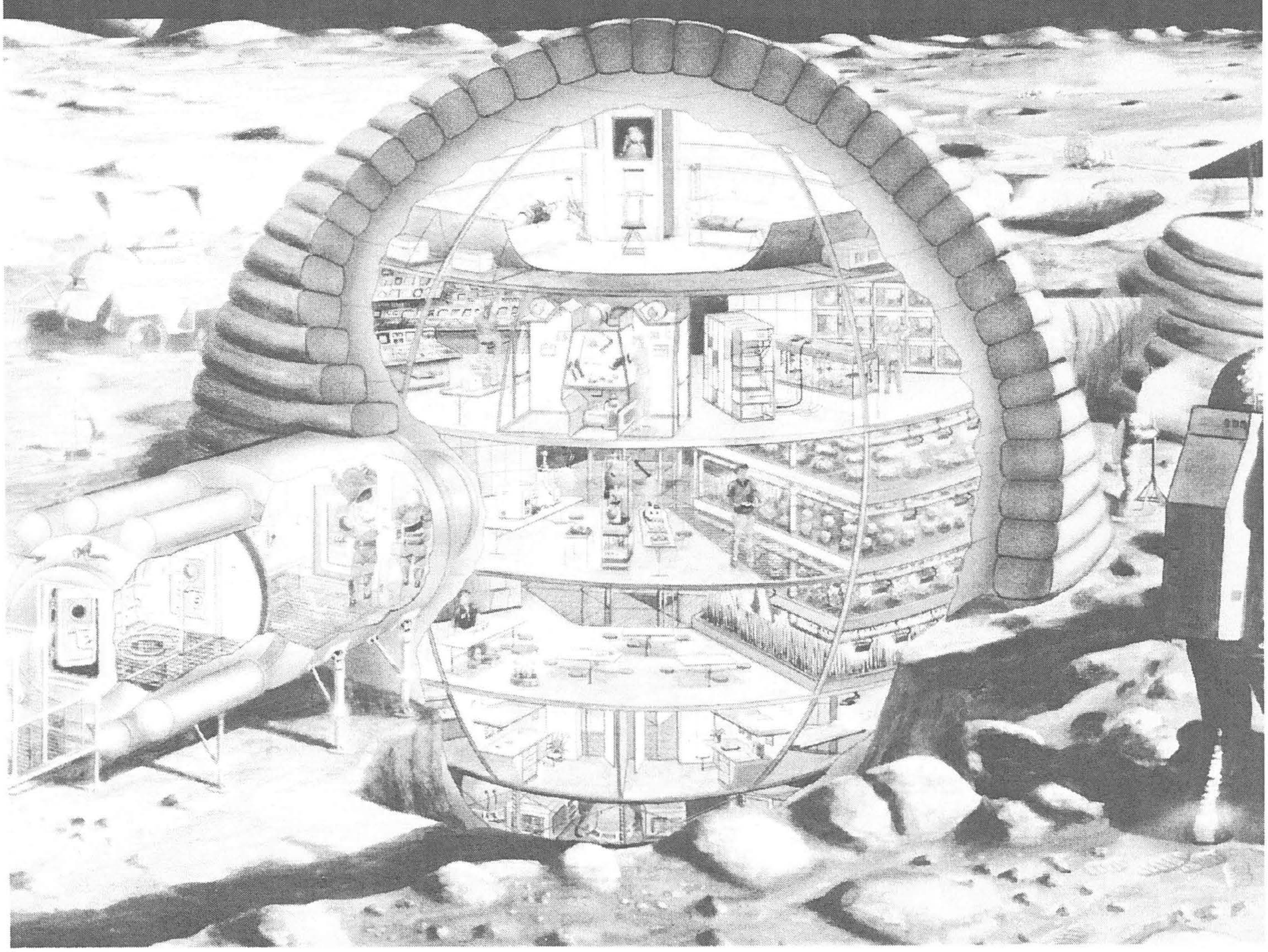
Lunar and Planetary Information
BULLETIN
Fall 1998/NUMBER 85 • LUNAR AND PLANETARY INSTITUTE • UNIVERSITIES SPACE RESEARCH ASSOCIATION

ROOM TO BREATHE

Using Plants to Create Self-Sufficient Habitats on Other Worlds



—*By Brian Anderson*

The Greenhouse Effect: LIVING AND WORKING WITH PLANTS ON OTHER WORLDS

Scientist Nigel Packham tends a crop of wheat during ALSP's Phase I experiment.

All illustrations courtesy of the Advanced Life Support Program.

To work the soil in such a way that it produces a nourishing vegetable is to experience firsthand the power of life. To do so on another planet, far from the rich soil, thick atmosphere, and warm sunlight of the Earth, would be nothing short of magic.

Yet scientists have long looked toward the possibility of harnessing the regenerative powers of plants as a means of making a hostile alien environment more livable. And as interest in long-term missions to Mars and the Moon grows, the idea of using plants as part of a cyclical life-support system is gaining prominence as a practical and cost-effective solution.

"For years, there has been a small group of people looking at using plants in long-duration missions," said Keith Henderson, a plant physiologist with NASA's Advanced Life Support Program. "The thinking is that if we had a really long mission we could use plants to clean up the air, produce food, and clean up the water."

Although many associate using plants on other worlds with the visionary notion of terraforming — actually converting a hostile atmosphere and surface into a lush, Earth-like environment over many years — plants have a more immediate role to play in the creation of closed-loop biosystems. Most scientists agree that plants would be an economic and efficient cornerstone of any long-term stay on Mars or the Moon.

Although most of the experiments thus far have been directed toward proving the ability of plants to generate sufficient oxygen to support humans in a closed environment, scientists are also examining the possibility of using plants to produce food (either as a main food source or to add variety to a staid processed diet) and purify water. In addition, plants can provide a much-needed psychological boost to a long-term stay on a hostile planet, creating a small garden oasis in the middle of a cold desert world.

"If you're in a closed environment for a long time, growing plants is a wonderful diversion from the monotony," said Henderson, while adding that mechanical-chemical processors would form an integral part of a closed-loop system by enabling astronauts to recycle air and water while waiting for the plants to reach maturity. "Most people would prefer plants to some chemical process because psychologically it's more appealing."

A system that performs all these functions in a closed environment has been dubbed a Controlled Ecological Life Support System, or CELSS. Although experiments using plants to regenerate oxygen began in the 1950s, NASA stepped into the effort in the 1970s as a way of supporting long-term manned missions. Under the direction of the Johnson Space Center in Houston, the Advanced Life Support Program pulls together the research and resources of botanists, engineers, and plant researchers dedicated to finding ways of making the closed-loop system as efficient and automated as possible.

The program's main directive has been to examine the construction and operation of surface-based systems that would recycle the carbon dioxide produced by humans to grow plants that would in turn provide oxygen and food. While some plants could conceivably be grown onboard spacecraft to provide food variety and psychological benefit, the ALSP focuses its efforts on building full-scale life-support systems for extended surface missions.

"The kinds of systems we now envision are complex systems that require a great deal of power and need 'real estate' — you can't cram all this equipment onto a spacecraft," Henderson said.

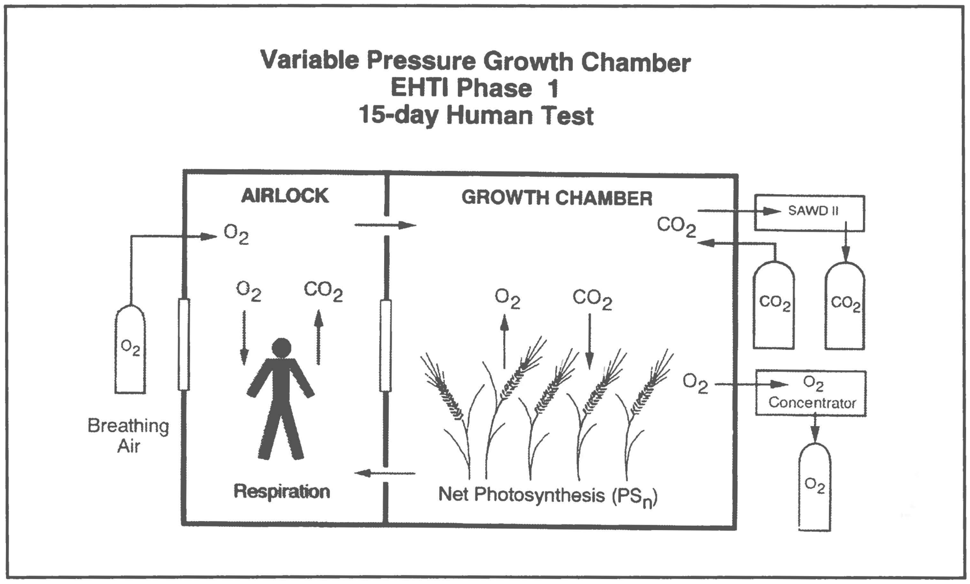
Thus far, ALSP has conducted three manned experiments in sealed chambers to test the efficiency of regenerative plant-based and chemical systems. During Phase I of the program, conducted in July 1995, scientist Nigel Packham lived in a 7.2-meter-long chamber in JSC's Building 7, which also houses the Plant Growth Laboratory. The chamber was divided into two compartments, a 4.2-meter plant-growth compartment and a 3.0-meter airlock chamber used for Packham's living quarters. By separating the chambers, scientists were able to monitor and maintain optimal oxygen and carbon dioxide levels in the plant and human compartments.

For Phase I, a productive variety of wheat was selected as the support crop, both for its ability to produce abundant oxygen and its ability to tolerate a 24-hour light cycle (enabling maximum photosynthesis). The wheat was grown hydroponically under high-pressure sodium lamps, which provided the equivalent of continuous three-fourths full sunlight. Humidity and temperature levels were maintained at constant levels.

Although the experiment provided a wealth of usable data, the basic conclusion was elegantly simple.

"We produced — exceeded — the oxygen required to support one person for the 15-day stay," Henderson said.

The test also revealed a significant relation between the metabolic activity of the human subject — who exercised daily on a stationary bicycle — and the rate at which the plants produced oxygen, suggesting that the relationship between humans and plants is a complex and synergistic one.



This diagram represents the channels of carbon dioxide and oxygen exchange during the Phase I experiment. During the first six days of the test, a physiochemical air removal system was used to complement the plant system.

Nigel Packham peers out from the Phase I plant-growth chamber.

"When he was exercising on the bike, and required more oxygen, the plants would respond to that," Henderson said. "We could get the system to 'speed up' during that time. The system could also be 'slowed down' during times of low activity."

While Phase II of the program used chemical and physical means to recycle oxygen and water, the 30-day test provided further data on closing the loop on air and water use. During the crew's 30-day stay in a three-story refurbished hyperbaric chamber (originally built in the 1960s for Skylab simulations), 90% of the water and air was recycled.

During Phase III of the program, conducted in late 1997, a crew of four sealed themselves in the same three-story chamber at JSC. Carbon dioxide waste was piped to the Plant Growth Facility, while oxygen produced by the plants was recycled back to the chamber. The 90-day test also saw the beginnings of experiments in recycling inedible plant biomass and incinerated human waste, which was sent to Kennedy Space Center and converted to a nutrient solution.

The culmination of the program, known as the Advanced Life Support Systems Integration Test Bed (or BIO-Plex), will incorporate five sealed chambers interconnected by tunnels in Building 29 at the Johnson Space Center. Two of the chambers will be dedicated to plant growth, while other chambers will be used for habitation and life-support equipment.

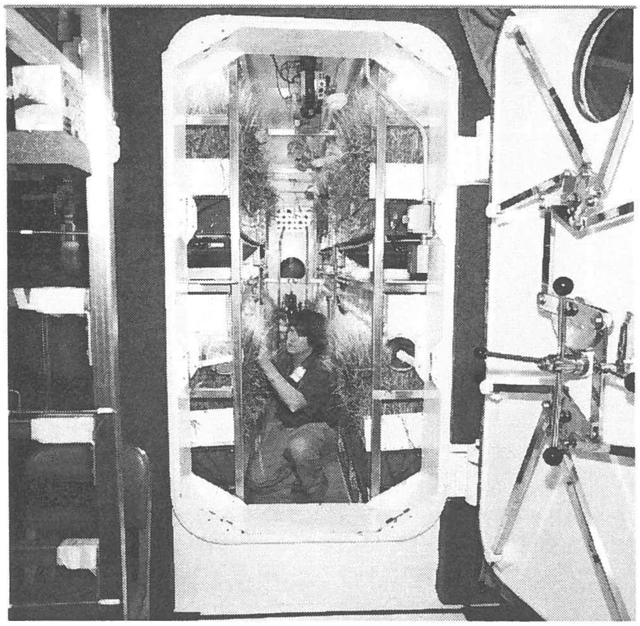
The first test of the BIO-Plex system, using only three of the chambers, is slated for 2001. Scientists hope to produce enough oxygen and 50% of the food required to support a set number of crew members for 120 days. The full run of the BIO-Plex project, a 420-day test, is planned for the year 2005 and may include some astronauts as part of the crew.

"If we're going to send astronauts to Mars or the Moon, they're going to have to know how to grow plants, in addition to having the usual engineers, medical personnel, and other specialties that are required on a space mission," said Henderson, who added that some of the farming activities will have to be automated to allow scientists to concentrate on other surface activities. "You can't spend 95% of your time trying to keep the equipment running."

The Earth-bound experiments have given scientists insight into how humans and plants interact in a closed-loop environment, and how such systems could be made more efficient and less costly. In turn, the need to grow highly productive plants in a small space has led to the development of several special plant varieties and soils.

The most prominent of these is a space-age wheat known as USU-Apogee, developed at the Crop Physiology Laboratory at Utah State University. The dwarf red spring wheat produces the equivalent of nearly 600 bushels of grain per acre, which is three times that of normal wheat varieties. Apogee was developed to thrive under "space farm" conditions, including constant artificial light and high carbon dioxide levels. The plant produces heads 23 days after germination, a full week sooner than other varieties, and stands only 18 inches tall when mature.

Botanists have also developed special productive varieties of sweet potatoes, rice, peanuts, and beans.



Visiting scientist Kenneth Corey monitors crop growth at the JSC Plant Growth Laboratory.

"Our list of plants for crop production is a short list based on nutrition, productivity, and ease of growth," said Henderson. "For a closed-loop system, we need dwarf plants that are highly productive."

Developing plants for food production in space has proved to be more of a challenge than growing plants for oxygen revitalization. In particular, botanists working in the program have yet to develop productive and space-saving varieties of such plants as sweet potatoes and rice. Nonetheless, Henderson and others remain optimistic that a CELSS system will incorporate both aspects of human life support.

"I think we can keep a crew of four to eight alive and produce food and oxygen for these people," he said. "It takes more to grow food. If I can grow enough crop to feed one person, I can grow enough to produce oxygen for four."

While most of the plant-growth experiments have used hydroponics to supply nutrients, researchers are also looking into the possibility of using recycled wastewater, composted plant biomass, and even processed martian soil to supply the nutrients and root support needed for crop growth.

Researchers working on the project have even developed an artificial soil from zeolite, a naturally occurring volcanic clay that is especially suited to absorbing chemicals and nutrients. By loading the zeolite with the right mix of chemicals necessary for plant growth, including phosphorous, potassium, nitrogen, carbon, magnesium, iron, and zinc, scientists are able to feed the plants directly through the artificial soil without the waste and runoff associated with traditional fertilizers and hydroponics systems. The NASA-created zeoponic plant growth media is marketed commercially by Zeoponix Inc. in Boulder, Colorado, and has been used on some golf courses.

"By using this material, you are able to eliminate some of the runoff of fertilizer," said Henderson.

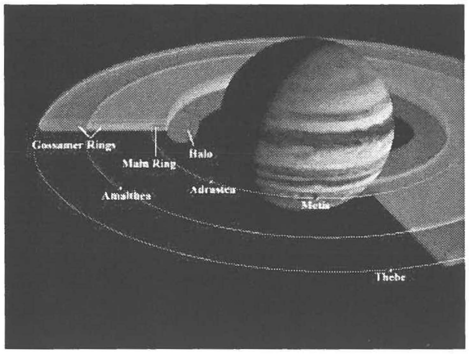
Of course, NASA's closed life-support and plant-growth experiments have already yielded some benefits beyond adding to the world's golf courses. NASA has been growing plants for years in space, onboard the MIR space station and space shuttle. These experiments have been conducted to study the way microgravity affects basic biological functions, but they have also provided some valuable lessons about controlling the growth environment, lessons that would be well heeded by even casual gardeners on Earth.

"The lesson we have learned is that you really do need good environmental control," Henderson said. "You can't just grow plants in a spacecraft without careful consideration of lighting conditions, trace contaminants, and carbon dioxide concentrations."

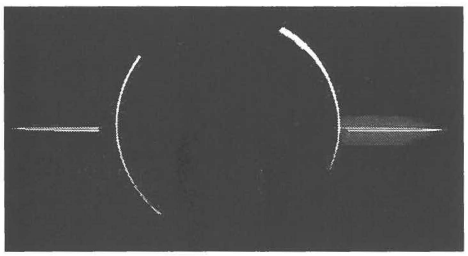
The program has also caught the attention of officials in remote areas of Alaska seeking solutions to growing crops and recycling waste in hostile Arctic conditions. Some architects have also paid close attention to the experiments, in hopes of developing closed-loop, environmentally conscious workplaces.

Visions of such modern buildings paradoxically filled with natural plants and gardens attests to the inexorable connection between plants and humans. The lessons learned on Earth about the importance of plants in maintaining the human population in the last 30 years have in some ways formed the vision of the ways humans will one day survive on other worlds. The vision of humans living and working alongside plants is not just about cost savings or efficiently recycling waste products. It's an aesthetic vision that appeals to one's desire to bring a small piece of Earth to a hostile, distant planet, and in the process, bring that planet home to Earth. ○

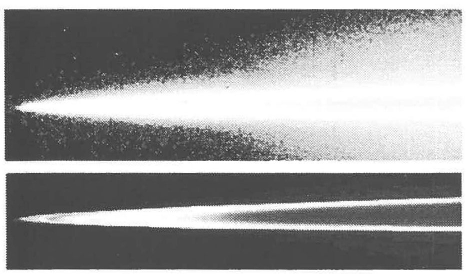
A revised version of this article will appear in Texas Garden Yearbook 1999, distributed by Book Marketing Plus.



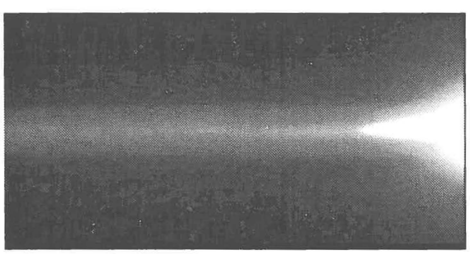
Jupiter's inner satellites and ring components.



Jupiter's ring system.



Jupiter's main ring and halo.



Jupiter's gossamer ring.

JUPITER'S RINGS FORMED BY DUST BLASTED OFF SMALL MOONS, SCIENTISTS SAY

Jupiter's intricate, swirling ring system is made up of dust kicked up as interplanetary meteoroids smash into the giant planet's four small inner moons, said scientists studying data from NASA's *Galileo* spacecraft. Images sent by *Galileo* also reveal that the outermost ring is actually composed of two rings, one embedded within the other.

"We now know the source of Jupiter's ring system and how it works," said Cornell University astronomer Joseph Burns, who reported on the first detailed analysis of a planet's ring system, along with Maureen Ockert-Bell and Joseph Veverka of Cornell, and Michael Belton of the National Optical Astronomy Observatories.

"Rings are important dynamical laboratories to look at the processes that probably went on billions of years ago when the solar system was forming from a flattened disk of dust and gas," Burns explained. "I expect we will see similar processes at Saturn and the other giant planets."

In the late 1970s, NASA's two *Voyager* spacecraft first revealed the structure of Jupiter's rings: a flattened main ring and an inner, cloudlike ring called the halo, both composed of small, dark particles. One *Voyager* image seemed to indicate a third, faint outer ring. New *Galileo* data reveal that this third ring, known as the gossamer ring because of its transparency, consists of two rings. Both rings are composed of microscopic debris from two small moons, Amalthea and Thebe.

"The structure of the gossamer rings was totally unexpected," Belton added. "These images provide one of the most significant discoveries of the entire *Galileo* imaging experiment."

Galileo took three dozen images of the rings and small moons during three orbits of Jupiter in 1996 and 1997. The four moons display "bizarre surfaces of undetermined composition that appear very dark, red, and heavily cratered from meteoroid impacts," Veverka said. The rings contain very tiny particles resembling dark, reddish soot. Unlike Saturn's rings, there are no signs of ice in Jupiter's rings.

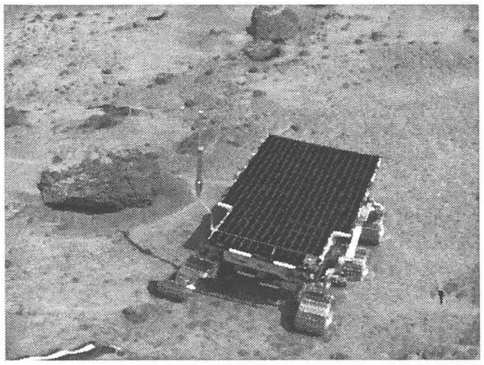
Scientists believe that dust is kicked off the small moons when they are struck by interplanetary meteoroids, or fragments of comets and asteroids, at speeds greatly magnified by Jupiter's huge gravitational field. The small moons are particularly vulnerable targets because of their relative proximity to the giant planet.

"In these impacts, the meteoroid is going so fast it buries itself deep in the moon, then vaporizes and explodes, causing debris to be thrown off at such high velocity that it escapes the satellite's gravitational field," Burns said. If the moon is too big, dust particles will not have enough velocity to escape the moon's gravitational field. With a diameter of just 5 miles (8 kilometers) and an orbit that lies just at the periphery of the main ring, tiny Adrastea is "most perfectly suited for the job."

As dust particles are blasted off the moons, they enter orbits much like those of their source satellites, both in their size and in their slight tilt relative to Jupiter's equatorial plane. A tilted orbit wobbles around a planet's equator, much like a hula hoop twirling around a person's waist. This close to Jupiter, orbits wobble back and forth in only a few months.

PATHFINDER DATA POINTS TO LONG DRY PERIOD ON MARS

A year after the landing of *Mars Pathfinder,* mission scientists say that data from the spacecraft paint two strikingly different pictures of the role of water on the Red



Sojourner Truth, Pathfinder's rover.

Planet, and yield surprising conclusions about the composition of rocks at the landing site.

"Many of the things that we said last summer during the excitement after the landing have held up well," said Matthew Golombek, Pathfinder project scientist at NASA's Jet Propulsion Laboratory. "But we have now had more time to study the data and are coming up with some new conclusions."

Similar to ongoing science results from NASA's *Mars Global Surveyor* spacecraft currently in orbit around Mars, Pathfinder data suggest that the planet may have been awash in water 3–4.5 billion years ago. The immediate vicinity of the *Pathfinder* landing site, however, appears to have been dry and unchanged for the past 2 billion years.

Several clues from *Pathfinder* data point to a wet and warm early history on Mars, according to Golombek. Magnetized dust particles and the possible presence of rocks that are conglomerates of smaller rocks, pebbles, and soil suggest copious water in the distant past. In addition, the bulk of the landing site appears to have been deposited by large volumes of water, and the hills on the horizon known as Twin Peaks appear to be streamlined islands shaped by water.

But *Pathfinder* images also suggest that the landing site is essentially unchanged since catastrophic flooding sent rocks tumbling across the plain 2 billion years ago. "Since then this locale has been dry and static," Golombek said.

While the area appears to have been untouched by water for eons, wind appears to have been steadily eroding rocks at the landing site. Analysis of *Pathfinder* images shows that about 1–2 inches (3–5 centimeters) of material has been stripped away from the surface by wind, Golombek noted.

"Overall, this site has experienced a net erosion in recent times," said Golombek. "There are other places on Mars that are net 'sinks,' or places where dust ends up being deposited. Amazonis Planitia, for example, probably has about 3–6 feet (1–2 meters) of fine, powdery dust that you would sink into if you stepped on it."

Chemical analysis of a number of rocks by the alpha proton X-ray spectrometer (APXS) instrument on *Pathfinder*'s mobile *Sojourner* rover, meanwhile, reveals an unexpected composition that scientists are still trying to explain.

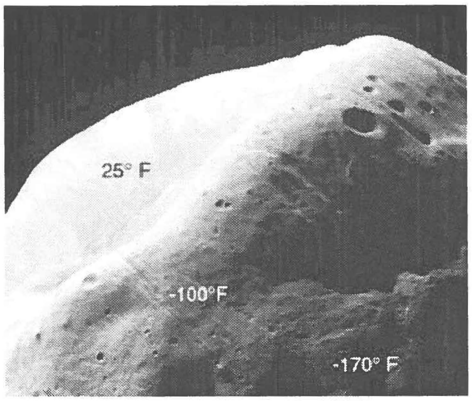
The current assessment of data from this instrument suggests that all the rocks studied by the rover resemble a type of volcanic rock with a high silicon content known on Earth as andesite, covered with a fine layer of dust. All the rocks appear to be far different chemically from meteorites discovered on Earth that are believed to have come from Mars.

"The APXS tells us that all of these rocks are the same thing with different amounts of dust on them," said Golombek. "But images suggest that there are different types of rocks. We don't yet know how to reconcile this."

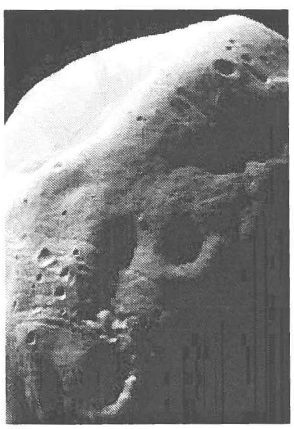
When molten magma oozes up from a planet's mantle onto the surface of the outer crust, it usually freezes into igneous rock of a type that geologists call a basalt. This is typical on the floors of Earth's oceans, as well as on the maria or "seas" of the Moon and in many regions of Mercury and Venus. By contrast, andesites typically form on Earth in tectonically active regions when magma rises into pockets within the crust, where some of its iron- and magnesium-rich components are removed, leaving rock with a higher silicon content. "We don't believe that Mars has had plate tectonics, so these andesites must have formed by a different mechanism," Golombek said.

The rocks studied by Pathfinder most closely resemble andesites found in Iceland and the Galapagos Islands, tectonic spreading centers where plates are being pushed apart, said Joy Crisp of JPL. Andesites from these areas have a different chemical signature from andesites formed at subduction zones (areas where one edge of a crustal plate descends below another), mostly because wet ocean sediments carry more water down into the mantle at the subduction zones. "On Mars, where the water content is probably lower and there is no evidence of subduction, we would expect a closer chemical similarity to Iceland andesites," said Crisp.

"In any event, the presence of andesites on Mars is a surprise, if it is borne out as we study the data further," said Crisp. "Most rocks on Mars are expected to be basalts lower in silicon. If these are in fact andesites, they are probably not very abundant."



The Thermal Emission Spectrometer measured the brightness of thermal radiation at the same time the camera acquired this image of Phobos.



Close-up image of the largest crater on Phobos, Stickney, which spans 10 kilometers in diameter.

MARTIAN MOON PHOBOS HIP-DEEP IN POWDER

New temperature data and close-up images of the martian moon Phobos gathered by NASA's *Mars Global Surveyor* indicate the surface of this small body has been pounded into powder by eons of meteoroid impacts, some of which started landslides that left dark trails marking the steep slopes of giant craters.

New temperature measurements show the surface must be composed largely of finely ground powder at least 3 feet (about 1 meter) thick, according to scientists studying infrared data from the Thermal Emission Spectrometer instrument on the spacecraft. Measurements of the day and night sides of Phobos show such extreme temperature variations that the sunlit side of the moon rivals a pleasant winter day in Chicago, while only a few kilometers away, on the dark side of the moon, the climate is more harsh than a night in Antarctica. High temperatures for Phobos were measured at 25°F (–4°C) and lows at –170°F (–112°C).

The extremely fast heat loss from day to night as Phobos turns in its seven-hour rotation can be explained if hip-deep dust covers its surface, said Philip Christensen of Arizona State University, Tempe, principal investigator for the experiment on the *Mars Global Surveyor* spacecraft.

"The infrared data tells us that Phobos, which does not have an atmosphere to hold heat in during the night, probably has a surface composed of very small particles that lose their heat rapidly once the Sun has set," Christensen said. "This has to be an incredibly fine powder formed from impacts over millions of years, and it looks like the whole surface is made up of fine dust."

New images from the spacecraft's Mars Orbiter Camera show many never-before-seen features on Phobos, the innermost and larger of the planet's two moons, and are among the highest-resolution pictures ever obtained of the rocky martian satellites. A 6-mile (10-kilometer)-diameter crater called Stickney, which is almost half the size of Phobos itself, shows light and dark streaks trailing down the slopes of the bowl, illustrating that even with a gravity field only about 1/1000 that of the Earth's, debris still tumbles downhill. Large boulders appear to be partly buried in the surface material.

NEPTUNE'S LARGEST MOON MAY BE WARMING UP

Observations obtained by NASA's Hubble Space Telescope and groundbased instruments reveal that Neptune's largest moon, Triton, seems to have heated up significantly since the *Voyager* spacecraft visited it in 1989. "Since 1989, at least, Triton

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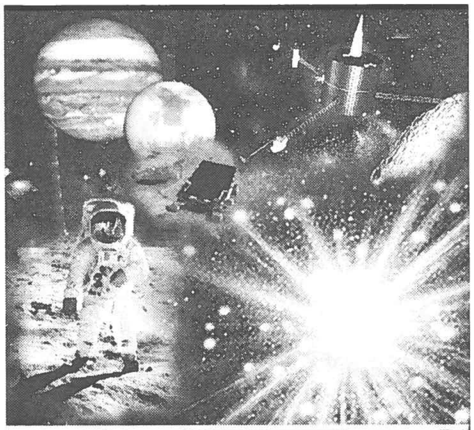

A Message From the Conveners of the 30th LPSC

Those of you who regularly attend the Lunar and Planetary Science Conference (LPSC) will have noted that we have been slowly evolving many facets of what long-time conference attendees have fondly referred to as the "yellow peril," i.e., the traditional yellow, three-volume conference abstracts. As the abstract submission process has technologically evolved to successful implementation of electronic abstract submission, we are subsequently evolving in terms of production of the abstract volume, with the use of CD-ROMs as the principal long-lasting product of the conference.

In general, this evolution has been greeted favorably, but there have been complaints about some of the changes. Many of these complaints have been accompanied by useful suggestions (which makes them the only kind of complaint worth listening to). As a consequence of this useful feedback, we are implementing changes to both the abstract submission form and the conference products (program booklet and abstract volume) for the 30th LPSC in 1999. We strongly urge that you note in particular the ***new required field*** on the abstract submission form.

Conference Products

The biggest change for next year, and one that will certainly meet with the most favorable response, is the new format of the program booklet. Beginning in 1999, the program will be in 8.5" × 11" format. This will allow us to provide additional information, as well as allowing space for marginal annotation as needed. The listing for each session will now provide, along with the titles and authors, the abstract number AND a summary of each presentation. This summary must be provided by the author(s) at the time of abstract submission. There will be a new field on the abstract submission form for this summary, and ***this summary for the program booklet will be required for all abstracts.*** The computer will limit entries in this field to 250 characters (including spaces). Comments we received have suggested that having such a brief summary would be beneficial to those who are trying to decide what a presentation is really about, because titles aren't always informative. As authors are writing their abstracts, they should be thinking about what they want the summary to say, remembering that what they input in that box on the abstract submission form ***will be printed*** in the program booklet distributed at the conference, and will be included in the online program and abstracts available on the Web prior to the meeting. Also in response to suggestions from participants, the program booklet will contain a list of those abstracts accepted for print only.

As in previous years, the abstract submission form will once again request keywords, lunar sample numbers, and meteorite names. The CD-ROM for the 30th LPSC will contain these indexes as well as a full author index. Also, to make it easier for those who want to print out all the abstracts, or perhaps all abstracts for certain sessions, we will add full session files that contain the listing for a session AND all the abstracts included in that session. (Participants who want to print out all the abstracts will therefore have only 40 or so print jobs instead of 940.) These files will be included in addition to the current format, where each title in a session is linked directly to the appropriate abstract.

Online Program and Abstracts

While many attendees are delighted at the Web version of the abstracts and preliminary program, there have been a number of useful suggestions for improvement, particularly from those with slow remote access. Some of the improvements that are being made to the CD are being incorporated in the online version of the abstracts: The online program will include the brief summaries mentioned above, and we will provide downloadable files for each session. These files will contain the program listing and all the abstracts for each session. We will still provide the traditional program and abstracts, where each title in a session is linked directly to the abstract.

These changes should address most of the concerns that were expressed following the last LPSC. In the end, we are always striving to make the LPSC experience as enjoyable, beneficial, and informative as we possibly can. We encourage and welcome any constructive suggestions from those of you who participate in this annual celebration of planetary science.

David C. Black
Co-Chair, LPSC

Carl B. Agee
Co-Chair, LPSC

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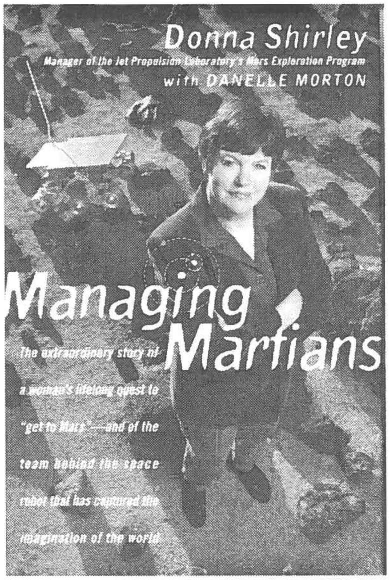


REVIEW

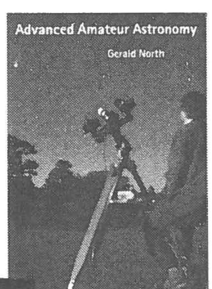
MANAGING MARTIANS: ***The Extraordinary Story of a Woman's Lifelong Quest to "Get to Mars" and of the Team Behind the Space Robot That Has Captured the Imagination of the World***
by Donna Shirley
Broadway Books, 1998
Hardcover. $25

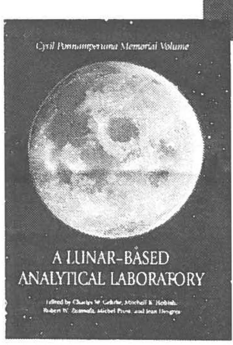
Donna Shirley's engaging memoir recounts her experiences breaking into the male-dominated world of aerospace engineering to spearhead the *Pathfinder* rover project as manager of the Mars Exploration Program at the Jet Propulsion Laboratory. Built on a "shoestring" budget of $25 million, the tiny rover known as *Sojourner Truth* became a symbol for the possibilities of imaginative aerospace engineering and design.

Managing Martians, which has enjoyed national media exposure and a first printing of 50,000, revisits the *Pathfinder* project from an insider's perspective, as Shirley wages political and personal battles to defend the vision of the rover project once seen as "at best a toy and at worst a joke."

The most compelling part of Shirley's book comes in her panged remembrances of an awkward adolescence spent reading science-fiction novels and daydreaming about airplanes and the possibilities of flight. Shirley triumphed over the many barriers facing any gifted and intelligent girl in the 1950s, only to face similar challenges as a woman in the burgeoning robotics-engineering program. Perhaps it took a young girl's imagination, as embodied in the determination and will of a grown woman, to lead the team that made an unlikely success out of the dark-horse robot known as *Sojourner Truth.* At any rate, Shirley's account presents one valuable angle in the story of humanity's triumphant return to the Red Planet, and her book reminds the reader that space exploration has implications for humanity beyond the realms of engineering and science.

— Brian Anderson
(Brian Anderson is the editor of the Lunar and Planetary Information Bulletin.)





RECENTLY PUBLISHED

Advanced Amateur Astronomy by Gerald North, Cambridge University Press, 1997, Hardcover $69.95, Softcover $24.95. This book offers practical exercises and advice for the amateur astronomer looking to move beyond the basics of backyard stargazing and into the world of data gathering. Includes advice on such topics as telescope hardware, astrophotography and electronic imaging, determining latitudes and longitudes, and measuring the brightness of celestial bodies.

A Lunar-Based Analytical Laboratory: Cyril Ponnamperuma Memorial Volume, Edited by C. W. Gehrke et al., A. Deepak Publishing, 1997. Based on the proceedings of the Second Lunar Analytical Laboratory Workshop in Dijon, France, this book addresses the problems and challenges facing the establishment of a lunar laboratory for chemical, biological, and physical analysis. Articles in the book tackle such topics as lunar resource utilization, the effects of microgravity, operational and medical support, and environmental toxicology.

NASA has released the third volume in its series *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program.* Titled *Using Space*, the new volume is edited by John M. Logsdon, with Roger D. Launius, David H. Onkst, and Steven J. Garber. ○

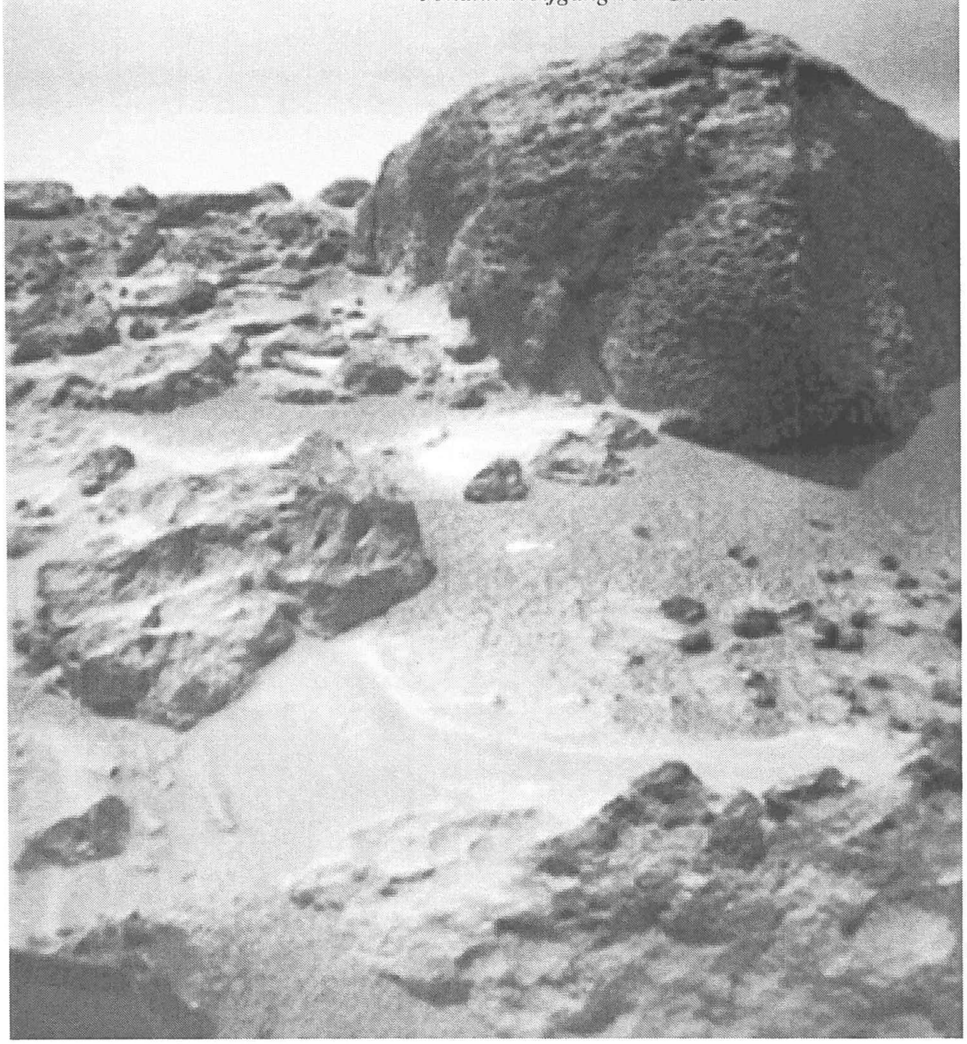
BRINGING MARS HOME

Opportunities and Challenges Presented by the Mars Sample Return Mission

by John H. Jones, NASA Johnson Space Center, and Allan H. Treiman, Lunar and Planetary Institute

Art is long, life short; judgment difficult, opportunity transient.

Johann Wolfgang von Goethe



The U.S. and the world have the opportunity, within the next decade, of obtaining samples of rock, soil, and atmosphere from Mars. A Mars sample return mission in 2005 is now being planned by NASA and its international partners. Returned samples will provide unprecedented opportunities to learn about Mars, and by analogy the Earth, using the diverse and sophisticated instruments and procedures available in terrestrial laboratories. Although spacecraft (orbiters and landers) are a critical part of any strategy for solar-system exploration, sample return has unique advantages. There are no limits to the quality or number of analyses, no limits to the flexibility and scope of investigations, and no limits on future use as new techniques are developed and new theories are proposed. These advantages contrast starkly with the power and mass limitations inherent in remote, robotic investigations.

However, a returned Mars sample raises serious concerns and issues, beyond the obvious public worry about biological contamination of the Earth. Some of these issues, as yet unresolved, include the following: (1) What investigations will be done on Earth (i.e., what are the scientific goals of sample return)? (2) What changes (including contamination) will arise from handling and transporting the samples? and (3) What kinds of samples should be returned?

These issues bring up many strategic and engineering decisions that will have profound consequences for the usefulness of the returned samples. In a "worst-case scenario," a seemingly trivial engineering decision early in mission planning could nullify a critical chemical or biological analysis. Thus, it is imperative that strategic and engineering planning for Mars sample return be guided by the advice of the relevant scientific disciplines (e.g., biology and geology). Mission decision makers should be aware of the potential scientific consequences of their decisions. Conversely, scientific advisors must recognize that their advice has potential implications for the cost and scheduling of the mission.

The Value of Returned Samples

Why should we return samples of Mars? Aren't remote analyses by spacecraft on Mars good enough? These are excellent questions in light of the public's concerns about planetary protection and the costs involved in returning samples. And answers to these questions are critical to understanding the importance and immense value of returning samples to Earth.

Today's spacecraft can indeed analyze rocks and other materials on planets or asteroids — as recently demonstrated by *Pathfinder* on Mars. *Pathfinder* obtained color images, chemical analyses, and analyses of the magnetic properties of rocks and soils on Mars. The *Mars Pathfinder* results have refined our understanding of martian floods, the compositions of rocks and soil, and left some tantalizing hints about the early history of Mars. But we could have learned much more with returned samples, including whether or not the *Pathfinder* rocks contained traces of ancient martian life.

The need for sample return to Earth arises from the fact that robotic spacecraft analyses are severely limited compared to Earth-based analyses:

- Analytical quality is limited, because of inherent restrictions on instrument sizes and mass, power requirements, and data transmission rates.
- The scope and flexibility of investigations is limited, because only a few instruments will fit on a spacecraft; and these instruments can be used in only certain ways.
- Remote analyses must "make do" with very limited sample preparation.
- Future, further investigations are severely limited or impossible.

Because of these underlying restrictions and limitations, robotic spacecraft analyses will always lack state-of-the-art accuracy and precision, and these investigations may also be limited by our preconceptions about what we expect to find. In contrast, studies in Earth laboratories can be of the highest quality possible and can be tailored to fit the samples exactly. In addition, studies of returned samples could take advantage of the instruments and knowledge available on Earth and would have nearly infinite flexibility to respond to what is actually in the sample. We only need to get samples from Mars to Earth.

Quality. The quality of analyses (precision and accuracy) that can be achieved in modern Earth-based laboratories is phenomenal. For example, Fig. 1 shows the oxygen-isotopic ratios of selected meteorites, analyzed in laboratories on Earth, compared with the *Viking* lander analysis of oxygen-isotopic ratios in the martian atmosphere, analyzed on Mars. From the error bars in Fig. 1, it is clear that oxygen-isotopic analyses on Earth are thousands of times more precise than the *Viking* lander's.

Oxygen isotopes are the "industry standard" for classifying extraterrestrial materials, including the affinities and sources of meteorites. Figure 1 shows that the Viking oxygen analyses are so imprecise that they have little value. From the Viking analyses alone, we cannot tell if the martian atmosphere was like martian meteorites, martian water, the Earth, or any other meteorite group (i.e., parent asteroid) on Fig. 1.

Of course, robotic instrumentation has improved since the *Viking* landers, but Earth-based instrumentation has also improved and continues to benefit from the advantages of essentially unlimited power, essentially unlimited mass, durability, availability of outside resources (e.g., liquid nitrogen), and "on-site technical support." Similarly, Earth-based laboratories can readily do complex sample preparations, whereas the technical challenges of remote sample preparation (e.g., making a microscope slide) can be daunting. Indeed, the process for analyzing the complete isotopic composition of oxygen is so difficult that only one or two laboratories in the entire world routinely perform such analyses on geologic materials.

Scope and Flexibility. To show the value of scope and flexibility, consider the rock named Barnacle Bill that *Pathfinder* imaged and analyzed. The APXS instrument on the *Sojourner* rover produced an X-ray chemical analysis (rather imprecise by terrestrial standards) indicating a composition like an andesitic volcanic rock. Lander and rover images of Barnacle Bill show no internal structures like layers, veins, or rock fragments; high-resolution images do show numerous small cavities. Barnacle Bill appeared as reddish-black, like basalt lava rock on Earth. Comparison of this chemical analysis with that of local soils suggests that the analysis was severely contaminated by soil stuck on Barnacle Bill.

This is all we know of Barnacle Bill. We do not know if it is igneous or sedimentary, or whether it represents a melt generated by a meteor impact. We do not know if it formed near the landing site, or was transported from far away. We do not know why it has cavities in it, and whether it has any tell-tale structures smaller than the *Pathfinder* camera could see. We do not know if Barnacle Bill is young or ancient. And we do not know if Barnacle Bill's chemical composition implies that

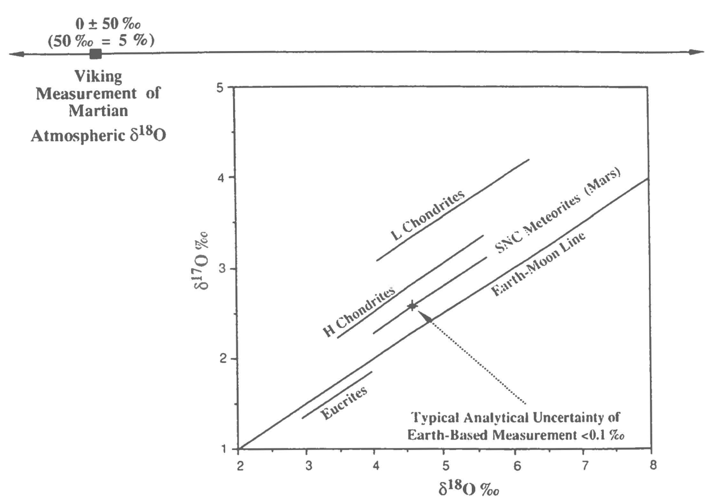
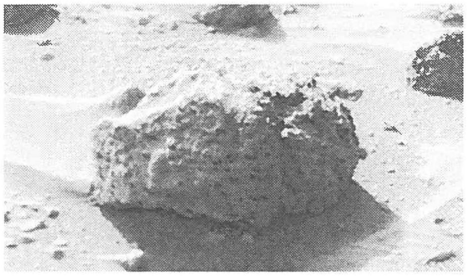


Fig. 1



Barnacle Bill

water was abundant on early Mars, as some scientists have suggested.

However, if a few grams of Barnacle Bill could have been returned to Earth, the scope and flexibility of Earth-based analyses would have allowed us to truly understand Barnacle Bill, including when it was formed. Earth-based analyses could even have given us an extended geologic history of the sample site. High-precision chemical analyses and optical microscopy might have shown, for instance, that Barnacle Bill was truly an andesite, a volcanic rock from a water-bearing magma.

Then, if Barnacle Bill were truly an andesite, electron-microbeam instruments could reveal its thermal and chemical history and whether it formed (as did many andesites on Earth) as a mixture of lavas. Radioisotope chronologies would give the age of its eruption, and perhaps allow Barnacle Bill to be traced to a particular volcano. Trace-element analyses coupled with radiogenic isotopic studies would allow us to understand its source — what melted inside Mars to form the lava — and when that source itself formed. If, as seems likely, Barnacle Bill is from the martian highlands, these analyses might tell us when the highlands formed, what in general they are made of, and whether significant amounts of water were involved in their formation.

In addition, chemical and mineralogical studies of late (postigneous) alteration materials or salts in Barnacle Bill would help us to learn about more recent water in the martian crust and perhaps the composition and age of the floods that scoured Chryse Planitia. Similar studies of the outer surface of Barnacle Bill would tell about weathering at the martian surface, and perhaps whether Mars' climate was once warmer and wetter than it is now. And, of course, biological and organic analyses (which were not possible on *Mars Pathfinder*) would search for traces of extant or ancient martian life, with far greater sensitivity than could be done on the martian surface.

Future Investigations. A returned planetary sample is a gift that keeps on giving. This is amply demonstrated by the Apollo samples from the Moon, which keep revealing their secrets to techniques that were not even imagined in the 1960s and 1970s. At least five radiochemical tracer and age-dating methods have been developed since *Apollo 17* (^{187}Re-^{187}Os, ^{190}Pt-^{186}Os, ^{176}Lu-^{176}Hf, ^{146}Sm-^{142}Nd, ^{182}Hf-^{182}W), several of which have been used on the Apollo samples. From them, we have refined the age of the Moon, learned more of when and how its crust formed, learned more of how it is related to the Earth, and learned how fast planets (and the Moon) formed early in the solar system. If the Apollo missions had not returned samples, none of these results would have been possible. And although not a substitute for additional sampling missions, having returned samples means that a new mission is not required whenever a new analytical technique is invented. A returned sample can be studied now and for generations to come.

Summary. Sample return is a long-term investment in knowledge; returned martian samples will be an inheritance that will pay off for decades to come. Robotic spacecraft analyses are, of course, critical to exploration of the solar system, but cannot address all of NASA's goals for understanding planetary evolution. Only through careful study of returned samples can we realize the full potential of the instrumentation and analytical skills that are available here on Earth. These studies will define the agenda for future Mars exploration — what we need to learn and where best to learn it — and will be crucial to any human habitation of Mars by the next generation of explorers.

What Types of Investigations Should Be Conducted?

Mars is unique in planetary science as the world most similar to our own. Mars offers us a comparison and contrast to the Earth, an opportunity to learn the history of a planet that was once suitable for life as we know it (according to current theories), and may yet harbor living organisms. Understanding the contrast, why Mars is now a cold dry desert and not a wet living world, will involve studies from a broad range of natural sciences: biology, climatology, geology, space physics, hydrology, etc. Our overall strategy for Mars sample studies must recognize this ecology of sciences. The study of any particular aspect of Mars will benefit enormously from coordinated investigation of its many aspects.

Within the span of Mars science, biology is now in the forefront. The most visible force behind Mars sample return is the search for life, extant or fossil. But because life and its history are inextricably connected with the physical factors of its environment (climate, hydrology, and geology), the study of Mars as a possible home for life requires the integration of the full range of physical and biological sciences. In this way, a mandate to understand martian life or the potential for martian life is a mandate to conduct balanced interdisciplinary studies.

It is not our place — and it is not possible — to dictate what kinds of investigations will or should be done using returned samples. However, we strongly advise that no one type of study be advanced over all others. In this regard we are not too different from a financial advisor who recommends having a diverse investment portfolio. And, as advisors, we recommend a mix of risky and safe investments.

Perhaps the riskiest study, in the sense of having an assured positive result, is the search for extant life on Mars. Returned Mars samples will be quarantined on the presumption that they contain viable life forms, but in actuality there is very little chance that viable organisms will be found in returned near-surface samples. The reasons for this are twofold: (1) water appears to be a universal requirement for life, and there has apparently been no liquid water near Mars' surface for a few billion years; and (2) highly oxidizing chemicals and ionizing radiation, both of which are harmful to organic molecules and to life, are abundant at Mars' surface. However, the potential scientific gains from a search for extant life are so great that it certainly should proceed.

Less risky, in terms of assured results, is a search for indirect signs of life. These signs are collectively called biomarkers and range from fossils to subtle chemical and isotopic signatures. Biomarkers can persist long after the life it represents has vanished — for instance, chemical and isotopic markers of life are preserved in some Earth rocks nearly 4 billion years old. In this way, a search for biomarkers is a search for an answer to the question of whether Mars ever supported life. Mars may never have had living organisms, so the search for biomarkers does not have an assured result. But again, the potential scientific gains from the recognition of biomarkers are so great that the search must take place.

Much safer, in terms of assured results, is the study of the past and present physical environment of Mars. The martian environment is the stage on which life may have arisen, evolved, and then either survived or perished. Whether or not life arose and flourished on Mars, physical and chemical analyses of returned martian samples will teach us about Mars' current environment and its past climate, its formation, and the ebbs and flows of its water and ice. From our experiences studying meteorites and lunar samples, we know that samples of any sort can yield insights both important and unexpected, and that even small samples (~0.5 g) can yield enormous insights into a planet's origin and history. We see no reason why returned Mars samples would be any less useful.

In short, the search for life is exciting but may not be fruitful. The harsh conditions of the martian surface may have proved inhospitable to life or even to organic molecules. However, physical and chemical studies will elucidate the history of Mars (exciting in itself) and define the ecological contexts for martian life (whether it is discovered or not).

Thus, we see diversity as the prudent approach to investigating returned Mars samples. There will likely be pressures to use all returned samples in one type of study or another (e.g., biochemical analysis or geologic age dating). These pressures must be resisted so that sample return is assured a positive result, which will be important as the mission is judged in the court of public opinion. If the presence of life cannot be determined, we can at least gain a better understanding of the environment that might have succored it.

What Types of Samples Should Be Returned?

Two factors will influence what types of samples will be returned from Mars: the scientific problems we wish to investigate and the engineering constraints on the mission. An ensuing consideration is that the types of investigations that will be possible will depend on how the samples are obtained and how they are treated subsequently.

In the following sections, we will discuss possible sampling, sterilization, and quarantine procedures that may affect scientific investigations on returned samples. For the limited purposes of this discussion, we assume that samples will be returned in such a way that all investigations are possible. We further assume that they will be collected by a rover within the capabilities likely available in the next ten years, at landing sites ±15° from the equator.

We have already concluded that broad-based scientific investigations will be required to search for life (extant and fossil) and to understand the environments and history that may have permitted life. What kinds of samples are needed for such a broad scientific program? Where should the lander set down to find these samples?

Broad investigations require a broad suite of samples, so we recommend returning as large and diverse a suite of samples as possible. Because complete diversity is not possible in a single mission, and because current mission rationales emphasize martian biology, sampling priority may well be given to those regions that are likely to retain a record of habitable (aqueous) environments. On Earth, such deposits are most commonly sedimentary rocks deposited at the bottoms of seas and lakes, but rocks altered by hydrothermal processes (e.g., hot springs) may also have hosted lifeforms. On Mars, the oldest rocks are key to the search for traces of life, as water was more abundant and more available for life at one time than it was in later times.

It is a challenge for mission planners to reliably locate deposits like these, and it is a challenge for mission engineers to develop landing methods capable of precisely deploying a lander to recover such a deposit. Therefore, it is conceivable that biological considerations might temporarily bow to concerns for a safe, predictable landing. But these are difficult issues that will require great deliberation in the scientific and engineering community. And possibly there will be a landing site that will easily satisfy both scientific and mission priorities.

However, we reiterate that sample diversity is critical to understanding Mars, and it seems reasonable that many potential landing sites on Mars will present a useful diversity of samples: (1) All sites will permit a sample of the atmosphere, which would tell us much about the history of volatiles on Mars and, therefore, much about the climatic history as well. (2) All sites will permit a sample of windblown dust, which is perhaps an average sample of Mars' surface; on Earth such dust deposits are useful in determining the mean age and chemical composition of the continental crust and may be similarly useful for Mars. (3) Landing sites within sedimentary deposits may have rocks transported by flowing water (as postulated for the *Pathfinder* site). (4) Given the age of Mars' surfaces and its extensive cratering history, it is likely that impact ejecta from distant sources may be found at almost any site.

At our present level of knowledge, it is nearly a certainty that *any* sample of Mars will yield new insights. Most of what we know about the atmosphere, hydrosphere, and biosphere of Mars comes from studies of basaltic rocks (the martian meteorites), which are hardly ideal for understanding water and biology. A returned sample of any other sort of martian material will dramatically increase the range of martian materials in our collection, thereby increasing our understanding of Mars. Thus, whereas some martian samples would be more ideal than others, all will be useful.

Other sampling issues also need to be considered: (1) Although we have emphasized sample diversity in this discussion, we take the opportunity to address the related issue of representative sampling. The sample return mission may encounter a terrain that has a dominant rock type, as appeared to be true at the

Mars Pathfinder site. It may well be that, in addition to sampling for diversity, we will also want to obtain several samples of a common rock to ensure that many different types of investigations can be performed on the same type of sample. (2) A contingency sample will likely be collected immediately after landing to ensure that some material is returned, regardless of the rover's fate. What should that contingency sample consist of? Atmosphere? Atmosphere and windblown dust? Atmosphere, windblown dust, soil, and a representative rock type? This is a decision that must be made by the time the mission lands.

To some extent, Mars sampling efforts can refer to the experience of the Apollo missions to understand issues of sample selection. In the later Apollo missions, there was a close integration between scientists, astronauts, and Mission Control, which led to the collection of a superb suite of samples. However, we recognize that, although there will be similarities in sampling strategies, there will also be differences. Lunar sampling took place over a period of hours; robotic sampling of Mars will occur over days to months. Coordination between the science team and the mission control team will, of necessity, be different. The complexity associated with Mars rocks is also likely to be greater than in the case of the Moon. No doubt this will complicate evaluation and selection, and may result in heated debate. For these reasons, it is important to have procedures in place that will serve to guide mission controllers and to act as an aid to the sleep deprived.

How Will Potential Return Samples Be Evaluated?

Before a sample is returned to Earth, it must be evaluated. Some samples are likely to be more representative than others. Some samples, though nonrepresentative, may give us important insights that typical samples would not. Some care in selection will be required. And, as we have alluded to above, there are difficulties in the evaluation of rocks when only analyses of their surfaces are available. Because the exterior of a specimen may be weathered, altered, or biodegraded, analysis of the surface may be misleading about the real nature of the rock.

Therefore, obtaining fresh, interior surfaces for analysis is important. On Mars missions, a rover should have a coring, abrading, or rock-splitting device that will provide fresh surfaces. These samples can then be evaluated using a variety of spectroscopic techniques (i.e., X-ray, optical/infrared reflectance, Mössbauer, Raman, etc.). It is important that all future Mars missions have the capability to expose and analyze fresh rock surfaces.

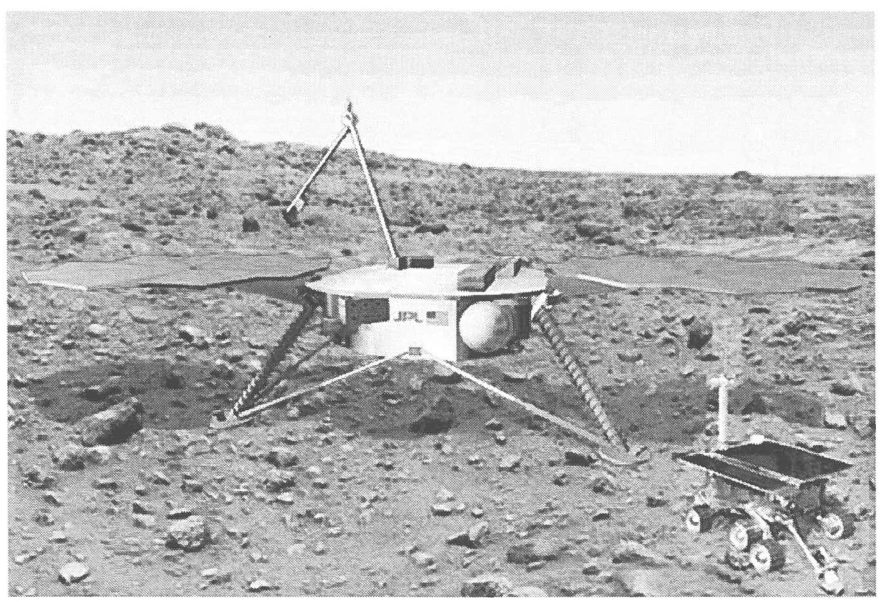
Of course, some samples will require only minimal, if any, evaluation. A sample of atmosphere should not require a selection strategy. The same is true (we think) for windblown dust, the composition of which seems to be very similar from site to site. However, we anticipate that care and sagacity will be required in the selection of rocks and soils. And to do this adequately for rocks requires fresh surfaces.

In conflict with the need for fresh surfaces, we also require that the sampling process not contaminate the sample. Organic contamination of Mars samples is a special concern, because potential organic biomarkers may be present only at miniscule concentrations. In addition, some inorganic materials that have highly desirable mechanical properties have chemical properties that can compromise important scientific investigations. Two prominent examples are tungsten carbide, which can grossly degrade trace-element analyses, and common (lead) solder, which interferes with age dating.

Consequently, the materials that could contact a returned Mars sample should be considered carefully. For example, the only materials allowed in the NASA Lunar Curatorial Facility are stainless steel, aluminum, and Teflon. While these materials are essentially inert against lunar materials, it remains to be seen if they are stable (e.g., resistant to oxidation) against martian materials. In addition, one might ask if Teflon could produce unacceptable organic contamination of Mars samples. Thus, the tools and containers must be chosen with care.

How Will Selected Samples Be Sealed For Return?

In the present plan, Mars samples selected for return to Earth are to be brought back by the 2005 mission. No matter which scenario leads to sample return to Earth, the samples must be stored safely throughout their journeys. How will the samples be stored? What types of containers will be used? Will the samples, or fluids liberated from them, react with the container? Will the samples be sealed and isolated from the martian environment and



The 2005 mission will touch down near the Mars Surveyor 2001 or 2003 landing site and samples previously collected and stored by the rover will be gathered and returned by this mission. The lander includes a sample collection and storage area and a return vehicle and ascent system.

from each other? If so, will the seal be of a type that ensures quarantine or will it be a temporary barrier, anticipating tighter isolation at a later date? Seals that are "airtight" may not meet quarantine standards, and many of the higher-quality seals may possibly contaminate the samples, either organically or inorganically.

These are difficult issues that must be confronted early in the mission design process, because the science that can be done on Earth will depend on how the samples are captured. Further, if the sample return mission is to retrieve samples cached on an earlier mission, the return mission should be designed before designing the sampling mission.

If procedures for collection and storage on the martian surface do not include sealing for return, this procedure will have to be performed later. Of some concern is the dust that is present in the martian atmosphere. Windblown dust may be deposited on exposed seal surfaces, and thereby compromise quarantine conditions. And the process of placing soils and rocks into any container may have the same result, if adhering soil or dust inadvertently drops onto the seal surface. Because planetary protection and quarantine are so important, the question of sealing is critical and requires thoughtful consideration.

How Will Samples Be Preserved During Their Return Trip?

After the samples have been evaluated, sealed, and liberated from Mars, there is the issue of preservation. Will the samples be maintained at ambient martian temperatures and pressures? If not, what scientific information will be lost as a consequence? Conceivably, the samples could be frozen at temperatures lower than those ambient on Mars, preserving delicate structures and minerals en route. On the other hand, this may not be feasible for a reasonable cost.

Temperature control has implications for sample integrity. If the samples are heated above Mars' ambient temperature, they will likely liberate fluids that could interact with other samples in the cache, influencing later analytical results. And liberated gas could conceivably generate enough pressure in the sample cache to threaten the containment vessel or quarantine.

The temperature environment of space is very different from that of the Earth's surface. Once the capsule has reentered the Earth's atmosphere, how long can it be kept at terrestrial temperatures before it thermally equilibrates? This is an issue of insulation as well as sealing. What insulating material will be used to keep the sample cold for as long as possible?

Thus, the issues surrounding sample preservation are complex. A careful cost-benefit analysis should be performed on the optimal thermal conditions for sample return.

Will Sterilization Be Necessary?

For planetary protection, it is likely that the exterior surfaces of the return capsule will need to be sterilized. How will this be accomplished? Heat treatment? Intense gamma radiation? Corrosive chemicals? How will this treatment affect the samples? For example, if heat treating is the sterilization method of choice, will the samples inside be heated as well? What science will be lost if this occurs?

If the exterior of the return capsule is sterilized, should the interior and the samples be sterilized as well? This procedure would negate the possibility of culturing living martian organisms, but it would prevent any pan-planetary infection. What would be the risks and benefits of such a choice? Will there be scientific information lost because of the sterilization process? Should some material be sterilized, while other material is kept pristine?

We advocate an approach that minimizes the potential hazards to the Earth's population and maximizes the retention of the returned samples' scientific value. For biological studies, at least part of the returned sample mass must be spared any sterilization procedure. Most geological studies may still be possible on sterilized samples, provided that a suitable technique is developed.

For geological studies, the most promising sterilization technique so far appears to be irradiation by gamma rays. This method can be performed at low temperature and does not heat the sample. It is the standard means by which the Centers for Disease Control and Prevention and the food industry routinely kill dangerous bacteria. Studies are now underway to determine the effects of intense gamma irradiation on geological and geochemical investigations. The results of these studies should be followed closely by mission planners.

Summary: Samples of rocks, soils, and atmospheres are valuable for studying the origin and evolution of planets. And understanding the biological and geological evolution of planets is of intrinsic interest to our species and may be important to our survival. Sampling Mars will tell us much about that planet and will allow us to evaluate the pervasiveness of life in our solar system. But the sampling act itself will have consequences that must be explored. In order to extract the maximum information from returned martian samples, their acquisition, storage, transport, retrieval, and quarantine must be carefully thought out in advance. We have raised more questions here than we can answer, but we are confident that remaining questions can be answered prior to the mission launch. However, it may take time to find the optimal solutions to these issues, and the time to address them is now.

This article was orignally prepared as a report for the Curation and Analysis Planning Team for Extraterrestrial Materials, which represents the interests and needs of scientists to NASA program and mission designers. ○

The *Lunar and Planetary Information Bulletin* is published quarterly by the Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.

Brian Anderson, Editor

Editorial and production support are provided by the LPI Publications and Program Services Department. Copy deadline for the next issue of the LPIB is Dec. 30, 1998.

The Bulletin welcomes the submission of articles and essays dealing with issues related to planetary science and exploration. Please send articles or announcements to:
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Phone: 281-486-2164, fax: 281-486-2125
E-mail: anderson@lpi.jsc.nasa.gov

CALENDAR 1998–1999

NOVEMBER

2–4

Martian Meteorites: Where Do We Stand and Where Are We Going? Lunar and Planetary Institute, Houston, Texas.
Contact: Publications and Program Services Department, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.
Phone: 281-486-2166; fax: 281-486-2160
http://cass.jsc.nasa.gov/meetings/marsmet98/

9–12

ESO Workshop on Minor Bodies in the Outer Solar System, Garching, Germany. Contact: Richard M. West.
E-mail: rwest@eso.org
http://www.eso.org/mboss98

DECEMBER

1–3

Origin of the Earth and Moon, Monterey, California. Contact: Publications and Program Services Department, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.
Phone: 281-486-2158; fax: 281-486-2160
E-mail: simmons@lpi.jsc.nasa.gov
http://cass.jsc.nasa.gov/meetings/origin98

JANUARY 1999

31–Feb. 4

Space Technology and Applications International Forum (STAIF–99), Albuquerque, New Mexico. Contact: Institute for Space and Nuclear Power Studies (ISNPS), University of New Mexico (UNM).
Phone: 505-277-0446
http://www.chne.unm.edu/isnps/isnps.htm

FEBRUARY

11–12

In Situ Resource Utilization (ISRU III) Technical Interchange Meeting, Denver, Colorado. Contact: Publications and Program Services Department, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.
Phone: 281-486-2158; fax: 281-486-2160
E-mail: simmons@lpi.jsc.nasa.gov
http://cass.jsc.nasa.gov/meetings/ISRU-III-99/

MARCH

15–19

Lunar and Planetary Science Conference, Lunar and Planetary Institute, Houston, Texas. Contact: Publications and Program Services

MARCH (CONTINUED)

Department, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.
Phone: 281-486-2158; fax: 281-486-2160
http://cass.jsc.nasa.gov/meetings/LPSC99/

APRIL

28–30

Workshop on Thermal Emission Spectroscopy and Analysis of Dust, Disks, and Regoliths, Lunar and Planetary Institute, Houston, Texas. Contact: Publications and Program Services Department, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.
Phone: 281-486-2158; fax: 281-486-2160
E-mail: simmons@lpi.jsc.nasa.gov
http://cass.jsc.nasa.gov/meetings/thermal99/

JUNE

13–18

Gordon Research Conference on Origins of Solar Systems, Henniker, New Hampshire. Contact: Alan Boss, DTM-CIW, 5241 Broad Branch Road, NW, Washington DC 20015-1305.
E-mail: boss@dtm.ciw.edu
http://www.grc.uri.edu/

JULY

1–7

111th Annual Meeting of the Astronomical Society of the Pacific, co-presented with the American Association of Variable Star Observers and the Royal Astronomical Society of Canada, University of Toronto. Contact: Laurie Keechler, ASP Meeting Planner, 390 Ashton Avenue, San Fransisco CA 94112.
http://www.aspsky.org

11–16

62nd Annual Meteoritical Society Meeting, Johannesburg, South Africa. Contact: Wolf Uwe Reimold, Department of Geology, Wits University, Private Bag 3, P.O. Wits 2050, Johannesburg, South Africa.
Phone: +27-11-716-2946; fax: +27-11-339-1697
E-mail: 065msoc@cosmos.wits.ac.za
http://www.wits.ac.za/metsoc99/

26–30

Asteroids, Comets, & Meteors Conference, Ithaca, New York. Contact: Beth E. Clark, ACM Conference, Space Sciences Building, Cornell University, Ithaca NY 14853-6801.
Phone: 607-254-8895; fax: 607-255-9002
E-mail: acm@scorpio.tn.cornell.edu
http://scorpio.tn.cornell.edu/ACM

CALENDAR 1998–1999

AUGUST

2–6

Sixth Bioastronomy Meeting: Bioastronomy 99: A New Era in Bioastronomy, Kohala Coast, Hawai'i. Contact: Karen Meech, Institute for Astronomy, 2680 Woodlawn Drive, Honolulu HI 96822.
Phone: 808 956-6828; fax: 808 956-6828
E-mail: meech@ifa.hawaii.edu
http://www.ifa.hawaii.edu/~meech/bioast/

AUGUST (CONTINUED)

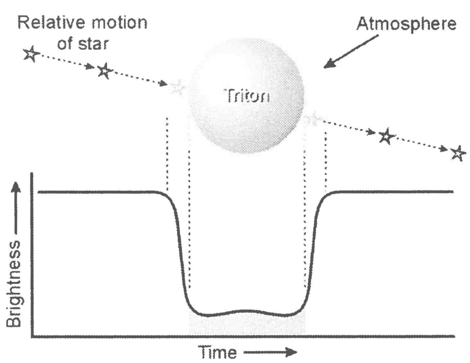
22–27

Ninth Annual V. M. Goldschmidt Conference, Cambridge, Massachusetts. Contact: Stein B. Jacobsen, Department of Earth and Planetary Sciences, Harvard University, Cambridge MA 02138.
Phone: 617-495-5233; fax: 617-496-4387
E-mail: goldschmidt@eps.harvard.edu
http://cass.jsc.nasa.gov/meetings/gold99/

Calendar listings may be submitted via e-mail to anderson@lpi.jsc.nasa.gov

NEWS FROM SPACE *continued*

Occultation of a Star by Triton



STSCI-PR98-23 • June 24, 1998 • J. Elliot (MIT) and NASA

has been undergoing a period of global warming — percentage-wise, it's a very large increase," said James L. Elliot, an astronomer at the Massachusetts Institute of Technology.

The warming trend is causing part of Triton's frozen nitrogen surface to turn into gas, thus making its thin atmosphere denser. Elliot and his colleagues from MIT, Lowell Observatory, and Williams College published their findings in the June 25 issue of *Nature*.

Even with the warming, no one is likely to plan a summer vacation on Triton, which is a bit smaller than Earth's moon. The 5% increase means that Triton's temperature has risen from about 37° on the absolute (Kelvin) temperature scale (–392°F) to about 39°K (–389°F). If Earth experienced a similar change in global temperature over a comparable period, it could lead to significant climatic changes.

Triton, however, is a very different and simpler world than Earth, with a much thinner atmosphere, no oceans, and a surface of frozen nitrogen. But the two share some contributing factors to global warming, such as changes to the Sun's heat output, how much sunlight is absorbed and reflected by their surfaces, and the amount of methane and carbon monoxide (greenhouse gases) in the atmosphere.

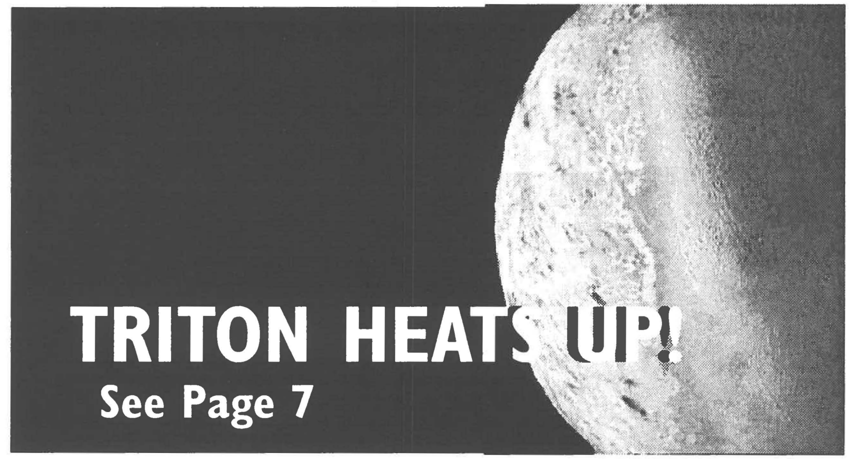
"With Triton, we can more easily study environmental changes because of its simple, thin atmosphere," Elliot explained. By studying these changes on Triton, the scientists hope to gain new insight into Earth's more complicated environment.

Elliot and his colleagues explain that Triton's warming trend may be driven by seasonal changes in its polar ice caps. Triton is approaching an extreme southern summer, a season that occurs every few hundred years. During this special time, the moon's southern hemisphere receives more direct sunlight, which heats the polar ice caps. "For a northern summer on Earth, it would be like the Sun being directly overhead at noon north of Lake Superior," Elliot said.

The scientists are basing a rise in Triton's surface temperature on the Hubble telescope's detection of an increase in the moon's atmospheric pressure, which has at least doubled in bulk since the time of the *Voyager* encounter. Any nitrogen ice on Triton that warms up a little results in a considerable leap in atmospheric pressure as the vaporized nitrogen gas joins the atmosphere. Because of the unusually strong link between Triton's surface ice temperature and its atmospheric pressure, Elliot says scientists can infer a temperature rise of 3°F over nine years.

Elliot and his colleagues list two other possible explanations for Triton's warmer weather. Because the frost pattern on Triton's surface may have changed over the years, it may be absorbing a little more of the Sun's warmth. Alternatively, changes in reflectivity of Triton's ice may have caused it to absorb more heat. ○

INSIDE



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