fluorescence spectroscopy fits the first requirement well, as it can be carried out rapidly, with no physical contact with the sample. Aromatic organic compounds with know fluorescence signatures have been identified in several extraterrestrial samples, including carbonaceous chondrites, interplanetary dust particles, and Martian meteorites. Their abundance vary among these sources with clear differences in terms of number of aromatic rings and degree of alkylation. This relative abundance information, therefore, can be used to infer the source of organic material detected on a planetary surface.

One detection scheme presently in use requires optical band-pass filters appropriately designed to bin emitted fluorescence photons of desired target molecules. To use native fluorescence for molecular specificity in a mixed system, a filter design based on molecular information regarding a suite of aromatic compounds is needed.

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Detectable Biosignatures For Mars: Biogenic Fe/mn Oxides In Caves And Surface Desert Varnish

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Microbial-mineral interactions involving oxidation of manganese and iron occur in many Earth environments including arid lands (i.e. as desert varnish), and in subsurface environments like caves (i.e. cave ferromanganese deposits, aka speleosols). Our work over the past decade on ferromanganese deposits found in some arid lands caves has shown remarkable transformations of ultra-low concentrations of reduced iron and manganese in the parent rock to highly concentrated Fe and Mn oxides. We have established that microorganisms are present in the underlying rock and ferromanganese deposits; that some microorganisms present group phylogenetically with known iron- and manganese-oxidizing organisms; and that iron and manganese enrichment cultures of cave organisms produce distinct and unique iron and manganese crystalline minerals over time (Boston et al. 2001; Northup et al. 2000, 2003; Spilde et al. 2001).

We have found both geochemical and biological similarities between this cave material and surface oxide deposits known as desert varnish. We believe that this connection between the biogenic minerals in the subsurface and the possibly biogenic coatings on surface rocks could be used both as an indication of previous biological activity on surface exposed rocks and perhaps point to a still-extant subsurface biosphere on Mars as postulated in previous work (Boston et al., 1992). Such a connection could provide a detectable biosignature usable on the surface that could be tied to a subsurface extant biota on Mars.

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Directed Panspermia, Astroethics, And Our Cosmological Future

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Astrobiology addresses the future of life. How can life expand in the universe? What are its maximum extend and cosmological future?

- 1. Expansion in space. With solar sails we can soon start microbial panspermia missions to nearby new solar systems and to young stars in interstellar clouds, where local life is unlikely yet (Mautner 1997, 2000). The microbial payloads can be captured in asteroids where they may multiply and disperse. Our bioassays showed that algae and bacteria can grow in early asteroid fluids (Mautner 2002). The stored microorganisms will be impact-delivered to planets.
- 2. The amount of life that develops at various habitats depends on available resources (Anderson 1981). We can quantify the extent of life in ecosystems of finite duration as time-integrated biomass (kg-years). Based on material and energy resources, Sun-like solar systems can accommodate 10^{41} kg-years of biomass in the galaxy; white dwarf stars, 10^{45} kg-years; red dwarfs, 10^{46} kg-years; brown dwarfs, 10^{39} kg-years; the galaxy, 10^{48} kg-years; the universe, 10^{59} kg-years of time-integrated biomass (depending on cosmological models) (Mautner 2003).
- 3. Ethical motivation: a life-centered, panbiotic astroethics. The expansion of life may be motivated by a science-based panbiotic astroethics that seeks to maximize life, based on: The unity of all Life, and our identity as living beings; the unique place of lour family of complex oganic ife in nature; and the propensity of life for self-propagation. Future life planted by these endeavours can immensely exceed the life that has existed to the present.

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2D/3D In Situ X-Ray Imaging Of Microorganisms In Meteorites.

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The identification of microbial cells in meteorites and in "returned samples" represents "the Holy Grail" in the search for extraterrestrial life traces. In such precious samples, general features of the bacterial and mineral distribution must be looked for with non-destructive and non-invasive techniques. State-of-the-art developments of scanning X-ray microscopy and X-ray computed microtomographies (CT), in the 5 to 20 keV range

(Simionovici, 2001) were applied at the ID21/ID22 beamline group of the ESRF in order to image fractures, aqueous alteration phases and remnants of life forms in sub-millimeter grains.

CTs were applied on an altered grain of the Martian NWA817 meteorite, stored in a capillary mimicking a quarantine. The precision achieved by the combination of absorption and fluorescence CT is sufficient to obtain the real 3D semi-quantitative view of the mineralogy (fracture and alteration phase), consistent with the one statistically depicted by destructive approaches (Lemelle et al. 2003). Correlation of the N, P, amino-acid-linked S, and sulphate fluorescence maps allowed identifying terrestrial microbial cells contaminating a Tatahouine meteorite fragment, 3D extension is developed.

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Life-On-A-Chip

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The search for life beyond the Earth must involve lab-on-a-chip technology. Microfluidics, microfabrication, and microelectromechanical systems can now be integrated into a system that has the potential to perform multiple analyses in real time on individual living cells. Cells are seeded into an environmental chamber and cell growth and metabolism can be monitored using intracellular fluorescent molecular probes. Single-cell microcultivation assays monitor environmental effects on isolated cells. A life-on-a-chip detection device could collect an environmental sample and measure the metabolism of a single cell.

A model system for assessing this type of single cell analysis is the facultative methylotrophic bacterium, Methylobacterium extorquens AM1. Fluorescent protein reporter constructs are being used to follow response to environmental change at the transcriptional level in this bacterium. An environmental chamber coupled to a laser scanning confocal microscope is being used to monitor cell growth and metabolism under different conditions. It is important to characterize cell growth and metabolism using lab-on-a-chip technology and compare it to analyses using genomic, microbiological, biochemical, and genetic methods. This type of technology will form the basis of future life detection strategies.

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The Effects Molecular Interactions With Minerals On The Detection Of Organic Chemicals In Rock And Sediment By Laser-induced Native Fluorescence

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Organic chemical biosignatures can be detected against a background of minerals, sediments (including ices), water and rock by laser-induced native fluorescence (Xiao et al., 2002). With a sufficiently short excitation wavelength and sensitive detection scheme, variation in fluorescence behaviour of key organics, either singly or mixed with other organics, can be differentiated from mineral fluorescence or phosphorescence. We can also observe the effects of single mineral powders, sediment and rocks on fluorescence wavelength and intensity. For example, a 50-50 % by volume mixture of phenylalanine (phe) and quartz (qtz) exhibits more intense fluorescence than a 90-10 % mixture of phe-qtz or 100% phenylalanine sample. This systematic study of target organic molecules, mineral phases and rocks is key to understanding the effects of the mineral background on the fluorescence response of organic molecules in geological materials. Indeed, it is essential for determining the requirements for lower limits

of detection for laser-induced native fluorescence biosignature detection experiments.

We have studied fluorescence levels in several pure samples and solid mixtures of organic chemicals (with each other and with minerals) that may be relevant as biosignatures on or in the martian surface. Here we present those results.

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Life In A Mars Analog: Microbial Activity Associated With Carbonate Cemented Lava Breccias From Nw Spitsbergen

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Low-temperature carbonate deposits in volcanic centres on NW Spitsbergen (Norway) comprise carbonate globules near identical to those in ALH84001 and represent a unique opportunity to examine water-rock interaction and possible microbial activity in a Mars analogue environment. Field observations show that abundant magnesite and dolomite were deposited in lava conduits after eruption, likely in the presence of standing water. SEM, PCR and fluorescence data suggest that there is microbial activity within vesicular lava breccias in these conduits. Raman spectroscopy demonstrated the presence of disordered carbon within the vesicles.

Handpicked fragments of carbonate coating and vesicular lava were analysed for $\delta^{13}C$ and $\delta^{15}N$ before and after leaching with 6N HCl to demineralise the samples. Lichen from the breccia outcrop was analysed for reference. Carbonate coating and unleached basalt show $\delta^{13}C$ values (%, PDB) between 1.0 and 1.5, organic carbon from leached basalt shows $\delta^{13}C$ between -11 and -13 and $\delta^{15}N$ around -4 to 1. Lichen carbon attached to the rocks show $\delta^{13}C$ between -22 and -26 and $\delta^{15}N$ between -8 and 1.

It would appear from these investigations that microbial cells are to be found within the vesicles of the carbonate breccia and are possibly using isotopically heavy carbon organic material as a food source. Further implications and the results of DNA extraction and sequencing as well as ToFSIMS and GCMS data will be presented.

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Solvent Extraction Of Organic Molecules From Terrestrial Samples: Quantitative Results Utilizing Different Organic Solvents

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Extraction of organics from field samples in a laboratory environment can be accomplished by a variety of methods such as heating in a pyrolysis oven, by utilizing various solvents (including HCl, organic solvents, pure water), supercritical fluid and Soxhlet extraction. On future robotic space craft, where resources are limited, very complex samples will be analysed with analytical instrumentation. This necessitates that the decision of the extraction method must take into account many factors including the simplicity of the extraction method and the extraction efficiencies of organic

molecules (so any null result can place an upper limit on the amount of organics present in the near surface material).

We have begun a systematic study of the extraction of organics from field samples using different solvents and extraction parameters (such as time and temperature). In order to concentrate on the extraction process, we have utilized a standard HPLC to analyse results from different extraction techniques and conditions. In addition, we look at the chemical complexity of the extract which results from different solvents. Different solvents can dissolve different mineralogical and salt components of samples, which can result in the masking of an organic signature. This is particularly true when electrospray ionisation is considered as an ionization technique. The ionic composition of some constituents of a liquid, particularly when water is the extraction solvent, result in chemical process that may mask the presence of organics in the electrospray process.

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Signs Of Life In Meridiani Planum – What Might OpportunityBe Seeing (Or Missing)?

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The Meridiani Planum hematite deposit is the landing site for the Opportunity spacecraft. Iron oxide and hydroxides, including hematite, can mineralize and preserve microfossils and physical biomarkers. Such mineralization occurs in a variety of terrestrial hematite deposits.

What Might Opportunity See? If the Meridiani Planum hematite carries a record of martian life, suggestive evidence may be revealed by the spacecraft instruments. The distinct colored stripes characteristic of banded iron formations should be obvious in Pancam images. The fossil record contains abundant examples of macroscopic biofilms that are observable at the resolution of the Microscopic Imager. Many hot springs precipitate minerals that fossilize and preserve colored microbial mats, as well as masses of organisms many centimeters across. Mineralized microbes sometime contain traces of carbon in abundances that could be detected by the APXS.

What Might Opportunity Miss? The Opportunity instruments are not designed to provide unambiguous evidence of life, particularly at the microscopic scales characteristically observed in terrestrial iron oxide and hydroxide deposits. Mineralized microfossils have typical dimensions significantly smaller than the resolution of any spacecraft instrument. Most fossil microorganisms are only detectable by optical and electron microscopy. The association of carbon with putative microfossils can only be confirmed using microbeam techniques. Thus, while suggestive evidence of martian microbial life may be detected in situ, confirmation will probably require the return of samples to terrestrial laboratories. A key function of the next generation of Mars landers will be to discover and certify sites for future sample return missions.

Photolysis And Radiolysis Of Ice As A Source Of False Biomarkers On Europa.

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If we find evidence of Life elsewhere in the Solar System it will probably be in form of chemical biomarkers, quintessentially biological molecules that indicate the presence of micro-organisms. While certain functionalized PAHs have been invoked as biomarkers, and some people think of molecules such as amino acids as good candidates, these molecules are produced non-biotically in abiotic radiation experiments and thus could be present on the surface of other planets even in the absence of Life. Understanding

how components of proteins and other molecules can form in sterile space environments is relevant to our search for life elsewhere in the Solar System (Astrobiology Roadmap Goal 7). Understanding the range of non-biological organic molecules that could act as false biomarkers in space is a prerequisite for any reasonable search for true biomarkers on other worlds

We will present the results of laboratory experiments that show that UV photolysis and MeV proton irradiation of extraterrestrial ice analogs produce seemingly biotic organic molecules such as and amino acids (Bernstein et al 2002a), quinones, and other functionalized aromatic compounds (Bernstein et al 2001, 2002b, 2003). In the past, molecules of these types have been invoked as biomarkers.

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Results Of A Four-year Contamination Study Of A Depth Profile Through Martian Meteorite NAKHLA

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Martian meteorite Nakhla has previously been shown to be contaminated by terrestrial microbiota of unknown origin and identity (Toporski et al., 1999; Toporski et al., 2000; Whitby et al., 2000). These studies investigated a depth profile through the meteorite consisting of four samples (fusion crust, underneath the fusion crust, midway through the meteorite and from the center). Although suggesting the presence of microbial organisms, the results were regarded as being controversial, because conclusive demonstration of biological origin remained difficult. We therefore aimed to demonstrate the possible (bio)dynamics of these valuable samples with continued observation after a time period of approximately four years. We continued electron optical observations to monitor morphological changes, microscopic alterations and distribution on the sample, combined with epifluorescens microscopy (biological stain DAPI) to demonstrate biological origin.

Although difficult to quantify, it became clear that the number of carbonenriched structures has increased over time. Furthermore, the morphology of some previously studied structures changed, and microscopic alteration in the surface texture was observed. Epifluorescens microscopy resulted in positive staining responses indicating biological material. From this study and our previous observations, we have no reason to believe that these structures are of abiogenic origin. Due to our observations we believe that these features represent microbiota, which has the capability to maintain metabolic activities under the given storage conditions. Current experiments involve the identification of the microbiota, which may serve as an important indicator of the contamination source and active metabolic processes and contribute to optimize definitions relevant in planetary protection.

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The Strange Case Of 133P/Elst-Pizarro: A Comet Amongst The Asteroids

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We present a new investigation of the dynamically asteroidal, yet apparently physically cometary, outer main-belt object 133P/(7968) Elst-Pizarro. As in 1996, when this object's comet-like activity was first noted, data from 2002 show a long, narrow dust trail in the projected orbit of the object. Observations over several months reveal changes in the structure and brightness of this trail, showing active generation over long periods of time. Finson-Probstein numerical dust modeling confirms this conclusion,

indicating dust emission likely occurred over at least 5 months in 2002. The practical identification of Elst-Pizarro as a comet (a mass-losing body) is not in doubt and the nature of its mass loss as volatile-driven is strongly suggested by the evidence. We consider two hypotheses: (1) Elst-Pizarro is a barely active Jupiter family comet that has evolved into an asteroid-like orbit, perhaps under the prolonged action of non-gravitational forces due to asymmetrical mass loss, or (2) Elst-Pizarro is an original member of the main belt on which buried ice has been recently excavated by impact. In either case, the direct implication of substantial preserved water ice on Elst-Pizarro bolsters the claim by Morbidelli et al. (2000) that the outer asteroid belt is the most plausible source of water accreted by the Earth in the early solar system. This work has been accepted for publication by The Astronomical Journal.

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Historical Science And The Use Of Biosignatures

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As I have argued elsewhere (Cleland 2001, 2002), historical and experimental scientists have access to different evidential relations. Rather than relying upon the results of controlled experiments, historical researchers search for traces of past events in the uncontrollable world of nature. Traces (e.g., iridium, shocked quartz) supply the evidence for historical hypotheses (the Alvarez's meteorite-impact hypothesis for the K-T extinctions). Successful experimental science requires that experiments meet certain general logical and empirical conditions such as repeatability under controlled conditions. It is thus only to be expected that the body of traces accumulated in support of a historical hypothesis must meet general logical and empirical conditions in order to constitute trustworthy evidence for the hypothesis. Not every collection of relevant traces provides equally strong support for an historical hypothesis. But what are these conditions? It is clear that they are not the same as those for classical experimental science. I identify some general logical and empirical conditions on bodies of traces that increase their trustworthiness as evidence for historical hypotheses. I sketch how these conditions could be used to guide the selection of a suite of biosignatures (e.g., isotopic records, biomolecules, and geochemical anomalies) for use in confirming hypotheses about both ancient terrestrial life and extraterrestrial life (in remote and in situ robotic investigations).

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Special Session In Memory Of Robert MacElroy

Influenza-A M2 Channel Transport Mechanism

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Influenza-A M2 trans-membrane domain comprises a very efficient and highly selective proton ion channel, essential for acidifying the interior of influenza virions during virus uncoating and maturation. The M2 transmembrane (TM) domain is a homotetramer containing four 19-residues that define the channel pore moiety. The pH gating of the M2 proton channel is governed by a histidine within the TM domain and it has been shown that the proton binds to the M2 channel during transport. We use molecular simulations to elucidate the working mechanism of transport of influenza M2 channel. We propose a transport mechanism involving the dynamic rearrangement of the water molecules lining the interior of the channel as a histidine residue becomes charged (load) and discharged (release). This two-stroke mechanism is tightly coupled to the protonation/deprotonation of a histidine N_s atom, which acts as a proton sensor and relay. This relay mechanism eliminates the need for histidine tautomerization and explains the available data, suggesting proton binding during transport. Our study suggests a model of striking simplicity for the M2 ion channel proton transport mechanism, with the water structure inside the channel playing a key role in defining its transport properties, and we show how subtle pH changes can regulate ion transport.

Structure, Function And Self-assembly Of Simple Membrane Proteins

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A viable protocell must have been able to transport material across membranous walls separating the cellular interior from the environment, capture and utilize energy and tranduce environmental signals. In modern organisms, these functions are carried out by membrane proteins. We make the parsimonious assumption that these functions were carried out by peptides in the protobiological milieu. While membrane proteins are large and complex, their building motifs are simple, with α-helical structures being common. Under protobiological conditions, peptides could have spontaneously formed and organized into simple, functional structures that were ancestors of modern protein channels and receptors. While the insertion of an α -helix into a membrane is generally unfavorable, some stability can be regained by the association of peptides into dimers and larger assemblies. This is also the first step in the formation of functional peptide assemblies. To help understand the factors affecting the stabilibly of transmembrane protein assemblies, we have investigated the peptide-peptide interactions in the formation of Glycophorin-A dimers, a system that has been well characterized experimentally. The stability of transmembrane aggregates of simple proteins is often only marginal and can therefore be regulated by environmental signals or small sequence modifications. This is important because a key step in the earliest evolution of membrane proteins was the emergence of selectivity for specific substrates. Many channels could become selective if a few properly chosen amino acids are properly placed along the channel, acting as filters or gates. This is a convenient evolutionary solution because it does not require imposing conditions on the whole sequence.

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Phylogenetic analysis of chromosomal data

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Large-scale comparative data sets are becoming more available to phylogenetic analysis as genomic techniques advance. A general framework for the optimisation and systematic analysis of chromosomal data is presented. The approach incorporates nucleotide substitution, insertion-deletion, and locus level phenomena such as rearrangement and the

origin and loss of nucleotide segments. By the application of simple rules, efficient, parsimonious evolutionary schemes can be generated and tested. The method is demonstrated and implications for genomic annotation discussed through the analysis of complete mitochondrial genomes.

Terrestrial Life Beyond Earth

Cellular Mechanisms Underlying Bone-Forming Cell Proliferative Response To Hypergravity

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Life on Earth has evolved under the continuous influence of gravity (1-g). As humans explore and develop space, however, we must learn to adapt to an environment with little or no gravity. Studies indicate that lack of weightbearing for vertebrates occurring with immobilization, paralysis or in a microgravity environment may cause muscle and bone atrophy through cellular and subcellular level mechanisms. We hypothesize that gravity is needed for the efficient transduction of cell growth and survival signals from the extra-cellular matrix (ECM) (consisting of molecules such as collagen, fibronectin, and laminin) in mechanosensitive tissues. We test for the presence of gravity-sensitive pathways in bone-forming cells (osteoblasts) using hypergravity applied by a cell culture centrifuge. Stimulation of 50 times gravity (50-g) increased proliferation in primary rat osteoblasts for cells grown on collagen Type I and fibronectin, but not on laminin or uncoated surfaces. Survival was also enhanced during hypergravity stimulation by the presence of ECM. Bromo-deoxyuridine incorporation in proliferating cells showed an increase in the number of actively dividing cells from about 60% at 1-g to over 90% at 25-g. Reverse transcriptionpolymerase chain reaction was used to test for all possible integrins. Our combined results indicate that beta1 and/or beta3 integrin subunits may be involved. These data indicate that gravity mechanostimulation of osteoblast proliferation involves specific matrix-integrin signalling pathways which are sensitive to g-level. Further research to define the mechanisms involved will provide direction so that we may better adapt and counteract bone atrophy caused by lack of weightbearing. (Supported by NASA 00-OBPR-01-066).

Terrestrial Planet Formation Around Close-Binary Star Systems

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More than half of all stars reside in multiple star systems; however, virtually all models of planet formation have assumed an isolated single star. Disk material has been indirectly observed around one or both components of young binary star systems. If terrestrial planets (which form by an accretion

process from dust and gas in a disk) form at the right places, they can remain in stable orbits within binary star systems for eons.

We are simulating the late stages of terrestrial planet formation around close-binary stars, using a new, ultrafast, symplectic integrator that we have developed for this purpose. The initial circumbinary disk of planetary embryos is the same as that used for simulating the late stages of terrestrial planet growth around the Sun and around each component of the a Centauri wide-binary star system. The sum of the masses of each binary system is one solar mass, and we vary the binary semimajor axis, eccentricity, and the inclination of the disk relative to the stellar orbit. Giant planets are included in these simulations, as they are in most terrestrial planet formation simulations of the Solar System. When the stars travel on a circular orbit with a semimajor axis of up to 0.1 AU about their mutual center of mass, the planetary embryos grow into a system of terrestrial planets that is statistically indistinguishable from those formed about single stars. A larger semimajor axis and/or a significantly eccentric binary orbit, however, can lead to a significantly more dynamically hot terrestrial planet system.

Applied Astrobiology: Space-based Genetic Banks For Endangered Species

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Astrobiology concerns the future of life, including its diversity. In this respect, 15-30% of the estimated 5-10 million species will disappear over the next 50 years (Wilcox 1988). With them, information will be lost that could help adapting life to extreme environments, including space. To prevent this loss, genetic materials of endangered species, including endangered human ethnic groups, can be collected and stored indefinitely below 100 °K (Mautner 1996). Storage on Earth will require permanent care, guarding and expenditure for centuries, which is insecure. However, lunar polar craters at 40-80 °K can accommodate free storage in deep cold permanently. Also suitable is storage on the icy moons of Saturn such as Enceladus or Phoebe, or storage satellites. These space-based sites provide permanent cold, and security against political instability and sabotage. Future re-cloning will require only 0.1gram material per individual, and materials from 20 unrelated individuals for genetic diversity. In all, 2 grams of materials can preserve a species. A payload of 2,000 kg can permanently secure the genetic information of one million species for only \$20 million at present launching costs, i.e., \$20 per species. Applications of new conservation methods of biomaterials in this program will be discussed. Such programs can contribute scientific and environmental/moral objectives to manned space programs. In the future, the preserved genetic material can help restoring lost species, and provide information on species adapted to diverse environments on Earth, which can be useful for adapting life to diverse new environments in space.

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