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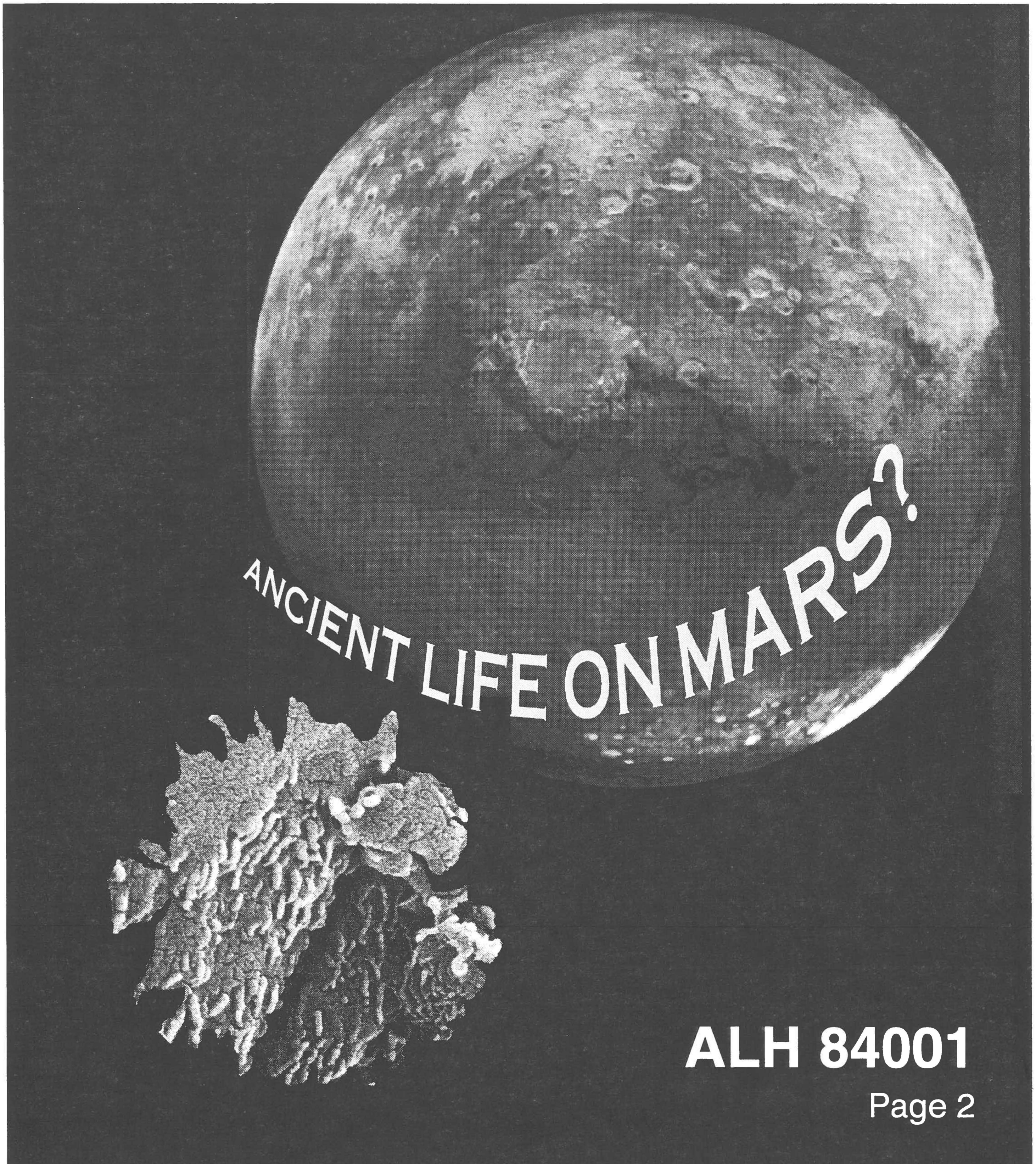
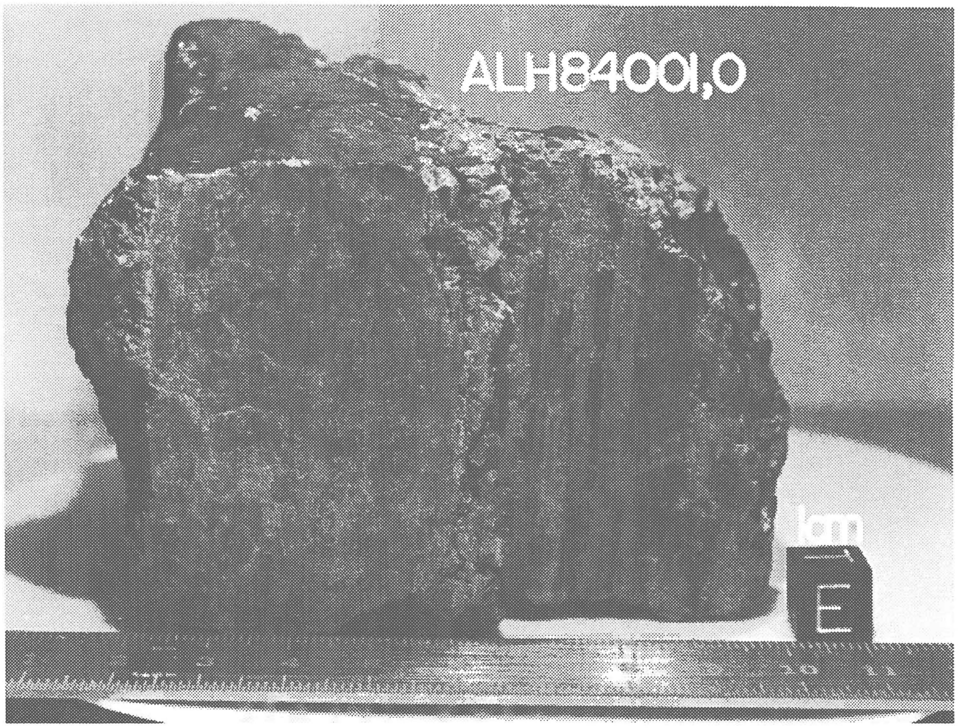


FOSSIL LIFE IN ALH 84001?



The meteorite

—by Allan H. Treiman

This article is an explanation in layman's language of the Science *(August 16, 1996) paper of Dr. David McKay and his co-workers, in which they give evidence that martian bacteria may have lived in the martian meteorite ALH 84001. Since the startling announcement, we at LPI have fielded dozens of questions from the public and press about the research presented in the paper. I've tried to organize and review the evidence that ALH 84001 contains fossils and traces of ancient martian life, and also tried to outline some counter-evidence and some likely questions about the evidence (presented in italics within the article). My intention is to present the work of McKay and co-authors even-handedly and nonjudgmentally.*

[EDITOR'S NOTE—Because of space limitations, this article is a condensation of a more detailed treatment of this subject that can be found on the World-Wide Web at **http://cass.jsc.nasa.gov/lpi.html.** The additional information includes much more about the meteorite itself, about the evidence for its martian origin, about the techniques used to establish important dates in the rock's history, and about the nature of the polycyclic aromatic hydrocarbons detected in it—all designed to be understandable by nonspecialists. In addition, the results of analyses of ALH 84001 by many researchers, which are merely summarized in this article, are linked directly to the abstracts and papers in which the findings are reported.]

In their paper in *Science* magazine, "Search for Past Life on Mars: Possible Relict Biogenic Activity in Martian Meteorite ALH84001," Dr. David McKay and his co-workers give evidence that martian bacteria may have lived in the meteorite. To set the stage, McKay and his co-workers review the evidence that ALH 84001 is from Mars, that it was infiltrated by liquid water while it was on Mars, and that the water infiltrated very long ago. Then, McKay and co-authors describe three sets of observations about ALH 84001 that all could have been produced by martian bacteria. But, as they say, "None of these observations is in itself conclusive for the existence of past life. Although there are alternative explanations for each of these phenomena taken individually, when they are considered collectively, particularly in view of their spatial association, we conclude that they are evidence for primitive life on Mars."

McKay and his co-workers *do not* claim that they found live martian bacteria; they only claim to have found evidence of dead, fossil bacteria and chemical traces that might have come from bacteria. They have no evidence for martian organisms more complicated than bacteria — no eucaryotes (cells with nuclei), no multicelled creatures, no plants, no animals, and no little green men.

PRECONDITIONS FOR FOSSIL LIFE IN ALH 84001

Before talking about their evidence for martian life in ALH 84001, McKay and co-workers need to establish some preconditions. These are not evidence for life, but evidence that life (as we know it) could be possible, and that the life could be martian.

1. ALH 84001 is from Mars

There is little doubt now that ALH 84001 is from Mars, even though people have never been to Mars and no rocks have ever been collected on Mars. In fact, there are 11 other meteorites, called the SNCs, that are also almost certain to be from Mars. The strongest evidence for their martian origin is that they, including ALH 84001, contain traces of gas that is identical to the martian atmosphere. We know the composition of the martian atmosphere because the Viking Lander spacecraft analyzed it, on Mars, in 1976. The martian atmosphere is quite different from the Earth's atmosphere, or Venus', or any other source of gas that's ever been found.

2. While on Mars, ALH 84001 was infiltrated by liquid water

Life as we know it cannot form, multiply, or survive without liquid water. Liquid water acts as a solvent or catalyst for almost all the chemical reactions of life. So, McKay and co-workers have to show that ALH 84001 was infiltrated by liquid water, at least once, while on Mars. Since all McKay's evidence for martian life is inside the carbonate mineral globules in ALH 84001, it is critical to show that the carbonate mineral globules are martian and that they were formed by liquid water.

There is little doubt that the carbonate mineral globules formed on Mars. The globules are much older than the meteorite impact event that launched ALH 84001 from Mars on its way to Earth. In addition, oxygen and carbon in the carbonate minerals have isotopic compositions that are characteristic of Mars.

Most researchers think that the carbonate-rich globules were deposited by liquid water, despite the lack of water-bearing minerals like clays or rust. On the other hand, two researchers recently reported evidence that the carbonate globules grew at very high temperatures, >650° C (>1200° F). If the carbonate mineral globules were so hot, it is very unlikely that they had anything to do with life. However, the evidence for high temperature could also be a result of bacterial action.

3. ALH 84001 was infiltrated by water very long ago

This point, that the carbonate mineral globules formed in Mars' ancient past, is not really critical to the evidence for life. But an ancient age makes life more plausible. If, as McKay and co-workers report, the globules are 3.6 billion years old, they formed when Mars' atmosphere may have been much thicker than it is now, when temperatures were much warmer, and when liquid water could have been abundant. The surface of Mars now appears to be a sterile, frigid desert, most inhospitable for life that requires liquid water. Showing that the carbonate globules formed when liquid water was abundant makes it more plausible that they might contain traces of life.

THE EVIDENCE FOR ANCIENT MARTIAN LIFE IN ALH 84001

McKay and his co-workers describe three kinds of features in ALH 84001 that they interpret as evidence for ancient martian life. These features are all in (and near) the carbonate mineral globules, which McKay and co-workers believe to have formed on Mars from liquid water. In the carbonate globules of ALH 84001, McKay and his co-workers found *microscopic shapes* that resemble living and fossil bacteria on Earth, *microscopic mineral grains* like some produced by living and fossil bacteria on Earth, and *organic chemical compounds* that resemble the decay products of bacteria on Earth.

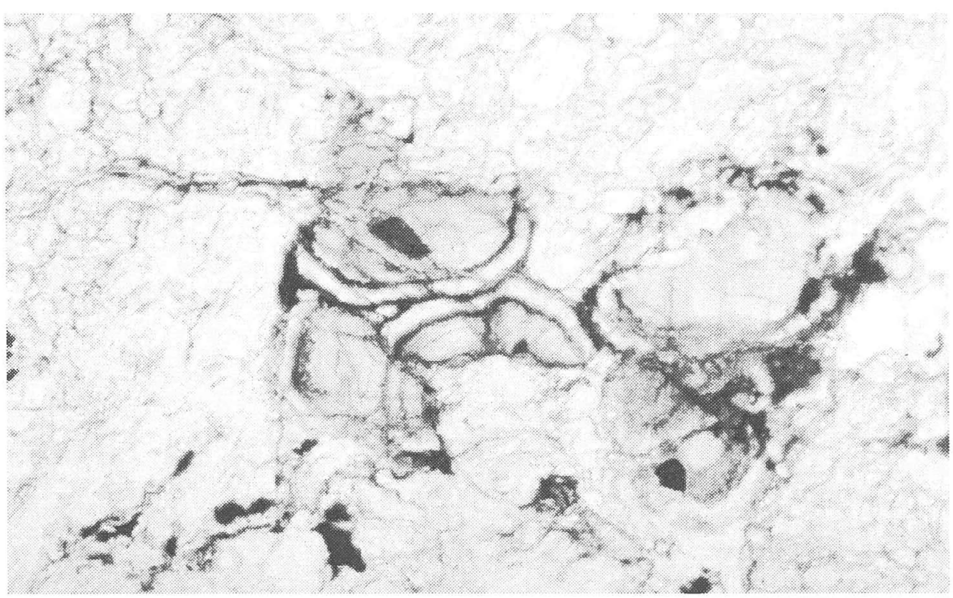
1. Shapes that Resemble Bacteria

McKay and co-workers observed elliptical, ropelike, and tubular structures in fractures in the carbonate mineral globules; they interpret the structures as possible fossil bacteria. These structures are so small, each only 20 to 100 billionths of a meter across (or nanometer, abbreviated "nm"), that they could only be seen with an advanced electron microscope. Figures 6a and 6b of their *Science* paper show these elliptical and sausage shapes, as do two other images they presented at the NASA press conference.

Even though the shapes look like bacteria, they may not actually be from bacteria. To show that the shapes could really be fossil bacteria, McKay and co-workers have tried to show that: (a) the bacteria shapes are actually the sizes and shapes of known living organisms, (b) the bacteria shapes are really part of the rock and were not produced accidentally while they prepared the sample for study, and (c) the bacteria shapes are not Earth bacteria that somehow wiggled into ALH 84001 while it was in Antarctica.

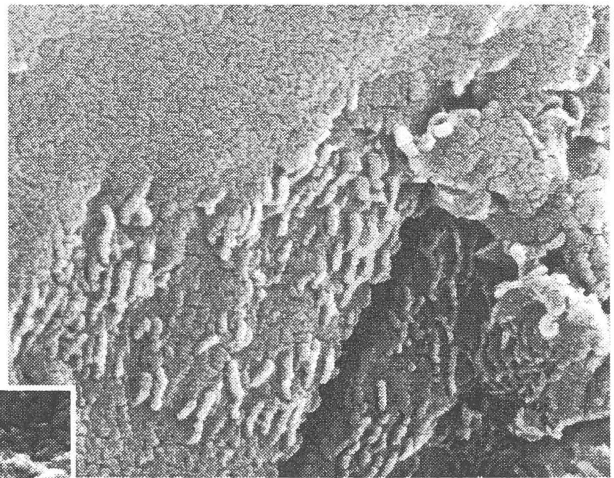
(a) It turns out that many Earth bacteria have essentially the same sizes and shapes as do the structures that McKay and co-workers found in ALH 84001. These minute Earth creatures, the "nanobacteria," were first discovered living inside rock, and have since been found inside rocks from many different places and environments. They have even been found growing happily in volcanic rocks (similar to ALH 84001) five kilometers beneath the surface of eastern Washington.

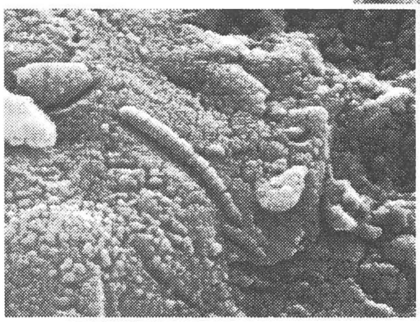
Even though the bacteria-shaped structures are the same sizes and shapes as some Earth bacteria, Dr. W. Schopf (an eminent paleontologist and expert on the earliest life on Earth who spoke at the NASA press conference on the McKay et al. findings) cautioned that the structures may not be bacteria. He



Carbonate-rich globules

Scanning electron microscope images (right): Shapes like bacteria (below).





warned that inorganic processes can sometimes produce elliptical and tubular structures, and that ancient bacteria on Earth were hundreds of times larger than the tubes and sausages in ALH 84001. Even more, he warned that finding bacteria-shaped structures isn't enough; to accept that these shapes are fossils, he'd want to see evidence of cell walls (which keep live bacteria apart from their surroundings), evidence of reproduction (bacteria shapes dividing or budding), evidence of growth (bacteria shapes in a range of sizes, with the largest beginning to divide), and evidence of colonies of cells.

(b) Electron microscope images often show features and structures that have nothing to do with the sample, such as dust, cleaning residue (high-tech "soap scum"), and the glue (epoxy) used to mount the sample. Also, samples for their electron microscope study need to be coated with metal or carbon; McKay and co-workers applied a very thin coating of gold and palladium. Sometimes this coating can obscure or change surface features. McKay and his co-workers tested for these kinds of artificial features by examining other rock samples besides ALH 84001 that had been treated exactly the same as the ALH 84001 samples with the bacteria shapes. McKay and co-workers did not see the bacteria-shaped features on the other samples, and did not see them on samples of ALH 84001 without carbonate mineral globules. They found that the gold-palladium coating did leave a very fine cracked surface on the samples, but much smaller than the bacteria-shaped objects. So, they conclude that the bacteria shapes in ALH 84001 were not accidental products (artifacts) of sample handling and preparation.

It is still possible that the bacteria shapes are artificial, and that McKay and co-workers did not consider all possible kinds of artifacts. In particular, there is some concern that the rounded bacteria shapes were produced accidentally during gold-palladium coating, or are "thick" gold-palladium sheaths surrounding much smaller, real objects.

(c) Finally, McKay and co-workers need to show that the bacteria-shaped features are not just terrestrial bacteria. The bacteria shapes in ALH 84001 are too small for direct chemical or biological analysis with the methods McKay and co-workers had available. So, they looked at other Antarctic meteorites, thinking that if bacteria could enter ALH 84001 in Antarctica, bacteria should certainly be present in other meteorites. McKay and co-workers found no evidence of bacteria in other meteorites from the same area where ALH 84001 was discovered, so they conclude that the bacteria-shaped structures in ALH 84001 are not Earth bacteria.

It remains possible that the bacteria shapes are Earth bacteria. Although McKay and colleagues found no bacteria shapes in three other Antarctic meteorites, they caution us that these other meteorites are not exactly like ALH 84001. Particularly, the other meteorites did not contain carbonate mineral grains. If it happened that a kind of Earth bacteria lived only on carbonate minerals, it could grow in ALH 84001 and not in the other meteorites.

2. Microscopic mineral grains

McKay and co-workers found microscopic mineral grains in the carbonate mineral globules of ALH 84001, grains that are similar to some produced by bacteria on Earth. So, McKay and co-workers suggest that these mineral grains in ALH 84001 may have been produced by martian bacteria. They do note, however, that similar mineral grains can be produced by inorganic processes, without any assistance from life.

To show that the mineral grains might be products of martian bacteria, McKay and co-workers present evidence that (a) the mineral grains formed on Mars; (b) the mineral grains have chemical compositions, crystal structures, sizes, and shapes like biologically produced grains on Earth; and (c) the different microscopic mineral grains, and the larger mineral crystals they occur in, are not likely to have formed by inorganic processes, without assistance from life.

(a) The microscopic mineral grains are almost certainly from Mars. They are inside the carbonate mineral globules, which did form on Mars.

There is little doubt that the microscopic mineral grains, inside the carbonate mineral globules, formed on Mars.

(b) McKay and co-workers analyzed the chemical compositions and crystal structures of the microscopic mineral grains by transmission electron microscope (TEM). The three minerals they identified (magnetite, pyrrhotite, and greigite) have all been found on Earth as products of biological activity. Some bacteria make magnetite to help them tell where they are going, just like a magnet in a compass. The other minerals, both iron sulfides, may be waste products. And some bacteria produce grains of iron oxide and iron sulfide simultaneously. In the electron microscope images presented by the McKay team, the mineral grains they identified in ALH 84001 are very similar in size, shape, and structure to some grains produced on Earth by bacteria.

The mineral grains in ALH 84001 do look very similar to the ones made by terrestrial bacteria. However, similar grains can be made by nonbiological processes, a fact that McKay and co-workers readily bring forward.

It is also possible that McKay and co-workers' analogies to Earth bacteria are misleading. For instance, the grain of greigite shown in Figure 5c is from a bacterium in a plant root on Earth. If formation of greigite is significant to the interaction of the bacterium and its plant host, then its formation is probably irrelevant to Mars.

Similarly, magnetite grains are secreted by some Earth bacteria so they can follow the Earth's magnetic field. Mars now has hardly any magnetic field, so magnetite grains would be useless now to a martian bacterium, except possibly as a waste product. It is completely unknown whether Mars had a magnetic field at the time when the carbonate mineral globules formed.

(c) Recognizing that biological or nonbiological processes could produce any of the microscopic mineral grains individually, McKay and co-workers looked to see if nonbiological processes could have produced the groupings of microscopic grains together with their host minerals. The most important grouping of these grains is in patches inside the cores of the carbonate mineral globules. There, grains of iron oxide mineral (magnetite) and an iron sulfide mineral (greigite) sit in patches of porous-looking magnesium carbonate.

McKay and co-workers infer that this grouping of minerals is very unlikely without intervention from living organisms. First, they interpret the porous look of the veinlets to mean that the carbonate minerals were partially dissolved, leaving holes behind. To dissolve the carbonate, the veinlets must have formed from acid water. But magnetite + greigite can only form nonbiologically from very alkaline (= not acid) water. If the water were acidic, the magnetite and greigite would have dissolved or appear partially dissolved, which they do not. So, McKay and co-authors say that the minerals magnetite + iron sulfides + magnesium carbonate could not have formed nonbiologically, and so must have been a result of biological processes.

This argument is subtle, and rests on interpretations of ambiguous textures and minerals. The porous zones could represent magnesium carbonate that was dissolved out, but could also represent another mineral that was dissolved out, for instance, a water-soluble mineral like salt. Also, although it may not be significant, the identification of "greigite" is not certain. These grains decomposed while they were being analyzed (by transmission electron microscope), so their actual chemical composition, structure, and stability in acid or alkaline solutions is not certain.

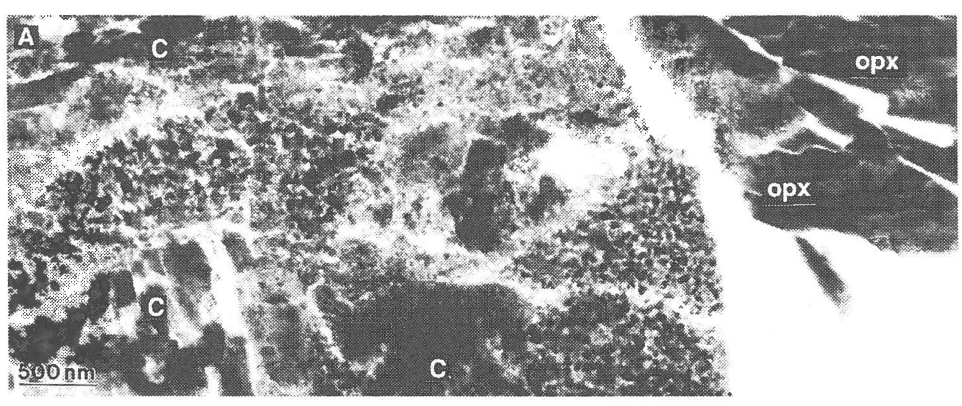
3. Polycyclic Aromatic Hydrocarbons

McKay and his co-workers found very small quantities of organic molecules near and in the carbonate mineral globules in ALH 84001. These molecules, called "polycyclic aromatic hydrocarbons" or PAHs, are a group of chemicals with similar structures; the only PAH that might be familiar to a nonchemist is naphthalene, the chemical in mothballs. PAHs can form during decomposition of bacteria, but can also form in many other ways. In fact, PAHs are abundant in the carbonaceous chondrite meteorites, which are from the asteroid belt and did not ever contain life as we know it.

McKay and co-workers try to show that the PAHs in ALH 84001 are derived from ancient martian bacteria by showing that they (a) are not contamination from laboratory procedures, (b) are not Earth PAHs that entered the meteorite while it was in Antarctica, (c) are not like PAHs in other meteorites (which have nothing to do with life), and (d) are consistent with decomposition of simple bacteria.

(a) PAHs form easily, in small quantities, from many human and laboratory activities. For example, PAHs are relatively abundant in burnt meat, and are the prime suspects in its supposed carcinogenic properties. So it is very important to be sure that the PAHs in ALH 84001 were not accidentally put there during its handling and laboratory study. To ensure that the PAHs in ALH 84001 really belonged there, McKay and co-workers took PAH-free objects (glass slides) through the identical handling and analysis procedures they used for ALH 84001. McKay and co-workers could detect no PAHs that came from their handling and analysis procedures. Then, they exposed meteorite samples, with and without PAHs, to the same handling and analysis procedures used for ALH 84001. Again, there was no evidence that that PAHs were added to the meteorite samples.

McKay and co-workers seem to have shown that the PAHs in ALH



Microscopic mineral grains along veinlets in the carbonate globules.

84001 did not get in during laboratory handling or chemical analyses.

(b) It is possible that the PAHs in ALH 84001 got in while the meteorite was in Antarctica. After all, PAHs are relatively abundant on Earth as natural organic products and from fire. McKay and co-workers applied a number to tests to show that the PAHs are not from Earth.

If the PAHs in ALH 84001 were from Earth, one might expect that they would be more abundant near the meteorite's surface, and less abundant deep inside. On the other hand, if the PAHs were extraterrestrial, they should have been vaporized away from the meteorite's surface during its fiery descent through the Earth's atmosphere. McKay and co-workers tested these ideas by measuring the abundances of PAHs inward from the outside surface (the fusion crust) of ALH 84001. They found that the abundances of PAHs increased as they worked in toward the center of ALH 84001. This increase inward suggests that the PAHs were already in the meteorite before it came through the Earth's atmosphere.

Today, the principal sources of PAHs on Earth are "anthropogenic emissions" — exhaust and smoke from burning fossil fuels and from industrial processes. McKay et al. show, however, that the specific PAH chemicals in ALH 84001 are not the same as those in the Earth's atmosphere. Particularly, sulfur-bearing PAHs are abundant in the Earth's atmosphere, but undetectable in ALH 84001.

McKay and co-workers also note that PAHs were much more abundant in the areas they analyzed in ALH 84001 than in ice from Greenland that formed before the industrial revolution. From this, they infer that the PAHs in ALH 84001 are too abundant to have come from preindustrial Earth sources, and so must be extraterrestrial.

McKay and co-workers seem to have shown fairly convincingly that PAHs in ALH 84001 were there before it landed on Earth. The decrease in PAH abundances near the fusion crust suggests that ALH 84001 contained these PAHs before the fusion crust formed. Because fusion crust marks ALH 84001's descent to Earth, the PAHs would be preterrestrial, and most probably martian. However, it is still possible that the PAHs formed on Earth, and that their decreased abundance near the fusion crust depends on some subtle change in the minerals or structure of ALH 84001 near its fusion crust.

(c) PAHs are abundant in a few other types of materials in the galaxy: carbonaceous chondrite meteorites, interplanetary dust, and interstellar dust grains. If the PAHs in ALH 84001 are related to ancient life, they should not be like the PAHs in the any of these other materials, which formed without any assistance from life (at least as we know it). McKay and co-workers found that the PAH molecules in ALH 84001 are not similar at all to those in most meteorites and in interplanetary or interstellar dust. The PAHs in ALH 84001 are similar to those in one class of meteorites, but still sufficiently different that they could not be related.

It seems fairly certain that the PAHs in ALH 84001 are not like those in known meteorites, cosmic dust, or interstellar dust. It is, of course, possible that there were other, unsampled sources of PAHs in the solar system or galaxy that dumped PAHs onto Mars early in its history. But without evidence for other sources of PAHs, it seems simplest to believe that the ALH 84001 PAHs originated on Mars by peculiarly martian processes.

(d) Finally, McKay and co-workers want to show that the types of PAH molecules in ALH 84001 are like those that form on Earth from the decomposition of bacteria. The PAHs in ALH 84001 contain only a very small fraction of the enormous variety of PAHs that occur on Earth. McKay and co-workers say that a limited variety of PAHs is just what would be expected, and has been observed on Earth, from the natural breakdown of simple living organisms.

McKay and co-workers have not demonstrated that the variety and abundances of different PAH molecules in ALH 84001 is actually what would form during the breakdown of simple living organisms. There may also be simple inorganic processes that could produce the limited variety of PAHs seen in ALH 84001, without any recourse to living organisms.

To summarize, the Science *paper of McKay and co-workers leaves many unanswered question. As they forthrightly state, their paper is not proof of life on Mars. Their paper presents evidence that, on its surface, is consistent with ancient life on Mars; McKay and co-workers believe that the evidence is more consistent with life on Mars than any other explanation or explanations. Almost all their conclusions can be disputed and will likely be disputed.*

From my perspective, their strongest conclusion is that ALH 84001 contains polycyclic aromatic hydrocarbons (PAHs) that formed on Mars. These PAH molecules may be related to martian micro-organisms, as McKay and co-workers suggest. The PAHs might also have formed without assistance from living organisms, in what might be called a prebiotic organic chemistry. Proof of a prebiotic organic chemistry system in Mars would be nearly as exciting as proof of life itself. —AHT, August 21, 1996.

(Dr. Treiman is a scientist at the Lunar and Planetary Institute. His research focuses on Mars and the SNC meteorites. He has studied ALH 84001 extensively; he is not a member of the McKay et al. research team whose recent work on the meteorite is discussed in this article.)

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NEW IN PRINT

These publications are available from the publisher listed or may be ordered through local bookstores.

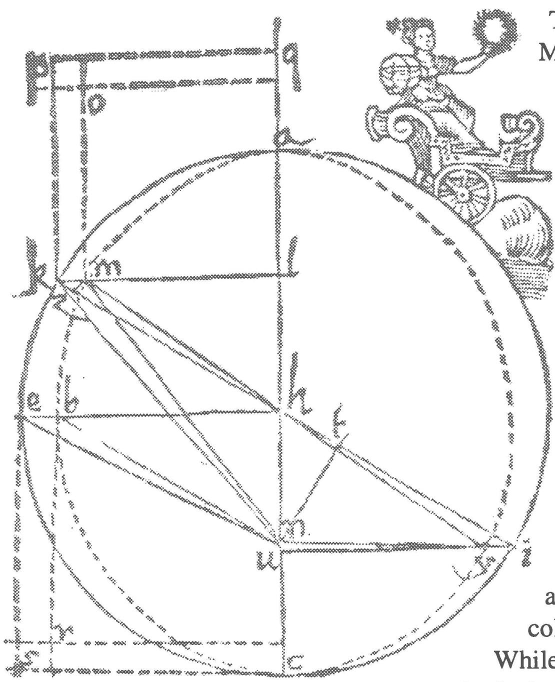
REVIEW

Planetary Science for the Common Man — Two Recent Books

Planets — A Smithsonian Guide
by Thomas R. Watters
Macmillan, New York, 1995, 256 pp.
Black and white and color photographs and illustrations. Hardcover. $24.95.

Planets and Their Moons — National Audubon Society Pocket Guide
by Gary Mechler, Steven K. Croft, Melinda Hutson, and Robert Marcialis
Alfred A. Knopf, New York, 1995, 192 pp.
Color photographs and black and white illustrations. Softcover. $7.99

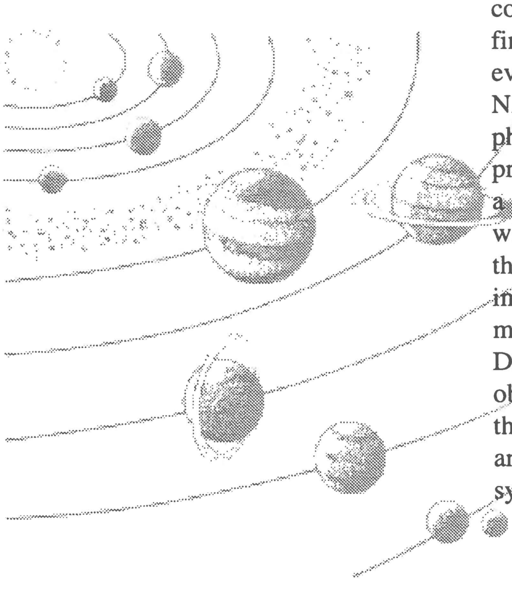
Despite all our efforts in the scientific community to make planetary exploration as exciting as a xeroxed viewgraph, the general public still thinks it's neat to look at and learn about the other planets in our solar system. There is a need for and a market available to those who can condense, explain, and showcase for the public the spectacular images that have been returned from over 30 years of manned and unmanned planetary exploration. Perhaps the most notable of past efforts at this is *The New Solar System*, which was edited by two popular science writers but had each chapter written by a scientific expert (in some cases a loose definition of the term "expert" is required). While it is an excellent book, *The New Solar System* is seven years out of date, and consequently lacks images and the resulting scientific discoveries from the Magellan, Galileo, Clementine, and Hubble missions. Here I review two up-to-date publications, both produced by organizations that excel at bringing science to the people. One of my interests in these books (and perhaps yours as well) is their potential use as a full-color supplement to planetary science textbooks, most of which are sparsely illustrated and all of which have only black-and-white images.



The first of these, *Planets*, is written by Tom Watters of the Air and Space Museum as part of a series of *Smithsonian Guides*. This book uses the format of a planetary science textbook, but its writing style and depth of presentation is intended for a popular audience. The book begins with an overview of the history of planetary exploration and a short summary of planetary formation theory. He then starts with the Sun and moves outward, describing some of the interesting features of each of the solar system bodies and discussing some of the science along the way. For example, for Saturn he begins with a history of exploration, then discusses Saturn's interior structure, follows with the composition, origin, and behavior of the rings, and concludes with brief descriptions and explanations of the geology of each of Saturn's larger moons. Interspersed among the object-by-object descriptions are a variety of feature articles describing such topics as cratering, individual NASA missions, phases of the Moon, etc. The last chapter, "Comparing the Planets," is perhaps the most interesting. It compares the distances, sizes, and interior structures of the planets along with surface features like craters and volcanos. Following the last chapter is a glossary, shaded relief maps of the terrestrial planets, comparison tables, and an index. The book is lavishly illustrated, both with spectacular images and color three-dimensional schematic diagrams.

While I was impressed with the book and thought it was quite good, it is not without its faults. Many of the images are noticeably false-colored with no identification of such. Someone at the Air and Space Museum must like the color green, because a lot of generally gray bodies end up green-tinted in the book. I know this isn't some bizarre error in the printing process because plenty of grayscale images come out gray in the book. It's not uncommon for images of the same body on the same page to be printed with completely different color schemes. There are also some examples of what I'd call sloppy writing. In some cases things are stated incorrectly: A description of how a radar altimeter works is given for how radar imagery is collected; poor wording and poor definitions of the terms "lithosphere" and "crust" make the discussion of terrestrial mantle convection and plate tectonics incomprehensible; the wrong (much smaller) crater is identified as Odysseus on Tethys, making the comparison with Hershel on Mimas quite confusing. In other cases the effort to simplify, in my opinion, reduces clarity and introduces incorrect concepts: Although the difference between mass and weight is defined in the glossary, throughout the text a person's weight on other planets is given in both pounds and kilograms; a map shows earthquake locations around the world without noting that these must be earthquakes above some magnitude and after a particular date; planetary distances in one case are given in terms of the travel time for a plane traveling at the speed of sound, but it is not noted that the speed of sound is a variable dependent on the properties of the material the sound is traveling through. These may seem like minor points, but the need for accurate and precise writing is greatest for books written for a popular audience, because while a scientist can recognize what the author really means by a poorly written statement, the general public will simply be left confused. The instances of sloppy writing are not numerous, but occur often enough that I wonder whether a thorough final review was performed at the galley-proof stage of publication. I hope the Air and Space Museum will tidy up these loose ends before the next print run, because overall *Planets* is a pretty good book.

The second book, *Planets and Their Moons*, an Audubon Society product and one of their *Pocket Guide* series, takes a very different approach to presenting the fruits of planetary exploration. There is a brief introduction that talks about solar system formation, similarities and differences of the planets, and planetary motions. Most of the remainder of the book is devoted to 4" × 6" images (the size of the book) of planetary bodies with an extended figure caption on the facing page. They begin with a couple of planetary comparison images, then work outward from Mercury to Pluto, and finish with comet images. In my opinion, this is the best collection of planetary images ever put into a single book. It is a masterful combination of telescopic images and NASA press release photos. The figure captions are clear and concise, putting each photograph in perspective, identifying important features, giving scales where appropriate, and explaining any unusual color schemes. While not written in textbook style, a great deal of planetary science is contained within the figure captions, and someone who reads the book cover to cover will come away with a pretty good understanding of the field. The flow of photographs is logical and well done. For example, Mercury images begin with telescopic images of a half-Mercury and a transit of the Sun, then move to a Mariner 10 mosaic of a half hemisphere, and finish with closeups of Discovery Scarp and Caloris Basin. The book closes with directions and tables for observing the planets, and then a very sparse index. While there are a few images of the Moon, there are none of the Sun: These two bodies are covered in great detail in another *Pocket Guide* entitled *The Sun and the Moon*. Whenever I have taught a solar system course I have always wished the students had a high-quality set of images to



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PUBLICATIONS FROM LPI

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	PRO-22	PROCEEDINGS OF THE LUNAR AND PLANETARY SCIENCE CONFERENCE, VOLUME 22	$10.00	
	B-ACM	ASTEROIDS, COMETS, METEORS 1991	$10.00	
		SLIDE SETS		
	S-HAWAII	VOLCANIC FEATURES OF HAWAII AND OTHER WORLDS (40 SLIDES)	$22.00	
	S-RED	THE RED PLANET: A SURVEY OF MARS (40 SLIDES)	$22.00	
	S-IMPACT	TERRESTRIAL IMPACT CRATERS (26 SLIDES)	$20.00	
	S-WINDS	THE WINDS OF MARS: AEOLIAN ACTIVITY AND LANDFORMS (30 SLIDES)	$20.00	
	S-STONES	STONES, WIND, AND ICE: A GUIDE TO MARTIAN IMPACT CRATERS (30 SLIDES)	$20.00	
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refer to, and *Planets and Their Moons* fits the bill perfectly. Its cost is low enough that I can make it a required supplement to the textbook I use in the course.

In summary, both these books represent high-quality, up-to-date, well-illustrated presentations of planetary science to the general public.

—Robert Herrick

(Dr. Herrick is a research scientist at LPI.)

ORIGINAL NATIONAL GEOGRAPHIC SOCIETY — PALOMAR OBSERVATORY SKY SURVEY AVAILABLE ON CD-ROMS

The Space Telescope Science Institute (STScI) and the Astronomical Society of the Pacific (ASP) have announced the availability of RealSky CD, the digitized Palomar Observatory Sky Survey, compressed by a factor of 100, on eight CD-ROMs. For the first time, amateur astronomers, educators, and the public have access to the actual sky survey plates used for more than 30 years by research astronomers. The unprecedented level of telescopic detail, especially of extended images like galaxies, clusters, and nebulae, is not available in any other astronomical software package.

The images are digitizations of the E plates from the first NGS-POSS, conducted with the Oschin Telescope (48" Schmidt) on Palomar Mountain during the 1950s. The NGS-POSS was funded by a grant from the National Geographic Society to the California Institute of Technology. With funding from NASA, the more than 750 plate images were first digitized during an intensive 8-year effort by STScI astronomers to prepare the Guide Star Catalog that provides the coordinates of target stars used by the Hubble Space Telescope to acquire and lock onto celestial targets.

RealSky CD is a more compressed version of the original Digitized Sky Survey (DSS), which was made available on 102 CD-ROMs two years ago. The DSS was compressed by a factor of 10 and offered images that were nearly indistinguishable from the original data. The compression factor of RealSky is not suitable for professional research but provides an invaluable tool for the educational and amateur communities. RealSky CD offers single-color (one passband) images of the entire northern sky, down to –15 declination — the approximate location of Sirius — and angular resolution of 1.7 seconds, revealing stars as faint as 19th magnitude.

The RealSkyView software included with the CDs allows users to view and manipulate the images under Windows (3.1, '95, NT) or Macintosh operating systems. UNIX and VMS software is also included with both versions. Both RealSky CD and the original 10× Digitized Sky Survey can be accessed directly from TheSky (v.4) astronomy software by simply clicking on the desired sky area and specifying image size. CDs are packaged with instruction manual and accompanying software.

The eight CD-ROM set costs $250.00. Within the U.S., add $16 for shipping and handling charges; Canada and Mexico residents add $20; all other countries add $50 for delivery by airmail. California residents please add applicable sales tax. Use your Visa or Mastercard to order at 1-800-335-2624 or send orders by check, credit card, or institutional purchase orders to The Astronomical Society of the Pacific, RealSky CD Orders, 390 Ashton Avenue, San Francisco CA 94112. USA. Phone: 415-337-1100; fax: 415-337-5205. E-mail: asp@stars.sfsu.edu

NEW FROM LGI

The Lunar Geotechnical Institute announces a new technical report, "Trafficability of Lunar Microrovers (Part 3)," TR96-01, available free on request from LGI, P.O. Box 5056, Lakeland FL 33807-5056. Phone/fax: 941-646-1842.

Return to the Red Planet

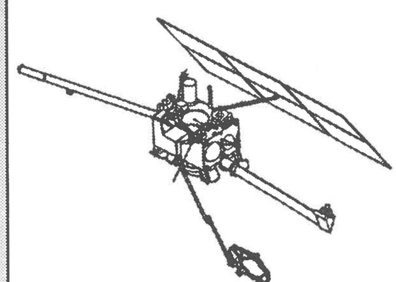
—by Joseph A. Burns, Ronald Greeley, and David H. Smith

Even before the recent announcement of the possible detection of ancient life in a martian meteorite, Mars was an object of high scientific priority and immense public interest. Indeed, anyone doubting that Mars holds a special place in the human imagination need only look to the recent phoenixlike rebirth of NASA's plans for the exploration of the Red Planet. NASA's hopes and dreams of exploring Mars, on hold since Viking in the late 1970s, were embodied in Mars Observer, which — just hours before entering orbit around Mars in August 1993 — ceased all communications with Earth. For scientists, years of effort were scuttled with the very public failure of this sophisticated and expensive probe. For policymakers, it was yet another addition to the ever-growing litany of NASA woes.

Today, with the imminent launch of Mars Pathfinder and Mars Global Surveyor missions, Mars exploration is about to be renewed. Moreover, Congress has already approved Mars Surveyor, a program to dispatch a pair of Mars-bound spacecraft every 26 months until 2005.

What changes hallowed this rebirth? The basic answer is that NASA's Mars program in 1996 is smaller, faster, and cheaper than its counterpart of a few years ago. While Mars Observer cost more than $600 million and took almost a decade to design and build, the new-style Mars missions are capped at about $100 million apiece and must be designed and launched in just a few years.

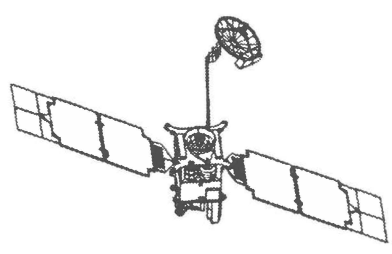
While the "smaller, cheaper, faster" mantra is widely invoked as a new way to explore space, is it anything more than a slogan? Can a series of small missions spread out over a decade produce sufficient scientific return to justify the still-significant cost? This question was the subject of a recent report published by the National Research Council's Committee on Planetary and Lunar Exploration (COMPLEX).*



Mars Observer

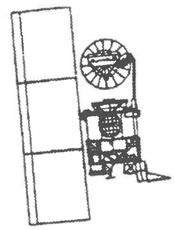
Before answering this question, we must be clear about why we are studying Mars. It makes no sense to spend $100 million or more on stunts. Missions must lead to a substantial improvement in our understanding of the planet most like Earth and the obvious target for human exploration beyond the Moon.

The three most important scientific topics to be addressed by future missions to Mars are: Why has Mars's climate evolved so differently from Earth's and why, in particular, is Mars so much drier and colder than in the past? How have geological processes created a martian landscape so similar to Earth's in some aspects and yet so different in others? Does evidence prebiological organic compounds or even extinct life remain on Mars?



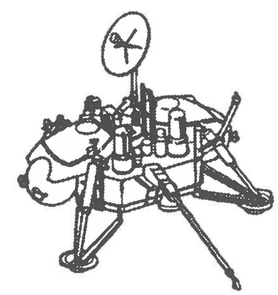
Mars Global Surveyor

Mars Global Surveyor, scheduled for launch in November, will use spare copies of many of Mars Observer's instruments to monitor the martian atmosphere, map the composition and topography of its surface, and study the planet's magnetic field. Mars Pathfinder,



MSP '98 Orbiter

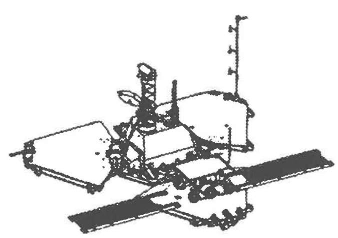
scheduled for launch in December, will land a science package, including a small roving vehicle, on Mars next July. Subsequent missions in 1998 and 2001 will carry the remainder of Mars Observer's instruments and will conduct more complex observations, both on the edge of Mars's southern polar cap and from orbit.



Viking Lander

The first few Mars Surveyor missions will measure the global characteristics of the wind-blown soil and well-mixed atmosphere. Access to martian rocks will be limited to the immediate vicinity of landing sites, yet evidence for past climate changes and ancient life, if any, is most likely to be embedded within rocks, probably in at most a few locales. Thus Mars Surveyor's inability to study a diverse sample of rocks and terrains is a major shortcoming.

An equally great worry is that Mars Surveyor includes no provision for designing and constructing innovative instruments. Can this program be smaller, faster, and cheaper if it must rely on bulky instruments using 1970s technology?



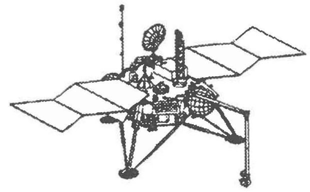
Mars Pathfinder

A longer-term concern is that as the program progresses it may become increasingly difficult to make major discoveries with the small landers currently envisaged. Larger landers — those capable of transporting sophisticated, long-range rovers to the surface — will be required for future missions. This is especially true for the Holy Grail of Mars exploration, a mission to return multiple samples of martian soil and rock to Earth for analysis. Although NASA has penciled in the launch of such a mission for 2005, its feasibility is uncertain.

Despite some shortcomings, Mars Surveyor holds great promise for enhancing our understanding of Mars' atmosphere and climate, its geological characteristics, and, to a somewhat lesser extent, its present and past potential for harboring life. This aggressive and exciting program deserves the full support of scientists and public alike.

*Copies of this report, *Review of NASA's Planned Mars Program,* are available upon request from the Space Studies Board, (phone: 202-334-3477).

(Burns, of Cornell University, and Greeley, of Arizona State University, are respectively the past and present chairs of COMPLEX. Smith, of the NRC, directs the Committee's activities.)



MSP '98 Lander

Galileo Explores Jupiter and Its Satellites:

The Ganymede-1 Encounter

For several years, the Galileo spacecraft has traveled through the solar system on its way to its primary target, Jupiter and its satellites. Launched October 18, 1989, Galileo initially headed in toward Venus to obtain a gravity assist to increase its velocity, came back to the Earth-Moon system in December 1990, swung out through the asteroid belt and passed close by the asteroid Gaspra, came back around the Earth-Moon system again in December 1992 for yet another gravity assist, passed through the asteroid belt again, obtaining images of the Rhode Island-sized asteroid Ida, and finally, in late 1995, deployed a probe into Jupiter's atmosphere and entered orbit around the giant planet. At that point it began its almost two-year-long primary mission of exploring the Galilean satellites and atmosphere of Jupiter.

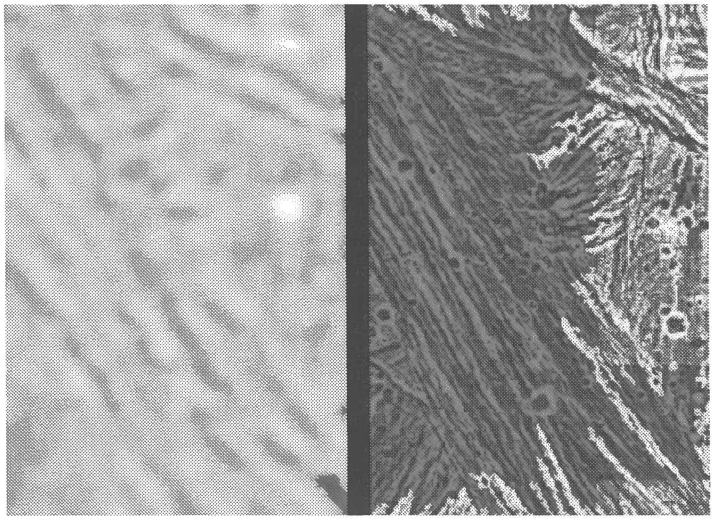
The Galileo spacecraft is now another satellite in orbit around Jupiter, the largest planet in the solar system, and on June 27 came within a few hundred kilometers of Ganymede to begin a series of 11 close encounters with Jupiter's four Galilean satellites: Io, Europa, Ganymede, and Callisto. The four moons form a miniature solar system around the giant gaseous planet. As revealed by the Voyager spacecraft in the late 1970s, Io, the innermost, is the size and density of the Earth's Moon and is constantly volcanically active as it is squeezed between the tidal forces of giant Jupiter and the nearest moon Europa. Europa also has a size and density similar to the Earth's Moon, but it is covered with a layer of highly fractured water ice and possibly a liquid water ocean below.

From here outward, the Galilean satellites change character from moons that resemble the inner, silicate-rich planets to bodies that are more similar in density and composition to objects in the outer solar system. Ganymede is larger than the planet Mercury, about one-third the diameter of Earth, but its density is less than 2 grams per cubic centimeter. Its surface is composed of half ancient, heavily cratered dark terrain and half younger, bright terrain that has been heavily tectonically modified. Both these surfaces are dominated by water ice with the older terrain having more darkening agents. Callisto is similar to Ganymede in size and density, but its surface is almost completely dark terrain that is even more heavily cratered than that of Ganymede.

These basic observations raise many questions about the formation and geologic history of these satellites and the system as a whole. Among a host of important scientific objectives, Galileo is designed to obtain high-resolution images of key terrain relationships and to fill gaps in coverage from the Voyager flybys in order to address these questions. The Galileo Solid State Imaging (SSI) Team, a group that consists of geoscientists and atmospheric scientists from several institutions and is headed by Team Leader Mike Belton of the National Optical Astronomy Observatories, works to obtain these images.

A few days after the late-June encounter, in a press briefing at the Jet Propulsion Laboratory, Galileo Project Scientist Torrence Johnson, along with Jim Head and Bob Pappalardo of Brown University, described the first SSI images of Ganymede's bright and dark terrain and the dramatic improvement in resolution over the Voyager images.

In the pair seen in Figure 1, the frame at left shows a 35 × 55 kilometer (25 × 34 mile) area of bright terrain known as Uruk Sulcus and was taken by the Voyager 2 spacecraft when it flew by in 1979, with a resolution of about 1.3 kilometers (0.8 miles) per pixel. The frame at right showing the same area was taken by Galileo and has a resolution of about 74 meters (243 feet) per pixel, more than 17 times better than that of the Voyager image. In the Voyager frame, line-like bright and dark bands can be seen, but their detailed structure and origin are not clear. In the Galileo image, each band is now seen to be composed of many smaller ridges. The structure and shape of the ridges permit planetary geologists to determine their origin and their relation to other terrains, helping to unravel the complex history of this planet-sized moon. Initial analysis suggests that extension and ductile stretching of the ice at depth is causing brittle failure in



NASA/JPL Photo P-47058

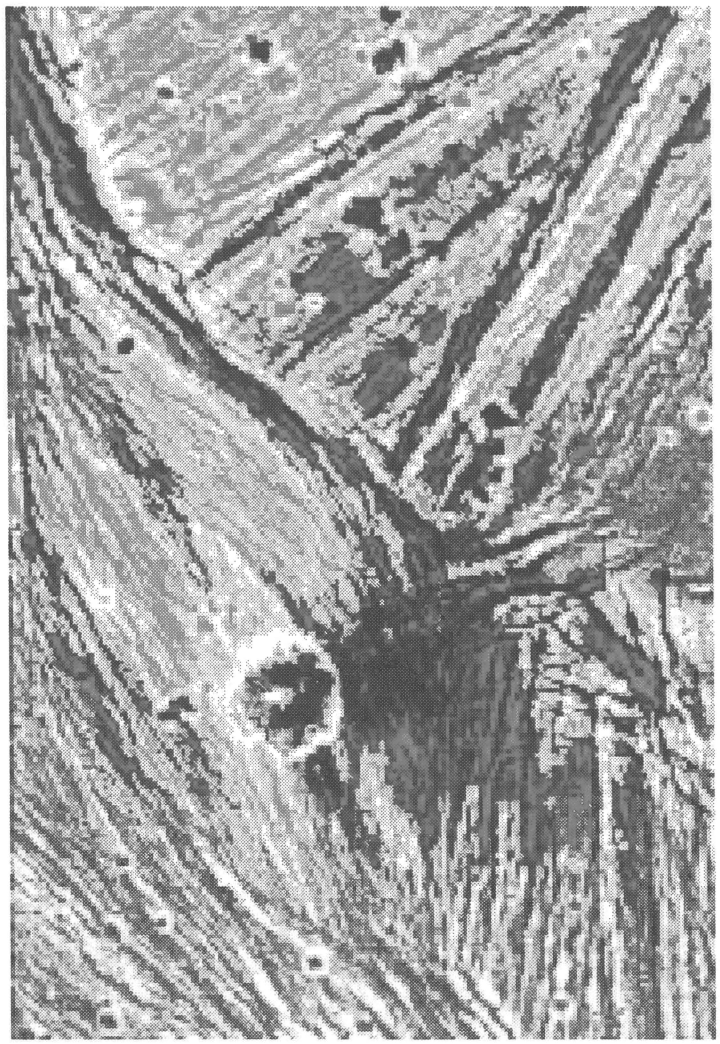
Figure 1. *Comparison of Ganymede's bright terrain in Uruk Sulcus in a Voyager image [left; 1.3 kilometers (0.8 miles) per pixel] and a Galileo image [right; 74 meters (243 feet) per pixel]. In each of these frames, north is to the top, and the Sun illuminates the surface from the lower left nearly overhead (about 77° above the horizon). The area shown is at latitude 10°N, 167°W and is about 35 × 55 kilometers (25 × 34 miles). The image was taken when Galileo was 7448 kilometers (4628 miles) away from Ganymede.*

the near-surface ice and the formation of lanes of rotated fault blocks. Evidence of shear displacement can also be seen in the zone crossing the image in the upper right.

In other parts of Uruk Sulcus, different relationships can be seen. In Figure 2, a mixture of terrains reveals fine details of bright areas that make up about half the surface of Ganymede. Pockmarked, ancient, heavily cratered terrain is seen at the top; it is cut by younger, line-like structures in the lower left of the image. At the lower Voyager resolution, the area in the upper right was thought to be smooth and relatively younger then the rest of the terrain in the image, perhaps having been emplaced by water ice volcanism. However, the higher crater density and the cross-cutting relationships shown in the Galileo image indicate that the previous thinking was reversed and that the material is actually older. The bright, circular feature in the lower middle is an impact crater with some dark ejecta superimposed on the linear ridges. These types of relationships revealed by Galileo are permitting scientists to work out the complex geologic history of Ganymede.

Images of the dark terrain provided similar increases in resolution and show important details of this ancient icy landscape (Figure 3). Abundant impact craters seen in this image of Galileo Regio [resolution about 80 meters (262 feet) per pixel] testify to the great age of the terrain, dating back several billion years. At the bottom margin, half of a 19-kilometer (12 mile) - diameter crater is visible. The dark and bright lines running from lower left to upper right and from left to right across the middle are deep furrows in the ancient crust of dirty water ice. These furrows may be ancient impact basin rings or tectonic structures resulting from very early convection in a liquid water mantle. The origin of the dark material is unknown, but it may be accumulated dark fragments from many meteorite falls that accumulated on Ganymede. Analysis of this and similar Galileo images will allow planetary geologists to assess these theories and to compare these results with images taken during encounters with other moons of Jupiter in the coming months.

In an amazing finding recently, NASA scientists reported on the possible detection of signs of fossil life on Mars. This has raised interest in another exciting aspect of the Galileo mission, the nature of the interior of the satellite Europa. During the Ganymede-1 encounter, SSI team members were able to obtain a few images of the surface of Europa. In a press briefing on August 13, SSI Team Member Ron Greeley of Arizona State



NASA/JPL Photo P-47065

Figure 2. *In this view of Uruk Sulcus, part of Ganymede's bright terrain, north is to the top and the Sun illuminates the surface from the lower left nearly overhead. The area shown, at latitude 10°N, longitude 168°W, is about 55 × 35 kilometers (34 × 25 miles), and the smallest features that can be seen are 74 meters in size. The image was taken on June 27 at a range of 7448 kilometers (4628 miles).*

University described Europa images that showed a cracked and previously mobile surface, which appeared as if thin plates of "sea-ice" had separated and drifted apart, causing liquid or slushy water to well up and freeze, creating dark patches in between (Figure 4). Of course, if liquid water does (or did) exist in the shallow interior of Europa, this could be a natural site for the development of life. Further encounters will provide much better resolution imaging of Europa to reveal surface features in more detail.

Information for this report was contributed by Jim Head, SSI Team member from Brown University. These images and information on their interpretation and the Galileo mission in general can be seen on the World-Wide Web at http://www.jpl.nasa.gov/galileo/ and http://www.jpl.nasa.gov/galileo/sepo/.

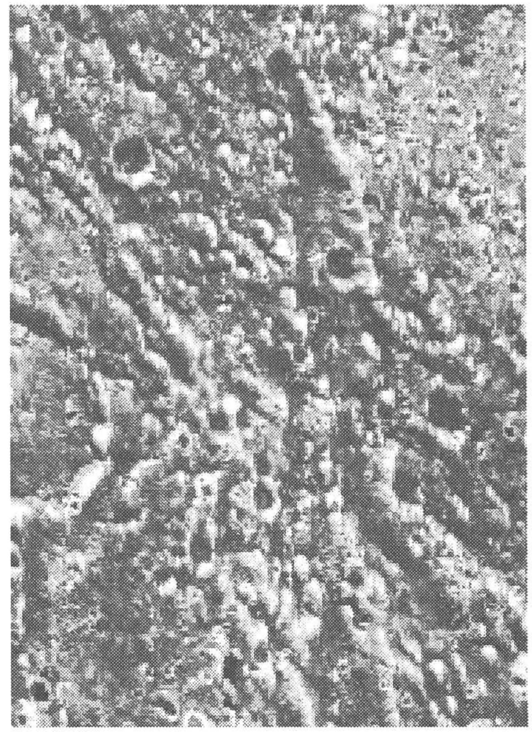


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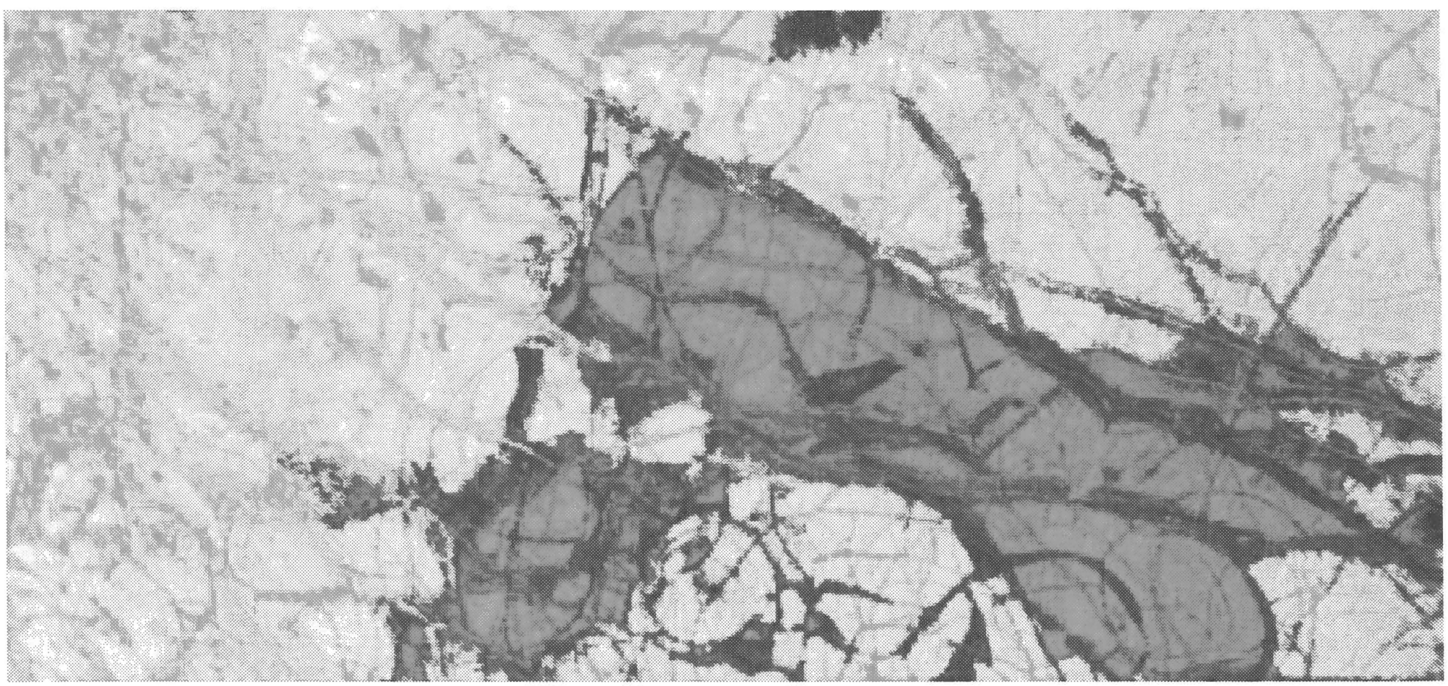
Figure 3. *(Right) Part of Ganymede's Galileo Regio dark terrain (latitude 18°N, longitude 147°W) about 46 × 64 kilometers (29 × 38 miles) in extent. Resolution is about 80 meters (262 feet) per pixel. The image was taken at a range of 7563 kilometers (4700 miles). North is to the top, and the Sun illuminates the surface from the lower left at about 58° above the horizon.*



NASA/JPL Photo P-47170

Figure 4. *Jupiter's moon Europa, as seen in this image taken June 27, 1996, by Galileo, displays features in some areas resembling ice floes seen in Earth's polar seas. Europa's icy crust has been severely fractured, as indicated by the dark linear, curved, and wedged-shaped bands seen here. These fractures have broken the crust into plates as large as 30 kilometers (18.5 miles) across. Areas between the plates are filled with material that was probably icy slush contaminated with rocky debris. Some individual plates were separated and rotated into new positions. Europa's density suggests that it has a shell of water ice as thick as 100 kilometers (about 60 miles), parts of which could be liquid. Currently, water ice could extend from the surface down to the rocky interior, but the features seen in this image suggest that motion of the disrupted icy plates was lubricated by soft ice or liquid water below the surface at the time of disruption. This image covers part of the equatorial zone of Europa and was taken from a distance of 156,000 kilometers (about 96,300 miles). North is to the right and the Sun is nearly directly overhead. The area shown is about 360 × 770 kilometers (220 × 475 miles or about the size of the state of Nebraska), and the smallest visible feature is about 1.6 kilometers (1 mile) across.*

CALENDAR 1996

SEPTEMBER

4–6
Exploring the Astrophysics of Extremes: Workshop on the Next Generation High-Energy Gamma-Ray Telescope, Greenbelt, Maryland.
E-mail: extremes@egret.gsfc.nasa.gov

11–12
The Scientific Impact of the Goddard High Resolution Spectrograph, (GHRS Science Symposium), Greenbelt, Maryland. Contact: Tom Ake, Co-Chair, LOC, Code 681/CSC, Goddard Space Flight Center, Greenbelt MD 20771. Phone: 301-286-3924; fax: 301-286-1752.
E-mail: hrssymp@hrs.gsfc.nasa.gov
WWW: http://hrssun.gsfc.nasa.gov/ghrs-home-page.html

11–13
Space Microdynamics and Accurate Control Symposium (SMACS 2), Toulouse, France. Contact: Agnes Letraublon, CNES, 18, avenue Edouard Belin-BPI 2011, 31055 Toulouse Cedex, France. Phone: 33-61-27-36-26; fax: 33-61-28-13-27.

24–27
ESO/IAC Workshop on Quasar Hosts, Tenerife, Spain. Contacts: Monica Murphy, Instituto de Astrofisica de Canarias, C/Via Lactea s/n, E-38200 La Laguna, Tenerife, Spain. Phone: 34-22-605261; fax: 34-22-605210. D. Clements, European Southern Observatory, Karl Schwarzschild Strasse 2, D-85748 Garching bei München, Germany. Phone: 49-89-320060; fax: 49-89-3202362.
E-mail: qhost@iac.es
E-mail: dclement@eso.org
WWW: http://www.iac.es/qhost/index.html

OCTOBER

7–10
Hypervelocity Impact Symposium, Freiburg, Germany. Contact: Susanne Deschoux, 1996 HVIS, Ernst-Mach-Institut, Fraunhofer-Institut fur Kurtzzeitdynamik, Eckerstr. 4, D-79104 Freibur I. BR, Germany *or* Mark Boslough, MS 0821, Sandia National Laboratories, P.O. Box 5800, Albuquerque NM 87185-0821. Phone/fax: 505-845-8851.
E-mail: mbboslo@sandia.gov

14–15
The Role of Small (0.6-2.0 m)Telescopes in Modern Astronomy: The First Annual Lowell Observatory Fall Workshop, Flagstaff, Arizona. Contact: Robert Millis, Lowell Observatory, 1400 Mars Hill Road, Flagstaff AZ 86001. Phone: 520-774-3358; fax: 520-774-6296.
E-mail: rlm@lowell.edu

OCTOBER (CONTINUED)

14–18
The 2nd International Lunar Workshop/ILEWG Meeting, Kyoto, Japan. Contact: Secretary of International Prigram Committee, c/o Japan Space Forum, Heiwa Building 7F, 1-7-1 Hamamatsu-cho, Minato-ku, Tokyo 105, Japan. Phone: 81-3-3459-1651; Fax: 81-3-5402-7521.
E-mail: KYQ03544@niftyserve.or.jp

16-18
Planets Beyond the Solar System and the Next Generation of Space Missions, Baltimore, Maryland. Contact: Cheryl Schmidt, Space Telescope Science Institute, 3700 San Martin Drive, Baltimore MD 21218.
E-mail: schmidt@stsci.edu
E-mail: soderblom@stsci.edu
WWW: http://www.stsci.edu/ftp/meetings/meetings.html

16–18
Workshop on Evolution of Igneous Asteroids: Focus on Vesta and the HED Meteorites, Houston, Texas. Contact: Publications and Program Services Department, LPI, 3600 Bay Area Boulevard, Houston TX 77058-1113. Phone: 713-486-2166; fax: 713-486-2160.
E-mail: enticknap@lpi.jsc.nasa.gov

22–25
28th Annual Meeting of the Division for Planetary Sciences of the American Astronomical Society, Tucson, Arizona. Contact: Steve Larson, Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721. Phone: 520-621-4973; fax: 520-621-4933.
E-mail: slarson@lpl.arizona.edu

28–31
Annual Meeting of the Geological Society of America, Denver, Colorado. Contact: Vanessa George, 3300 Penrose Place, Boulder CO 80301. Phone: 303-447-2020; fax: 303-447-1133.

31–Nov 2
Astrophysical Implications of the Laboratory Study of Presolar Material, St. Louis, Missouri. Contact: Thomas J. Bernatowicz, Department of Physics, Campus Box 1105, Washington University, St. Louis MO 63130.
E-mail: tom@howdy.wustl.edu
WWW: http://tbland.wustl.edu/stardust.html

NOVEMBER

4–7
IAA Symposium on Small Satellites for Earth Observation, Berlin, Germany. Contact: Bernd Kirchner, Symposium and Program Coordinator, DLR/WS. Phone: 49-30-69545-545; fax: 49-30-69545-532.
E-mail: iaa.symp@dlr.de

CALENDAR 1996–1997

NOVEMBER (CONTINUED)

12–14

Europa Ocean: An International Conference, San Juan Capistrano, California. Contacts: Doug Nash, San Juan Institute, 31872 Camino Capistrano, San Juan Capistrano CA 92675. Phone: 714-240-2010; fax: 714-240-0482. Dennis Matson (Program Chair). Phone: 818-354-2253; fax: 818-393-4495.
E-mail: nash@sji.org
E-mail: dmatson@jpl.nasa.gov
WWW: http://www.sji.org/conf/europa.html

17–20

Third Annual International Lunar and Mars Exploration Conference: Life in Space — Past, Present, and Future, San Diego, California. Contact: Michael Simon or Greg Nemitz, International Space Enterprises, 4909 Murphy Canyon Road, Suite 220, San Diego CA 92123. Phone: 619-637-5773; fax: 619-637-5776.
E-mail: isehq@aol.com

DECEMBER

2–5

Aerospace Technologies in Earth Sciences, Moscow, Russia. Contact: MIIGAIK, 103064, Gorochovskiy per., Moscow, Russia. Phone: 7-095-267-5436; fax: 7-095-267-4681 *or* Russian Aerosol Society, 103064, Vorontsovo pole str., 10, NIFHI, Moscow, Russia. Phone: 7-095-916-6389; fax: 7-095-147-4361.
E-mail: kirill@cc.nifhi.ac.ru

9–11

American Astronautical Society National Conference and 43rd Annual Meeting— Space Exploration and Development: Beyond the Space Station, League City, Texas. Contact: Willy Sadeh, AAS, 6352 Rolling Mill Place, Suite 102, Springfield VA 22152-2354. Phone: 703-866-0020; fax: 703-866-3526.
E-mail: 74673.724@compuserve.com

15–19

American Geophysical Union Fall Meeting, San Francisco, California. Contact: AGU Meetings, 2000 Florida Avenue NW, Washington DC 20009. Phone: 202-462-6900; fax: 202-328-0566.

30–Jan 1

Astronomical Time Series (Wise Observatory 25th Anniversary Symposium), Tel- Aviv, Israel. Contact: Dan Maoz, School of Physics

DECEMBER (CONTINUED)

and Astronomy, Tel-Aviv University, Tel-Aviv 69978, Israel.
E-mail: dani@wise.tau.ac.il

1997

JANUARY

7–10

The Three Galileos: The Man, The Spacecraft, The Telescope, Padova, Italy. Contact: C. Bargieri, Department of Astronomy, University of Padova, Vicolo dell'Osservatorio 5, I 35122 Padova, Italy. Phone: 39-49-875-4343; fax: 39-49-875-4345.

26–30

Space Technology and Applications International Forum (STAIF-97), Albuquerque, New Mexico. Includes: **14th Symposium on Space Nuclear Power and Propulsion; 2nd Conference on Commercial Development of Space; 2nd Conference on Next Generation Launch Systems; 1st Conference on Future Space and Earth Science Missions; 1st Conference on Synergistic Power and Propulsion Systems Technology; 1st Conference on Applications of Thermophysics in Microgravity.** Contact: Mohamed S. El-Genk, Technical and Publications Chair, or Mary Bragg, Institute for Space & Nuclear Power Studies, University of New Mexico, School of Engineering, Albuquerque NM 87131-1341. Phone: 505-277-4950; fax: 505-277-2814.
E-mail: mjbragg@unm.edu

FEBRUARY

13–18

AAAS Annual Meeting and Science Innovation Exposition, Seattle, Washington.
E-mail: iau164@nrao.edu.
WWW: http://www.cv.nroa.edu/library/meetings.html

MARCH

10–20

Formation and Evolution of Solids in Space: A NATO Advanced Study Institute—4th Course of the International School of Space Chemistry, Erice, Sicily. Contact: J. Mayo Greenberg, Huygens Laboratorium, P.O. Box 9504, 2300 RA Leiden, The Netherlands. Fax: 31-71-5275804.
E-mail: mayo@rulhl1.leidenuniv.nl

CALENDAR 1997

MARCH (CONTINUED)

17–21
28th Annual Lunar and Planetary Science Conference, Houston, Texas. Contact: Publications and Program Services Department, LPI, 3600 Bay Area Boulevard, Houston TX 77058-1113. Phone: 713-486-2166; fax: 713-486-2160.
E-mail: simmons@lpi.jsc.nasa.gov

JUNE

2–6
Seventh Annual V. M. Goldschmidt Conference, Tucson Arizona. Contact: Michael J. Drake, Department of Planetary Sciences, Lunar and Planetary Laboratory, The University of Arizona, Tucson AZ 85721. Phone: 520-621-6962; fax: 520-621-4933.
E-mail: goldconf@lpl.arizona.edu

8–13
12th IAA Man in Space Symposium: The Future of Humans in Space, Washington, DC. Contact: Terri Jones, USRA, Division of Space Life Sciences, 3600 Bay Area Boulevard, Houston TX 77058-1113. Fax: 713-244-2006.
WWW: http://cass.jsc.nasa.gov/12misf.html

15–20
Gordon Research Conference on Origins of Solar Systems, Henniker, New Hampshire. Contact: John Kerridge, Department of Chemistry 0317, UCSD, La Jolla CA 92093 *or* Alan Boss, Department of Terrestrial Magnetism, 5241 Broad Branch Road, Washington DC 20015. [Contributed papers in the form of poster talks welcomed.]
E-mail: jkerridg@ucsd.edu
E-mail: boss@axp1.ciw.edu

19–25
9th Rencontres de Blois: Planetary Systems—The Long View, Blois, France. Contact: L. M. Celnikier, Observatoire de Paris-Meudon, 92 Meudon, France. Fax: 1-45-07-74-69.
E-mail: blois97@mesiob.obspm.fr

JULY

17–19
Workshop on Parent Body and Nebular Modification of Chondritic Materials, Maui, Hawai'i. Contact: Publications and Program Services Department, LPI, 3600 Bay Area Boulevard, Houston TX 77058-1113. Phone: 713-486-2166; fax: 713-486-2160.
E-mail: cangelosi@lpi.jsc.nasa.gov

21–25
60th Meteoritical Society Meeting, Maui, Hawai'i. Contact: Publications and Program Services Department, LPI, 3600 Bay Area Boulevard, Houston TX 77058-1113. Phone: 713-486-2144; fax: 713-486-2160.
E-mail: cangelosi@lpi.jsc.nasa.gov

21–25
CHERBS '97—Conference on the High-Energy Radiation Background in Space, Snowmass, Colorado. Contact: Pam Solomon, Code 691, NASA Goddard Flight Center, Greenbelt MD 20771. Phone: 301-286-8797; fax: 301-286-1629.
E-mail: xrphs@lepvax.gsfc.nasa.gov

AUGUST

30–Sept 5
Sudbury 1997: Large Meteorite Impacts and Planetary Evolution, Sudbury, Ontario. Contact: Burkhard Dressler, LPI, 3600 Bay Area Boulevard, Houston TX 77058-1113. Phone: 713-486-2112; fax: 713-486-2162.
E-mail: dressler@lpi.jsc.nasa.gov

NOVEMBER

11–14
International Conference on Isotopes in the Solar System, Ahmedabad, India. Contact: J. N. Goswami, Physical Research Laboratory, Ahmedabad 380 009, India. Phone: 91-70-462129; fax: 91-79-6560502.
E-mail: isotope@prl.ernet.in

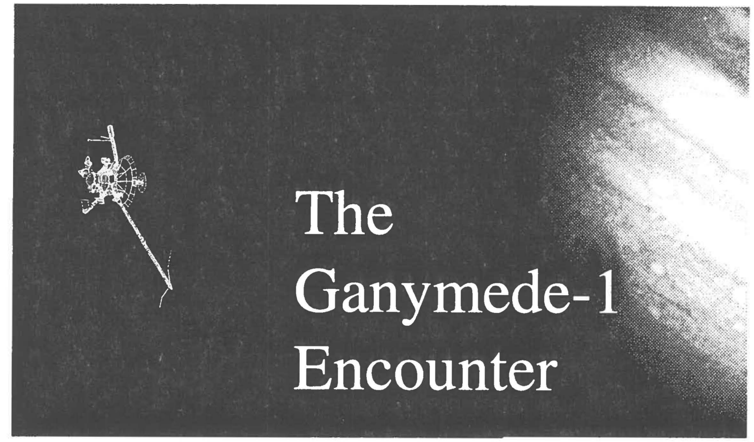
28th LPSC Abstract Deadlines

January 8, 1997, 6:00 p.m. CST is the deadline for ***hard-copy submission*** of abstracts. Hard-copy abstracts received after this date will be immediately returned to the author.

January 10, 1997, 6:00 p.m. CST is the deadline for ***electronic submission*** of abstracts. Late electronically submitted abstracts will not be accepted after this time.

Detailed information regarding abstract preparation and submission will be available on LPI's Web site (http://cass.jsc.nasa.gov/LPSC97) and will be included in the second conference announcement to be mailed in mid October. Authors are encouraged to read this information very carefully!

INSIDE



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