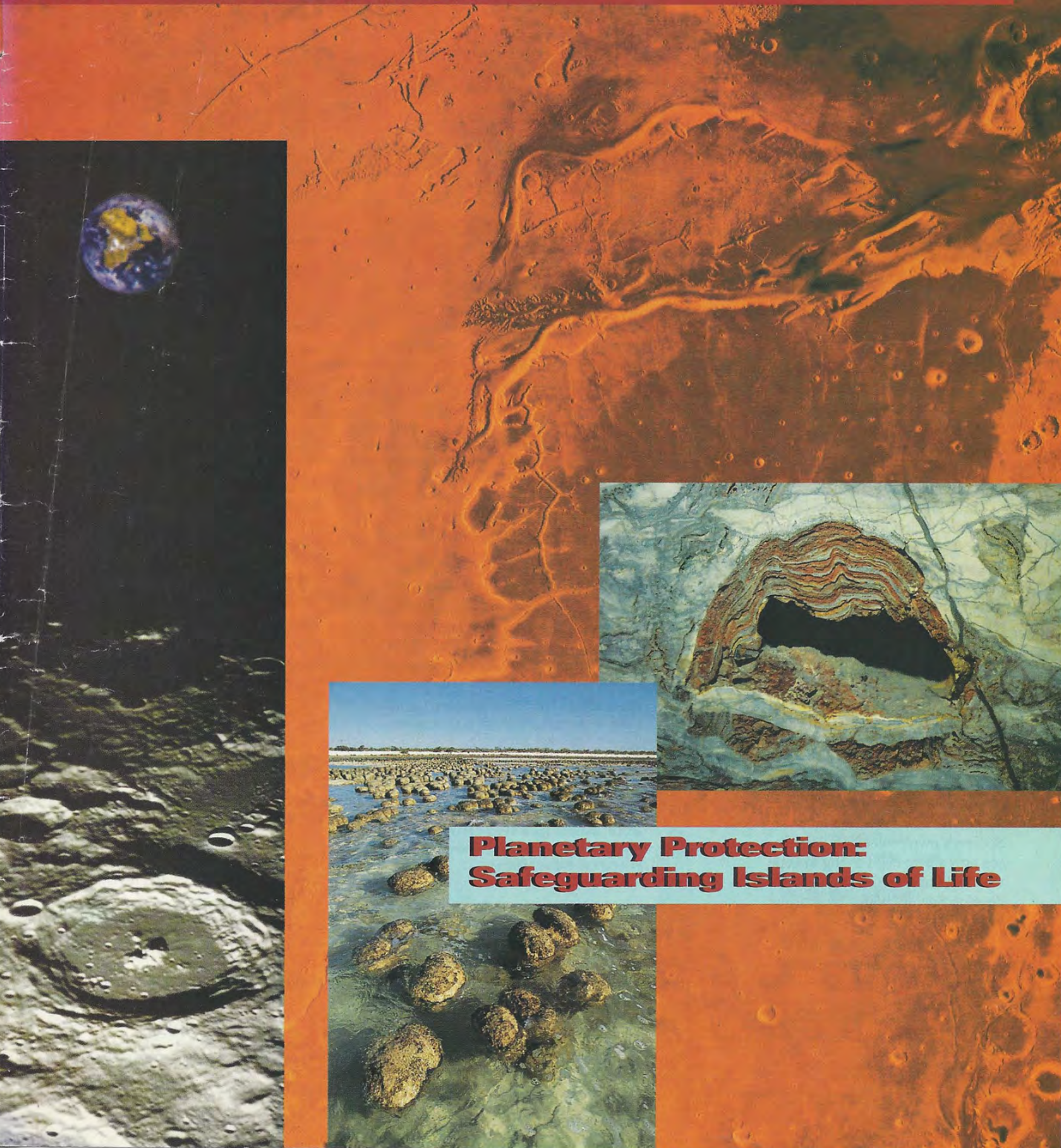
The PLANETARY REPORT

Volume XIV Number 4 July/August 1994



Planetary Protection: Safeguarding Islands of Life

On the Cover:

Our experience in exploring the Moon revealed no danger to earthly life from lunar life-forms—there were none—but the case on Mars may not be so easy. We know that some terrestrial life-forms—such as the stromatolite-building algae (insets, center and right)—are not always easily identified as living things. Martian life-forms may be more difficult to recognize. Dry, ancient martian river-beds (such as Kasei Valles, background) tell us that Mars once supported liquid water and, therefore, the possibility of life. Can we be sure there is no life there now, that we will not contaminate Mars ourselves, or that samples sent to Earth from Mars will not endanger our biosphere?

Background: United States Geological Survey
Insets (clockwise from right): Fred Bavendam, Peter Arnold, Inc.; Schafer and Hill, Peter Arnold, Inc.; Naval Research Laboratory/USGS

Table of Contents

Volume XIV
Number 4
July/August 1994

Features

Departments

From The Editor

In plans for the next century, missions to return samples from other planets to Earth have been given high priority by space agencies. Could these missions pose a danger to life on Earth? Conversely, could microbial invaders riding on terrestrial explorers—robotic or human—threaten what life might exist on other worlds?

These are two of the most serious questions facing mission planners today. The engineering, political and economic hurdles facing them may be easy compared to the scientific, ethical and moral issues to be resolved.

In The Planetary Society, we are not afraid to grapple with difficult subjects, and in this special issue we explore the conundrum of planetary protection. You'll hear from people who've thought long and deeply about the problem.

We've enclosed a survey so you can give us your opinions. We've also included an article on the Society's own projects so you can see how we've been trying to cope with it. I hope you'll help us further develop Society policy by sharing your views.

—*Charlene M. Anderson*

The Planetary Report (ISSN 0736-3680) is published bimonthly at the editorial offices of The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106-2301, (818) 793-5100. It is available to members of The Planetary Society. Annual dues in the US or Canada are $25 US dollars or $30 Canadian. Dues outside the US or Canada are $35 (US). Printed in USA. Second-class postage pending at Pasadena, California, and at an additional mailing office. Postmaster: Send address changes to The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106-2301. Canada Post Agreement Number 87424.

Editor, CHARLENE M. ANDERSON
Assistant Editor, DONNA ESCANDON STEVENS
Production Editor, MICHAEL HAGGERTY
Technical Editor, JAMES D. BURKE
Copy Editor, GLORIA JOYCE
Art Director, BARBARA S. SMITH

A Publication of
THE PLANETARY SOCIETY

Is It Dangerous to Return Samples From Mars to Earth?

by Carl Sagan

During the *Apollo* days, returning lunar astronauts and their samples were quarantined in a special containment facility in Houston. Steps were taken to see whether the astronauts developed exotic diseases and whether anything in the returned samples was alive. In each of the early *Apollo* missions, only after these concerns were satisfied were the astronauts allowed out of the quarantine facility and the samples distributed to laboratories throughout the world.

We knew even then, of course, that the Moon is airless and waterless and its surface fried by radiation; the chance of anything alive, much less pathogenic, seemed remote. Indeed, one impatient geochemist volunteered to *eat* some lunar sample if this would speed the process of getting his lunar samples to his laboratory earlier. But we were ignorant of the Moon, we had never returned a sample from another world, and we had to design policy to deal with a very low probability of a very great danger. (The novel and movie *Andromeda Strain* were inspired by the lunar contamination question.) Sure enough, as everyone guessed, the Moon proved lifeless. Nonetheless, I don't think the precautions were a waste of time and money. When the stakes are high you must be very careful.

We are now entering an age when samples from other worlds may be returned to Earth. The *Rosetta* mission of the European Space Agency proposes to bring back cometary samples, and a time is fast approaching when Mars surface samples will be returned—perhaps, if plans materialize to manufacture oxidizer and fuel on Mars for the return voyage, much more quickly and cheaply than had hitherto been thought possible.

Is there a danger to life on Earth from returning samples from, say, Mars? There are arguments pro and con. Among the arguments suggesting no danger are these: (1) The *Viking* microbiology and organic chemistry results at two sites 5,000 kilometers (about 3,100 miles) apart on a planet marked by prevailing eolian transport of dust mean, according to the prevailing scientific consensus, no contemporary life anywhere on Mars; (2) certain meteorites were ejected from Mars to Earth without being raised to very high temperatures (meaning that if there are martian pathogens, Earth might have already been infected many times); (3) there are no reports of indigenous organisms in these meteorites; (4) an independently arisen martian biology is unlikely to be pathogenic to terrestrial organisms (microbial parasites are very specific to their hosts); and (5) we would not undertake a sample return mission unless the sample containment was reliable.

Arguments suggesting caution about returning samples from Mars include the following: (1) The martian soil *did* react with all three *Viking* microbiology experiments in ways that are not yet fully explained (NASA should spend a little more money to understand the *Viking* results better); (2) below perhaps the top meter of the martian surface, a zone begins that is shielded from the ultraviolet-induced oxidation chemistry that is thought to destroy surface organic matter; (3) four billion years ago, when life was arising on Earth, Mars seems to have been wet and warm; (4) if putative martian organisms were originally transferred to Mars by collisions with Earth, they may be enough like us that they could be pathogenic; (5) in the first return of a sample from Mars, there are likely to be technological and human errors.

The barren dunes of Mars look familiar to earthly eyes, yet they exist on an alien world. The Viking *landers returned to Earth thousands of images and data that revealed no evidence of life on Mars, yet can we rule out the possibility that, in some protected recess, martian life-forms flourish? Can we be sure that no samples we collect there would carry microorganisms that could endanger life on our planet?*

Image: JPL/NASA

This issue of *The Planetary Report* is devoted to an assessment, from many different points of view, of this question. It is like a range of other concerns that the space program must come to grips with. For example, is it dangerous to launch plutonium-powered electrical generators into space? (Without them our exploration of Mars and beyond would be severely hobbled.) Is there any plausible level of rocket launches that will make a significant contribution to depleting the protective ozone layer? I myself do not think that any of these issues is a showstopper for planetary exploration. But they are legitimate concerns, the public welfare is involved, and those of us engaged in space exploration need to consider them seriously.

Carl Sagan is the David Duncan Professor of Astronomy and Space Sciences and Director of the Laboratory for Planetary Studies at Cornell University.

Protecting Our Planet,

Preserving Other Worlds

by Donald L. DeVincenzi

When humans first walked on another world, 25 years ago, we had no way of knowing for sure whether life existed there. The *Apollo* astronauts and the samples they carried back from the Moon might have been contaminated by organisms that could have been harmful to life-forms on Earth.

To protect the terrestrial environment, for the first three lunar landing missions both astronauts and samples were placed in quarantine immediately upon their return to Earth. After extensive analysis demonstrated there was no hazard, the quarantine was lifted, but that didn't end the debate over the possible biological dangers of exploring other worlds.

In this special issue of *The Planetary Report*, we will examine the controversial topic of planetary protection, which we will define as the prevention of biological cross-contamination of planets during exploratory missions. We are concerned with two types of possible problems: *forward contamination,* where microbes from Earth are inadvertently carried to another planet by a spacecraft, and *back contamination,* where extraterrestrial life-forms riding on planetary samples invade Earth's biosphere.

The current focus on Mars, the planet with the best chance of harboring life, by Earth's spacefaring nations has rekindled the debate about planetary protection. A goal for Mars exploration is to return samples to Earth during the next decade. Later, humans may walk on the Red Planet. Before a Mars sample return mission is launched, and before we plan a human mission, we will have to give serious attention to questions of planetary protection.

The world has changed since the time of *Apollo*. Consciousness of environmental dangers has increased dramatically, indicating that we need to address societal and legal issues raised by missions such as a Mars sample return at the same time that we confront scientific and engineering aspects. Indeed, in a 1992 report, the Space Studies Board noted that there is a great need for public education and involvement on this issue.

The nations of Earth addressed the question of planetary protection even before the first *Apollo* mission. In 1967, the United States, the Soviet Union and other nations signed a treaty requiring that the exploration of planets be pursued without their harmful contamination, and that Earth's environment be protected as well. The treaty spawned a policy now monitored by the Committee on Space Research (COSPAR) of the International Council of Scientific Unions to prevent biological contamination, whether forward or back.

Both the United States and the Soviet Union landed spacecraft on the Moon, Mars and Venus. Little is known about planetary protection measures taken by the Soviet Union, but the US has applied controls to several missions. The best known is, of course, *Apollo*, but the *Viking* missions to Mars involved rigorous measures taken both to protect against the forward contamination of that planet and to avoid interference with the life-detection experiments that were carried by the spacecraft.

Despite this experience, we are still grappling with planetary protection, for two major reasons. First, it is extremely difficult to detect extraterrestrial life and, if we find it, to assess whether it poses a hazard to terrestrial life. We don't even know if hardy terrestrial life-forms could survive on other planets. With only speculation to go on, we have to deal with probabilities instead of hard numbers in addressing the issues of contamination.

Second, to implement planetary protection measures on a mission will be enormously complex technically. Our experience shows that it will add to both the difficulty and the cost of a mission. This is a serious concern for mission managers trying to conduct ambitious missions in a cost-constrained world.

It seems prudent to conclude that we will have to explore Mars extensively by robot before we can commit to human missions. To start, we will send landers and rovers equipped with instruments to probe the martian environment to help us determine if there still might be secluded niches where life might exist. Then, spacecraft equipped with onboard laboratories will follow to complete in situ analysis. Eventually, if we are to approach certainty about the ability of Mars to support life, we will probably have to return samples to Earth.

It was with all this in mind that we planned this special issue of *The Planetary Report*. We begin with a quick look at international policy for planetary protection and then take a look back at lessons learned from the *Apollo* program. We will wrestle with difficult questions, such as, Can Mars support a biota? Could possible extraterrestrial life pose a threat to life on Earth? Has Earth already been contaminated by materials from Mars?

Finally, we will try to evaluate the societal and legal implications. Planetary protection is a topic that will raise strong opinions, not only among those who support planetary exploration, such as Planetary Society members, but among the general public as well. We encourage you to consider the issues raised by these articles carefully and then share your views with us. We have bound a questionnaire into this magazine; please complete it and mail it back to us. We will share the results in a future issue of *The Planetary Report* and let you know of progress in dealing with the difficult problem of planetary protection.

Donald L. DeVincenzi, deputy chief of the Space Science Division at NASA's Ames Research Center, is the guest technical editor for this special issue of The Planetary Report. *He also served as planetary protection officer for seven years at NASA headquarters.* *Harold P. Klein of the University of Santa Clara, Benton C. Clark of Martin Marietta and several colleagues at Ames provided invaluable advice and assistance during the preparation of this issue.*

Where No One Has Gone Before . . .

What Is Planetary Protection, Anyway?

by John D. Rummel and Michael A. Meyer

Picture a team of scientists examining the first samples returned from the Valles Marineris on Mars. The samples have been treated with the utmost care and kept at ambient martian conditions. Of particular interest are some drill-core samples of martian permafrost, containing pristine samples of water and dissolved gases.

But are the samples really pristine?

Why Planetary Protection?

On Earth, living organisms are distributed throughout our planet—in rock at depths of over 1,000 meters (about 3,000 feet), in soil frozen for more than 3 million years, in 110-degree Celsius (230-degree Fahrenheit) seawater and so on. We know that life can reach high abundances in the right environments (a human body contains about 50 percent nonhuman cells, by number, and sheds about 50,000 living cells per day). It is impossible, under normal conditions, to visit Earth and not encounter life.

On Mars, the planet most like Earth, however, our visits have not found evidence of life, and life on the martian surface is probably nonexistent. It stands to reason, then, that the greatest threat to the pristine condition of martian samples is not from martian life, but from Earth life.

In fact, perhaps one of the greatest successes of the *Viking* missions is that they *didn't* discover life on Mars—which would have been all too easy if each spacecraft had not been treated before launch to reduce the biological load it carried. The *Viking* life-detection experiments would have allowed the growth of Earth organisms, and it would have been tragic if *Viking* had gone all the way to Mars to discover bacteria from Florida or Colorado. It would be equally tragic if the future exploration of Mars were to be halted to protect earthly contamination, masquerading as "indigenous" martian life.

The Policy Takes Shape

Since the earliest days of the space program, the worldwide scientific community has been concerned about protecting other solar system bodies from biological contamination. This concern culminated in the wording of the 1967 Outer Space Treaty, which said that nations should pursue studies of solar system bodies "so as to avoid their harmful contamination and also adverse changes in the environment of the Earth." By that time, the recommendations of the Committee on Space Research (COSPAR) of the International Council of Scientific Unions were crucial in shaping international principles for space exploration.

Since 1967, the policy adopted by NASA has matured in an interactive process that has included the Space Science Board (now the Space Studies Board) of the National Academy of Sciences, as well as COSPAR. The policy is expressed in the following statement from NASA's instruction on planetary protection:

"The conduct of scientific investigations of possible extraterrestrial life forms, precursors, and remnants must not be jeopardized. In addition, the Earth must be protected from the potential hazard posed by extraterrestrial matter carried by a spacecraft returning from another planet. Therefore, for certain space-mission/target-planet combinations, controls on organic and biological contamination carried by spacecraft shall be imposed in accordance with directives implementing this policy."

This policy was adopted in turn by COSPAR in 1984, and is applied to all robotic missions to other solar system bodies and for all sample return missions. It is expected to be applied to missions carrying human explorers as well.

How Does It Work?

Implementing the basic policy involves placing constraints on spacecraft, depending on the nature of the mission and the identity of the target body (or bodies). Both forward contamination, the potential contamination of another solar system body by Earth organisms, and back contamination, the potential contamination

(continued on page 23)

The **Viking** *landers that reached Mars in 1976 underwent extensive sterilization before launch to protect possible martian life from earthly invaders.* Image: JPL/NASA

Rocks in Quarantine:

Apollo's Lessons for Mars

In ecology, the same [as uncontrolled growth of malignant cells] would happen if, for some reason, one particular type of organism began to multiply without limit, killing its competitors and increasing its own food supply at the expense of that of others. That, too could end only in the destruction of the larger system—most or all of life and even of certain aspects of the inanimate environment.
—Isaac Asimov
"The Case Against Man," 1991

by John R. Bagby

Almost lost in the glory surrounding **Apollo** ***was the Soviet achievement of collecting and returning lunar samples to Earth using robots. In 1970,*** **Luna 16** ***delivered a small sampling to Soviet scientists. At top is a sample on display in Moscow; at bottom is a vacuum chamber being prepared to receive the samples for study.***

Photograph: ITAR–TASS/SOVFOTO

In that passage, Dr. Asimov was addressing the interrelatedness of all life on Earth, not the possibility of contamination from extraterrestrial sources. But scientists have long discussed the possibility of back contamination—harmful effects on Earth organisms if extraterrestrial pathogens were to be introduced into Earth's biosphere.

Whether the consequences of such an introduction would be disastrous or negligible is a subject of intense controversy. Some believe that extraterrestrial organisms would be so drastically different from Earth forms that the two groups would be unable to recognize each other as life-forms and would be unable to interact. Even if these organisms were different, however, there is no way to be certain that they would *not* be harmful. Others think that extraterrestrial organisms could acquire pathogenic characteristics after their introduction to Earth's biosphere through interaction with terrestrial life; such extraterrestrial pathogens could then affect terrestrial organisms that had originally acquired immunity to them.

The controversy passes beyond the realm of the academic with Mars sample return missions on the drawing board. Decisions will have to be made regarding planetary protection long before any such missions are launched. How the issue was handled during NASA's lunar *Apollo* program is well worth examining today.

During the summer of 1962, the Space Science Board of the National Academy of Sciences reviewed the subject of back contamination by returning outer space flights. It recommended that NASA do everything possible to minimize the risk of back contamination and called for the use of quarantine and other procedures in handling astronauts, samples and spacecraft.

The first in-depth discussions of back contamination took place in 1964 in Washington, DC, at a National Academy of Sciences conference chaired by Allan H. Brown. Although finding life on the Moon was considered unlikely, the assembled scientists concluded that quarantine procedures were necessary no matter how slight the possibility of life might appear to be, and they developed recommendations that became the broad policy guides for the

The battered surface of Earth's Moon reveals no evidence that it ever harbored life or even conditions that might have supported life. Nonetheless, during the Apollo *program NASA and other US government agencies set up procedures to protect terrestrial life from possible contamination by lunar life-forms. The resulting quarantine was not perfect. No traces of lunar life were ever found.*

Photograph: Stocktrek, Tom Stack & Associates

control of astronauts, samples and vehicles returned from the Moon.

Between October 11, 1968, and December 7, 1972, 11 *Apollo* missions carried humans beyond Earth's atmosphere. Six of the 11 were completed lunar landing missions, each with extravehicular activity on the lunar surface. They returned to Earth 380 kilograms (835 pounds) of lunar material, 18 astronauts who had been exposed to lunar material, and various items of equipment, including six *Apollo* command vehicles.

Apollo 11—Compromising the Quarantine

The first of the lunar landing missions, *Apollo 11*, was launched at 8:32 a.m. on July 16, 1969. Approximately 195 hours later, the command module, following an automatic reentry sequence, reached about 10,000 feet altitude above the Pacific Ocean, where a post-landing ventilation system was activated.

That action opened the contents of the command module to Earth's atmosphere and provided the first potential contamination of the biosphere by extraterrestrial matter through human intervention. Although in-flight checklists directed the astronauts to clean the command module's interior by operating vacuum systems that would filter the air through lithium hydroxide canisters, it is unlikely that all dust was removed from the cabin atmosphere, and some of it could have escaped through the vent to the outside.

The command module landed near the primary recovery ship, the USS *Hornet*. Soon after landing, the hatch was opened, marking the second break in strict isolation. After donning biological isolation garments, the astronauts were retrieved by helicopter and transferred to the *Hornet*. There they stayed, along with the lunar material they brought back, in the Mobile Quarantine Facility en route to the Lunar Receiving Laboratory at the Manned Spaceflight Center in Houston, Texas. They remained in isolation for 21 days while they were medically evaluated, and the lunar material was examined behind double biological barriers.

The agency charged with directing the isolation of the extraterrestrial materials was the Interagency Committee on Back Contamination (ICBC), which had been established in 1966 by NASA in cooperation with the United States Public Health Service, the Departments of Agriculture and Interior, and the National Academy of Sciences. The committee faced almost unbelievably complicated problems with regard to technology and administration and shared with the *Apollo* mission office an extreme constraint on time imposed by the commitment to land men on the Moon during the 1960s. Of all the issues facing the

Some of the more memorable images from the Apollo 11 *mission came not from the Moon, but from the quarantine facilities after the astronauts had returned to Earth. Upon reaching the USS* Hornet*, the aircraft carrier that picked them up after splashdown, they stepped onto the deck wearing biological isolation suits (right). They then entered the Mobile Quarantine Facility (above, seen behind the command module) and remained in isolation for 21 days. The astronauts' families had to welcome them home from across a steel and glass barrier. Neil Armstrong (left) spoke with his family by telephone.* Photographs: NASA

ICBC, time became the most critical as compromises of strict quarantine were negotiated to meet mission flight schedules.

The second most important constraint was in the area of administration and management. Many people associated with the *Apollo* program were convinced that the probability of dangerous contamination being found in lunar materials was so low that less than a full commitment to containment was reasonable. This resulted at times in overt resistance to ICBC policy, and at the very least in serious lack of communication.

Compromises of strict quarantine were all related either to time or to administrative decisions, and none directly to deficiencies in technology; scientifically sound techniques for strict isolation were available. Absolute quarantine would have required that the astronauts remain within the spacecraft upon landing, with all spacecraft openings closed until after it had been lifted to the deck of the recovery vessel and an impervious tunnel had been secured between the spacecraft and the Mobile Quarantine Facility. Although the ICBC had originally ordered such strict isolation procedures to be followed, the aforementioned factors of time and administrative decisions led to the recovery compromises described. For example, only a few days before the launch of *Apollo 11*, the ICBC was notified that the recovery vessel was not equipped with a crane capable of lifting the command module aboard with the crew inside, and the vessel's deck plates could not support such a crane. If the Manned Spaceflight Center had been serious about planetary protection, it would have delayed the launch to correct the situation.

The Lunar Receiving Laboratory at the Manned Spaceflight Center in Houston was designed and built specifically for the containment and examination of samples, equipment and astronauts. Time-dependent examinations of the material under high vacuum conditions required the most expensive design and construction features of the building. Those who examined the samples worked

ditions more suitable than the Moon's to the support of biological systems, the whole concept of protection against back contamination must be reconsidered by those in positions of authority.

There needs to be an effective management structure set up within NASA with full authority to design and implement a realistic containment system years in advance of the return of extraterrestrial materials. The containment facility and the scientific protocols for examination and release of the specimens from quarantine must be in place and intensively tested long before return samples are actually received. The tests should be carried out with pathogens to ensure serious attention to safety and must include experiments specifically designed to identify organisms that would be harmful to terrestrial plants and animals, whether through competition or through disease.

The quarantine protocol for investigating the Moon samples was designed under contract by researchers at Baylor University, and it was very ambitious. It called for the exposure of lunar material to at least one representative species from each phylum of terrestrial plants and animals. Great progress has been made in the biological sciences since that time. With new science, it should be possible to dramatically reduce the number of test systems and to much more rapidly determine the level of safety or degree of threat posed by release of the samples. In addition, new technology for containment should be reviewed.

Mission design for sample return missions will bear heavily on the nature and location of the containment and examination facility required. For example, it will be necessary for any returned sample to be held within a closed, sealed container that is sterile on the exterior until it is recovered and placed inside the receiving laboratory for examination. It is obvious, therefore, that planning for planetary protection must be incorporated into mission design from the very beginning to avoid one of the major problems encountered during the lunar missions.

through glove boxes with atmospheric pressures negative to the rooms, and the rooms themselves were under negative pressure to the outside.

Although the glove box system was state of the art and worked rather well, some difficulties were apparent. The people who worked through the gloves were allowed to move in and out of the building, and little control over their activities was possible. In any future operation of a similar nature, consideration should be given to isolating the people who work with the samples behind a secondary barrier for a quarantine period.

Mars Missions—Protecting Earth

If time had been available, or if protecting Earth's biosphere had been paramount in planning the *Apollo* missions, it is likely that the strictest possible containment would have been required. Before future missions return materials and equipment from other bodies in the solar system, particularly those bodies with environmental con-

Those who tried to carry out quarantine mandates during the *Apollo* experience simply did not have enough time to incorporate their requirements without destroying the mission schedules, and compromises were made. Increased public awareness of environmental issues since the 1960s, the creation of the Environmental Protection Agency, and the less hostile environment of Mars all warn us that such compromises must not be allowed when we return martian soil to Earth.

John R. Bagby is professor emeritus of microbiology at Colorado State University and former deputy director of the Centers for Disease Control and Prevention. He served as co-chairman of the Interagency Committee on Back Contamination during the Apollo *missions.*

Lessons from *Viking*:

The Search for Life on Mars

by Norman H. Horowitz and Arden L. Albee

The picture of Mars that prevailed in the early 1960s, when spacecraft began to explore the planets, was very different from the picture we have today. Seen from a distance, Mars is remarkably Earth-like in appearance. It has a nearly 24-hour day, and because of the tilt of its spin axis, it has seasons like our own. It has polar caps that wax and wane with the seasons, and large areas that change color seasonally. All of this proved to Percival Lowell, an American astronomer at the turn of the century, that Mars harbored life: To him, the caps were water ice, and the color changes demonstrated the response of vegetation to seasonal variations in the availability of water.

To this, Lowell added what was for him convincing evidence that Mars also had intelligent life: the famous canals, a network of straight, thin lines covering the planet's surface. Even in Lowell's day, the canals were regarded by skeptics as figments of his imagination, and we know today that they do not exist.

The Real Mars

By 1969, new observations from Earth and from *Mariners 4, 6* and *7* completed the "delowellization" of Mars. The atmosphere was found to be mostly carbon dioxide, the ice caps were frozen carbon dioxide, not water ice, and the temperature and pressure of the atmosphere prohibited the presence of liquid water on the surface; the evidence for vegetation was illusory. By 1970, Mars presented so unpromising a scene biologically that it would have been hard to justify a search for life there.

The biological outlook improved significantly in 1971 when the camera of *Mariner 9* found large extinct volcanoes—and clear evidence of ancient streambeds. Liquid water is essential to life as we know it, and it may well be essential for life anywhere in the universe, since no other substance possesses all of its remarkable physical and chemical properties. Any planet found to have water on its surface, where it is exposed to sunlight, the ultimate energy source for living things, should be considered a promising object for biological investigation. Conversely, dry planets

Caution and Humility:

Where There's Water...

by Elliott Levinthal

The return of a sample from Mars is an exciting prospect. But before we undertake a sample return mission, we need to address two crucial scientific questions: Is there extant life on Mars? And, if such life does exist, is there danger in contaminating Earth with such organisms?

A great deal of humility needs to go along with addressing these questions, because of how little we actually know. The answer to the first question depends on our knowledge of Mars and on our understanding of microbial life on Earth; both are incomplete. There is no theory of evolutionary processes to inform us concerning the range of life-forms that might evolve in the universe and in particular on Mars.

Most scientists agree that the *Viking* landers did not find any biological activity at the landing sites. If the *Viking* results can be extrapolated to the entire planet, the surface of Mars would certainly appear to be inhospitable to life. However, the *Viking* landing sites were not chosen to optimize the search for life, and the biological experiments focused on a limited variety of metabolic types and sampled only a few centimeters below the surface at two locations. The depth is significant in the search for water. Thomas Gold has even proposed that organisms may exist—and that life may have begun—5 to 10 kilometers (3 to 6 miles) below Earth's surface, and at similar depths on Mars. He suggests that we may even find that "microbial life exists in all locations where microbes can survive." Some humility about answering the question of extant life on Mars should be engendered by this statement.

The question of whether there is a danger of contaminating Earth has been a subject of concern for a long time. In 1977, Thomas H. Jukes concluded that there are no biological risks. (See page 13.) However, the nucleic acid bases used in martian informational macromolecules (on Earth, these molecules are DNA) or the set of amino acids specified by combinations of four nucleic acid bases may well be the same as for terrestrial biota. Without an accepted theory of evolution, we don't know whether the informational macromolecule DNA is universally dominant. Even if only the nucleic acid bases but not the specific martian proteins are the same, why *couldn't* a martian "virus" reproduce within a terrestrial host cell using that cell's biochemical machinery—enzymes, tRNA, ribosomes and so on?

are not thought to be attractive biological targets.

The *Viking* Mission

If water ran on Mars in the past, life may have originated there too. This became an important theme for the *Viking* mission, which had two spacecraft, each consisting of an orbiter and a lander and carrying identical sets of instruments. In 1976, one lander put down in Chryse Planitia in the northern hemisphere of Mars; the other, in Utopia Planitia, 1,500 kilometers (about 930 miles) farther north and on the opposite side of the planet. The biologically important observations consisted of global temperature and water-vapor measurements from the orbiters and, from the landers, close-up photography, organic analysis of surface samples, and attempts to detect metabolic activity of soil microorganisms.

The cameras sent back memorable landscapes of a desolate, rocky Mars, with no traces of life. This was no surprise, since only microbial life seemed possible for Mars, and the *Viking* cameras could not have detected it. Organic analysis of the soil was more likely to be informative, although it was recognized that even a lifeless Mars would probably have organic matter (compounds containing carbon and hydrogen) in its soil.

Meteorites provide nonbiological sources of organic matter. Mars should have accumulated enough meteorite material over the ages to be detected by the sensitive *Viking* instrument. The actual finding—no trace of organic matter at the parts-per-billion level of detectability—essentially excluded the possibility of life in these soils.

The* Viking *biological experiments detected no unequivocal evidence of life on Mars. They did discover that martian soil is chemically reactive, containing an oxidant that could destroy any organic molecule that might fall upon it.
Image: JPL/NASA

Of the three microbiological experiments *Viking* carried, two assumed that martian organisms, if any, lived in an aqueous environment. These experiments brought martian soil into contact with aqueous solutions of organic compounds and measured the metabolic response. The third experiment employed gases known to be present in Mars' atmosphere—carbon dioxide (CO_2) and carbon monoxide (CO)—as probes of metabolic activity; no liquid water was used.

(continued on next page)

There is no known reason that an infective agent or predator has to have the same biochemical pathways or the same macromolecules that its victim has. There are flukes of nature. The botulism bacillus developed an exotoxin that also has an effect on the nerve cells of animals. This doesn't seem to confer any survival advantage to these soil organisms. We are not concerned about large probabilities but rather the possibility of flukes.

We can't reject out of hand the possibility of a martian organism seriously affecting our ecology by successfully competing for, or sequestering, nutrients, or otherwise changing the terrestrial environment or food chain.

There are terrestrial examples. Peter Vitousek has described the ecosystem-level consequences of an ongoing biological invasion by the microorganism *Myrica faya* Ait, a nitrogen-fixer, which acts on nitrogen-deficient sites: "Invaders can change ecosystems where they differ substantially from the natives in resource acquisition or utilization."

Where there's water, there's the possibility of life. On Mars, large erosional features carved by flowing water show us that this planet was very different in the past. If the right conditions existed there once, might life have arisen? And might it still be there in some protected hideaway?
Image: JPL/NASA

Water, Water, Anywhere?

Site selection for a return sample is crucial. The search for water is the critical factor in determining the necessary suite of precursor missions and the choice of sites for sample return. Poor site selection for return samples can have serious consequences. We should be wary of a single negative result that might be false. Such a false negative could lead to taking imprudent risks on premature human missions. A wise policy would be to plan a series of orbiters and robotic landers before bringing a sample back from a carefully selected site. Such a policy will create public confidence.

It is plausible that life got started on Mars during an epoch when there were areas on the surface of Mars with free water. We know from our experience on Earth that, if life ever did get started on Mars, organisms would have developed to occupy surprisingly hostile environments and utilize unusual and sparse resources. Life can use rather

(continued on next page)

All three experiments sent positive signals from Mars. Given the fundamentally different assumptions of the experiments, it seemed clear that they could not all be detecting the same martian life. The question was whether any of them had found life—a finding that would be hard to reconcile with the failure to detect organic matter in the soil—or whether they had discovered a chemically reactive Mars. The latter turned out to be the case.

The aqueous experiments were, in all probability, responding to hydroxyl (OH) radicals (or peroxides derived from them) in Mars' soil. OH is produced from atmospheric water vapor by solar ultraviolet light. On Mars it would diffuse into the dry soil and there act as a strong oxidizing agent. Its oxidizing power can explain not only the results of the aqueous experiments, but also why organic matter is missing, and why Mars is a rusty red color. As for the dry experiment, laboratory simulations indicate that it was probably measuring a reaction between carbon monoxide and certain iron-containing minerals.

The two *Viking* sites were very similar in their surface chemistry. This similarity reflects the importance of global forces in shaping Mars' environment, forces like the extreme dryness, the pervasive short-ultraviolet radiation and the planetwide dust storms. *Viking* found that Mars is even drier than was previously thought. The highest abundance of atmospheric water vapor was found around the edge of the north polar ice cap in midsummer. Equatorial latitudes, where temperatures rise above freezing and which might be thought to be more favorable for life, are the driest part of the planet. The dryness alone would suffice to guarantee a lifeless Mars; combined with its radiation flux, Mars becomes almost Moon-like in its hostility to life.

Looking Ahead

The picture we now have of Mars is coherent and realistic, but it needs to be confirmed and expanded. This can best be done with samples returned to Earth, where they can be examined, and the active chemicals identified, in terrestrial laboratories. The samples should include a deep core to be analyzed for organic material; if any is found, it should be characterized to determine if it is of biological or nonbiological origin. Preserving the validity of these studies will require that appropriate care be given to forward and back contamination.

Everyone should understand, however, that the question of early martian life is more likely to be answered by a comprehensive study of the geological history of Mars than by a single returned sample. This will be the challenging task of mobile robot missions of the future.

Norman Horowitz is professor emeritus of biology at the California Institute of Technology and was a member of the Viking *biology team. This article was condensed and updated by Arden Albee, project scientist for the Mars Global Surveyor mission and professor of geology at Caltech, from an earlier article in* The Planetary Report.

---

exotic ways of acquiring and storing water resources. In addition, there are Gold's conjectures about life with its origins and maintenance deep below the surface.

The search for extant life on Mars should begin with a thorough global examination of possible ecological niches. Of particular concern is the distribution of water. Ground ice on Mars near the equator may be isolated from the atmosphere by as much as 500 meters (about 1,600 feet) of soil and rock. We do not yet have good instruments for measuring the depth and horizontal distribution of water.

Orbiters can detect seasonal changes in permafrost-induced ground patterns. Gamma ray observations of hydrogen and thermal emission spectrometer indications of thermal variation can also reveal meaningful seasonal variations. A radar altimeter of a wavelength that could penetrate the surface is a good indicator of subsurface changes and could be flown on an early mission.

In the near term, the Russians are contemplating a radar experiment using a 60-meter (200-foot) antenna that would gather information from about 200 meters (650 feet) into the ground. Side-looking radar has been used to locate subterranean water formations in the Sahara.

Using information derived from many sources will help us locate the most suitable sites. If we should find possible "oases," we would need to follow up with more detailed explorations using robotic rovers equipped to carry out on-site analysis. Without careful prior site selection, there would have to be a large number of rover missions, or the rovers would need an extensive exploratory range.

A Call for Caution

Let's say we've found a suitable site and we've figured out how to return a sample safely to a quarantine facility on Earth. Yet another problem remains to be solved. We need to set up experimental protocols to help us decide if it is safe to release the sample. The tools we have today for searching a sample for a low density of an exotic life-form are inadequate for this job. They are most suited to finding life-forms whose characteristics are similar to those of terrestrial biota. We need to develop new concepts and technologies, and should begin work in this area before a sample return mission is launched.

A public perception of prudence is required to respond to societal concerns. Hopefully, this would be achieved by a sufficient set of precursor missions as well as fail-safe procedures for handling the return sample. Public confidence requires that planetary quarantine be supervised by a well-funded authority with the belief that there is in fact a risk and which is independent from those responsible for carrying out the mission. It would be tragic if, after a huge investment of money and talent, public protest prevented a launch.

Elliott Levinthal is professor emeritus, School of Engineering, Stanford University. He served as deputy team leader of the Viking *1975 lander imaging team. He also has served as a member of the NASA Advisory Council, the National Academy of Sciences Space Studies Board and its Committee on Human Exploration.*

Lessons from Evolution:

Ruling Out Danger

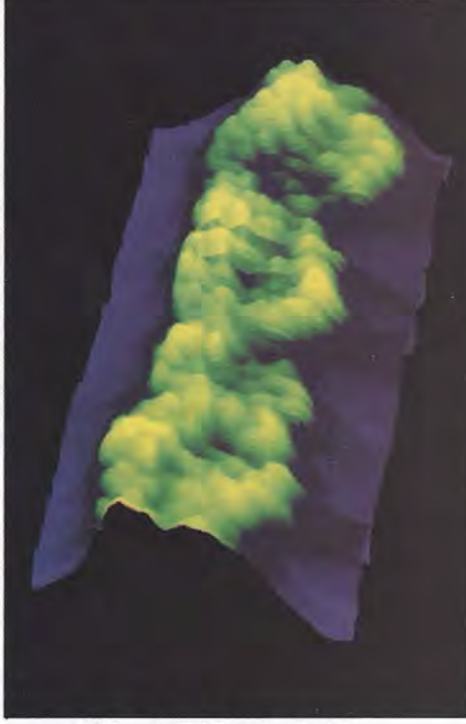
by Thomas H. Jukes

Does the knowledge of evolution help us to evaluate the possible dangers of returning a surface sample from Mars to Earth?

The renewed proposal of returning a sample of surface material from Mars to Earth was described by Harold Klein and Don DeVincenzi in a 1993 article in *Advances in Space Research*. This stimulates consideration of possible hazards. Public fear of "danger from Mars" was aroused in 1938 by the radio program by Orson Welles describing giant martian invaders. Another fictional story was that of a "green plague" of contaminant microbes. A Space Science Board report suggested that an extraterrestrial organism might "sequester a nutrient, such as fixed nitrogen, in a stable form which could not be attacked or utilized by terrestrial organisms. In time, the terrestrial flora would experience nitrogen starvation." Such a "stable form" of fixed nitrogen is unknown, even though scientists have thoroughly investigated compounds of nitrogen.

The theory of evolution by descent with modification says that all terrestrial life had a common origin, and that differences between living species accumulated and increased as they diverged from this origin. Despite diver-

(continued on next page)



All life on Earth is based on double-helical DNA, seen here magnified 25 million times in a view reconstructed by scanning tunneling microscopy data. The odds of any putative martian life, if of independent origin, using the same genetic code are vanishingly small.

Image: John D. Baldeschwieler, California Institute of Technology

Considering the Improbable:

Life Underground on Mars

by C.P. McKay, M. Ivanov and P.J. Boston

The *Viking* results have been widely interpreted as implying that there is no life on the surface of Mars. (For more on *Viking,* see page 10.) Conditions there are just too cold, too dry and too oxidizing. This may be true, but beneath the surface things might be quite different.

First, let's consider why conditions on Mars might be more hospitable underground. What makes the surface of Mars particularly inhospitable is the absence of liquid water—the result of the low atmospheric pressure and the low temperatures. Below the surface, with the weight of the overlying soil, obtaining pressures suitable for liquid water to exist would be no problem. Temperatures above freezing, however, would require a subsurface heat source—a smoldering volcano, or a magmatic hot spot.

Hot Evidence

Some intriguing evidence for recent (on the geological time scale) volcanic activity comes from a meteorite that fell in Shergotty, India (and other, similar meteorites thought to have a common

(continued on next page)

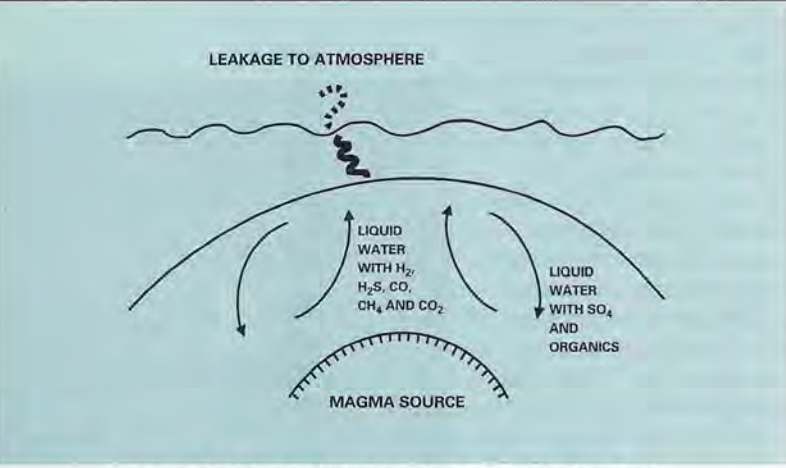
Geothermal vents on Earth provide a model for how water on Mars might remain in liquid form and have the potential to support life. In this earthly example, the Moon glows through the plume of the Old Faithful geyser in Yellowstone National Park.

Photograph: Jeff Foott, Tom Stack & Associates gence, terrestrial organisms all use the same 20 amino acids in reproducing themselves by protein synthesis, which is the means by which new cells are made, and use almost the same genetic code to translate the information stored in DNA.

Also, they share the use of many essential biological catalysts such as riboflavin, which is also a vitamin. Inheritance is by means of DNA, consisting of four nucleotides abbreviated as A, C, G and T. As the evolutionary distance shortens between organisms, they become increasingly similar. Vertebrates originated about 500 million years ago and show wider differences between species than do mammals, which had a common ancestor about 120 million years ago. If there is life on Mars, it might well be based on A, C, G and T, but the vast distance between Earth and Mars indicates that it must have had an origin separate from that of terrestrial life. The genetic code is a product of terrestrial evolution. There is no reason to assume that martian organisms would use the same amino acids or genetic code as does terrestrial life. Some amino acids, such as norvaline, are found in meteorites but are not included in the genetic code.

Could martian viruses attack terrestrial organisms? Viruses depend on host organisms for their existence, and the range of acceptable hosts is limited; cowpox will grow in humans, but virus diseases of plants do not invade animals or bacteria. The possible identity of any martian virus with a terrestrial virus by chance can be ruled out by statistical calculations. For example, there are 4^{300} different ways of arranging a sequence of 300 of the four nucleic acid bases. This sequence could code for a short protein. Viruses would probably be unstable to desiccation on the incredibly dry surface of Mars, where the concentration of water is only one-thousandth of that on Earth's surface. Viral reproduction requires specific enzymes and nucleic acid sequences in host cells, indicative of coevolution of a virus and its host, which could not have taken place between a martian virus and a terrestrial host. Cross-infection of terrestrial cells by martian viruses, or of martian cells by terrestrial viruses, seems to be ruled out.

Would martian microorganisms such as bacteria attack life on Earth? This could be prevented by current laboratory containment procedures, because these are adequate to stop deadly terrestrial microflora from starting pandemics, disease outbreaks that hit hard and spread abruptly far and wide. Evolutionary differences in hosts would also work against the likelihood of martian organisms causing disease. The possibility of potato blight was used in attempting to quarantine lunar return samples (and astronauts). But there are no potatoes on the Moon!



In this model of a possible hydrothermal habitat for life on Mars, heat from magma drives water through the crust. Volcanic gases carrying nutrients that might support life travel upward, while oxidized materials and organics produced by the life-forms travel downward. Traces of this underground habitat might leak to the surface and the atmosphere.
Chart: adapted from Boston et al., **Icarus** ***95, 300–308, 1992***

martian origin). The density of cosmic ray tracks in the meteorite's lava crystals suggests that the lava flowed on the surface of Mars about 200 million to 400 million years ago. The other martian meteorites are between 200 million and 1 billion years old (page 16). It is improbable that Mars was volcanically active for 4 billion years, only to become inactive in the last 200 million years. Nonetheless, it is important to keep in mind that no active volcanism has yet been observed on the Red Planet.

Volcanic activity by itself does not provide a suitable habitat for life; liquid water, presumably derived from the melting of ground ice, is required. A volcanic source in the equatorial region probably would have depleted any initial reservoir of ground ice, and there would be no mechanism for renewal—although there are indications of geologically recent volcano/ground ice interactions in this area. Closer to the poles, any ground ice would be stable. It is conceivable that a geothermal heat source here could bring about a cycling of water through the cryosphere. The heat source would melt ice and draw in water from any underlying reservoir of groundwater, brine or ice that might exist.

Moreover, the outflow channels we see on the martian surface appear to be the result of the catastrophic discharge of subsurface aquifers of enormous size. There is evidence based on craters and stratigraphic relationships that these floods have occurred throughout martian history, and intact aquifers may remain. Furthermore, the debris fields and outwash regions associated with the outflow channels may hold evidence of life that existed within the subsurface aquifer just prior to its catastrophic release.

Energy Without Light

The major disadvantage of living underground is that sunlight is not available for photosynthesis. Organisms would have to find another way to get the energy needed for life. There are examples of such light-less ecosystems on Earth. In deep-sea hydrothermal vents, the base of the food chain is the chemical oxidation of hydrogen sulfide (H_2S) coming from the vent. Oxygen dissolved in the seawater is the oxidant.

This particular reaction would not work on Mars, because there is not enough oxygen in its atmosphere. However, there are other chemical schemes that microorganisms use that could be directly applicable to Mars with its carbon

Antarctic organisms have been separated from those in the temperate zones for a long time, but there is no evidence, or fear, that Antarctic organisms are dangerous. Separation *decreases* any such danger by producing divergent evolution.

Another proposal, by J.F. Danielli, suggested that martian DNA might spread by vectors—biological intermediates such as mosquitoes or flies—throughout terrestrial species with "risks of catastrophic pathologies." This is negated by the fact that despite a small amount of gene transfer, terrestrial DNA predominantly stays within species so that they remain separate from each other during evolution. We humans are continually exposed to the DNA of billions of disintegrating bacteria within our intestines, and we do not assimilate their genes. Any small quota of martian DNA would be effectively diluted out by the DNA of intestinal bacteria, and would ultimately suffer the same fate of hydrolysis (fragmentation) by enzymes in the intestinal contents.

The final safeguard is the absence of known life on Mars, or even the absence of organic compounds in its surface, despite global distribution by dust storms, which should spread any life all over the surface. Norman Horowitz said, "*Viking* found no life on Mars, and, just as important, it found why there can be no life." (See page 10.) The strategy proposed by Klein and DeVincenzi for martian exploration includes "the identification and quantitation of organic compounds," and the "search for biomarkers [biological compounds] as evidence of extinct life," neither of which poses danger if samples are returned to Earth. The strategy also lists examination of the sample "for extant life" as of lower importance and "contingent upon the discovery of potentially suitable environmental niches for extant biology." But as Horowitz says, "For some, Mars will always be inhabited, no matter what the data say."

The further biological exploration of Mars should enhance public perception that Earth is the sole abode of life in the solar system, and that efforts to conserve our planet must be increased.

There is no justification for spending money on quarantining returned martian samples to protect Earth. The funds for space science research are quite small, and should not be spent on unnecessary efforts.

Thomas H. Jukes is professor of biophysics at the University of California, Berkeley. He served as chairman, Life Sciences as Related to Space, for COSPAR (the Committee on Space Research, International Council of Scientific Unions) from 1979 to 1984.

---

dioxide (CO_2) atmosphere. For instance, a class of organisms known as methanogens can derive their life energy from the reaction of hydrogen (H_2) and carbon dioxide to produce methane (CH_4) and water (H_2O).

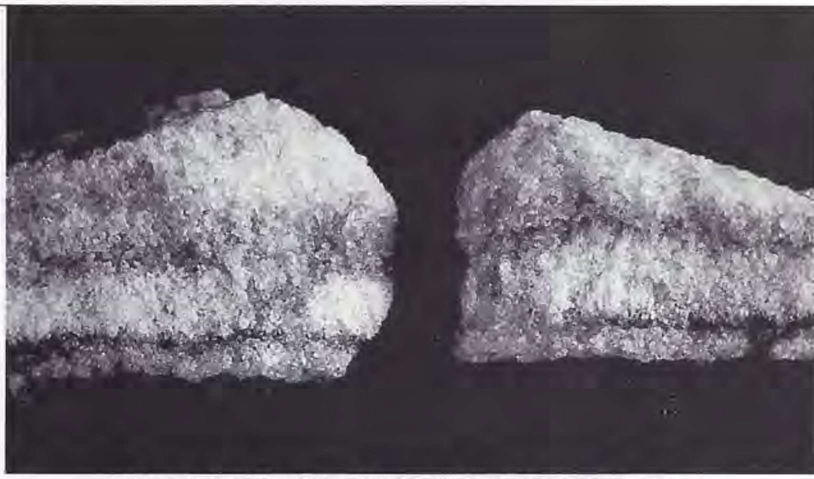
Given a liquid water environment containing a source of hydrogen, these organisms could form the base of a food chain—without light, without oxygen. The hydrogen would come from the volcanic activity below the surface. Thus, in addition to providing the heat to melt ice into liquid water, the geothermal source would also provide the basic chemical energy to support microbial life. Chemical schemes involving methane and hydrogen sulfide could work as well.

Life in (Imperfect) Isolation

We think life could exist underground on Mars. But if it does, what are the implications for planetary protection?

First, consider that such subsurface ecosystems must be isolated from the surface. If they were not, they would not be able to maintain the salubrious conditions suitable for life but so dissimilar to the surface conditions. But they are unlikely to be completely closed either. There will inevitably be some leakage of material and organisms to the surface through vents and along cracks.

The isolated nature of these systems probably makes them resistant to contamination from terrestrial organisms deposited on the surface, so forward contamination by surface landers may not be an issue. However, from the point of view of back contamination, the situation *is* serious. If organisms living in subsurface niches develop spores capable of surviving, albeit in a dormant state, when exposed to the surface, then even small amounts of leakage from a geothermal habitat could spread these spores over the surface. Such spores would have been virtually undetectable by *Viking,* since the level of organic material implied was too low to be detected, and the *Viking* biology experiments were not equipped to search for them. It may be that the life and times of Mars' underground will be a factor in future Mars missions.



In the McMurdo Dry Valleys of Antarctica, some of the most Mars-like places on Earth, life thrives in an unusual habitat: within rocks. Layers of lichen and bacteria grow beneath the rocks' protective surface, while pores in the rock trap water to sustain them. Hardy martian life-forms might have found refuge in similar habitats on Mars.

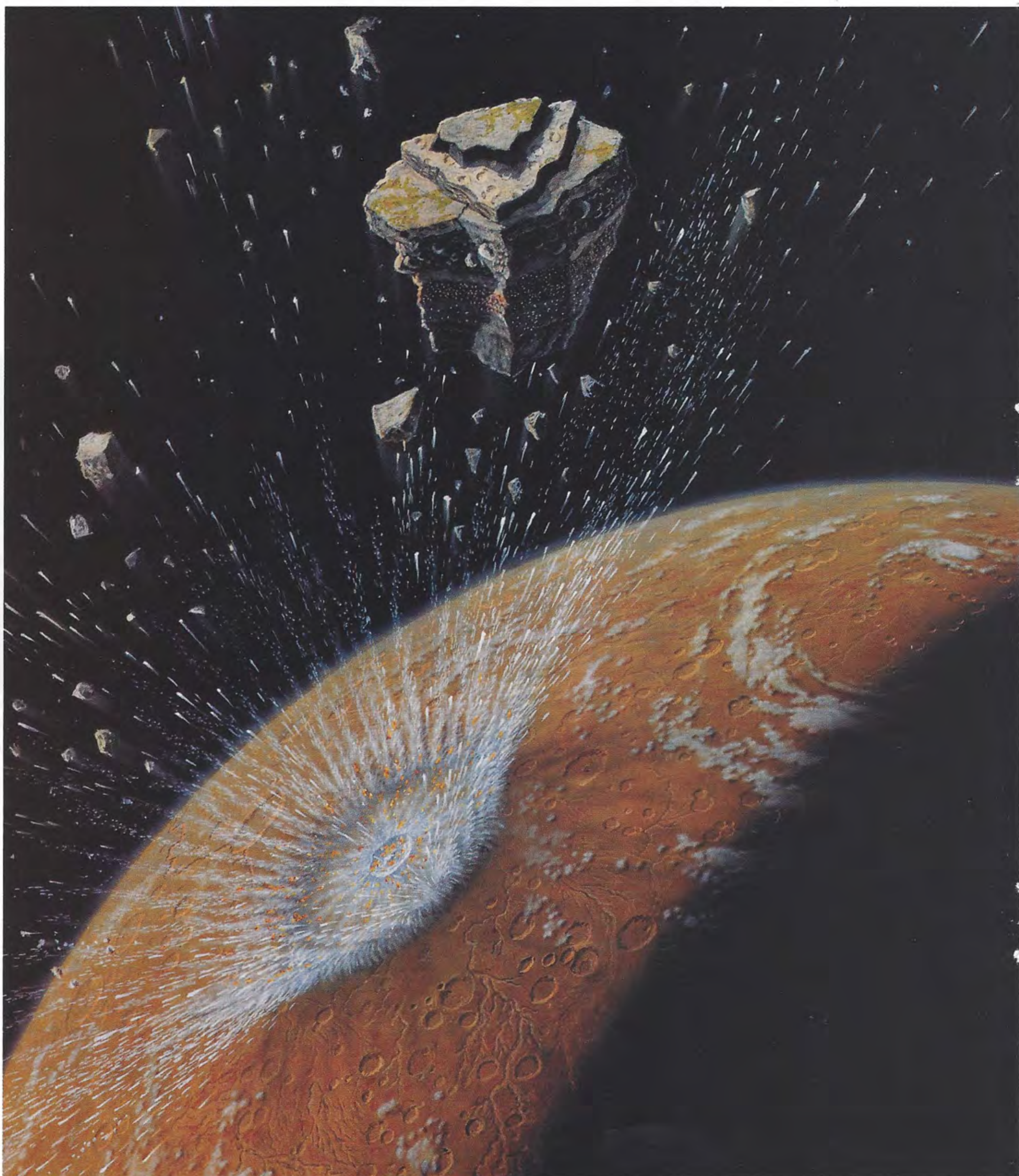
Photograph: E. Imre Friedmann

C.P. McKay is a planetary scientist with NASA's Ames Research Center. M. Ivanov is a microbiologist and director of the Institute for Microbiology of the Russian Academy of Sciences. P.J. Boston is a microbiologist with Complex Systems Research and a consultant to NASA.

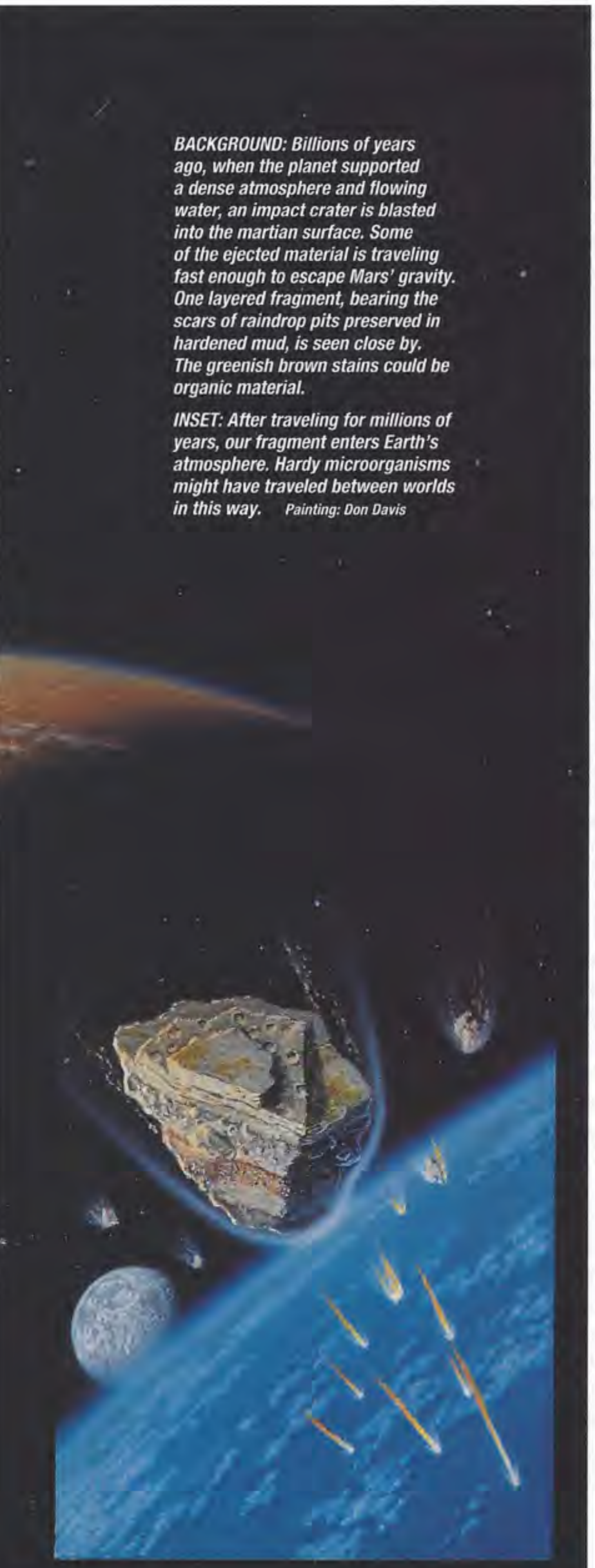
Swapping Rocks:

Exchange of Surface Material Among the Planets

by H. Jay Melosh



The returning *Apollo 11* astronauts' triumphal reception in July 1969 was somewhat delayed by a strict and lengthy biological quarantine. In those days, no one was certain that the Moon was entirely sterile. No one knew whether the lunar rocks might harbor deadly microorganisms. One wonders whether the level of concern would have been as high if scientists had known that dozens of lunar rocks had been lying in the Antarctic ice for thousands of years, or that about 10 small fragments of the Moon must fall onto Earth's surface every year. Unfortunately for the astronauts, the first lunar meteorite was not recognized until 1982. Before that time, no one seriously believed that nearly unaltered rocks could be blasted off the surface of one planet and later fall onto the surface of another.



BACKGROUND: Billions of years ago, when the planet supported a dense atmosphere and flowing water, an impact crater is blasted into the martian surface. Some of the ejected material is traveling fast enough to escape Mars' gravity. One layered fragment, bearing the scars of raindrop pits preserved in hardened mud, is seen close by. The greenish brown stains could be organic material.

INSET: After traveling for millions of years, our fragment enters Earth's atmosphere. Hardy microorganisms might have traveled between worlds in this way. Painting: Don Davis

Now, however, not only do we know that lunar rocks occasionally fall to Earth, but we are also reasonably certain that a group of nine meteorites, the so-called SNCs (for Shergotty, Nakhla and Chassigny, named after the sites where they landed), originated on the planet Mars. Although all of the lunar meteorites were collected long after they fell, four of the SNCs were observed dropping from the sky. In 1911, a piece of Nakhla, which fell near Alexandria, Egypt, killed a dog, scoring the only known fatality (of a mammal) caused by a meteorite.

The total flux of martian material falling onto Earth has been estimated at about half a ton per year. Under these circumstances, it may seem silly to worry about hypothetical martian organisms contaminating Earth, since martian material has evidently rained down on our planet throughout its history. Although a good case can be made for limiting modern biological contamination of Mars by terrestrial spacecraft, the discovery of Mars rocks on Earth brings up the immediate question of whether Earth rocks have been ejected into space, eventually to fall onto Mars, thus closing the circle of potential contamination.

Blasting Rocks off Planets

Only a few years ago, the question, "Can rocks be launched from the surface of a major planet or satellite by natural processes?" would have been answered with a resounding no by experts on both impact and volcanism, the only geological processes known to eject solid material at high velocities. The existence of the lunar and SNC meteorites has, however, forced these experts to rethink the mechanics of ejection. Although volcanic eruptions still seem incapable of achieving planetary escape velocity, the ejecta from large impacts are not so limited.

Older work on the maximum velocities achieved by impact ejecta focused on the relationship between the pressure in the shock wave generated by the impact and the velocity of material just behind the shock. Measured directly in laboratory experiments, the shock pressure needed to accelerate material to planetary escape velocities—2.4 kilometers per second (about 5,000 miles per hour) for the Moon, and 5.0 kilometers per second (about 11,000 miles per hour) for Mars, implying pressures of 0.44 and 1.5 megabars (a megabar equals 1 million times Earth's atmospheric pressure at sea level) for lunar and martian basalts, respectively—would have been high enough to melt or even vaporize the ejected rock. Yet study of the lunar meteorites indicates that their ejection was accompanied by no more than about 0.2 megabar of shock, and the most highly shocked martian meteorites (which contain pockets of once-melted glass) still indicate only about 0.4 megabar.

The problem with the pressure–velocity relationship is that it applies only to material completely engulfed by the shock wave. Very close to the target surface, however, the ambient pressure is zero. No matter how strong the impinging shock wave, the free surface can never be raised to a pressure higher than zero. This effectively shields surface rocks from strong compression. However, the pressure increases very rapidly with depth below the surface, which translates into a powerful acceleration that throws lightly shocked surface rocks out at speeds comparable to the original impactor's speed.

An experiment performed several years ago by Andy Gratz and colleagues at the Lawrence Livermore Laboratory has verified the general correctness of this model. An aluminum projectile about the size of a penny was fired at a granite block at about 4 kilometers per second (9,000 miles per hour). Material from the face of the block was ejected at about 1 kilometer per second (2,000 miles per hour). This material was caught in a foam cylinder and, upon analysis, proved to be composed of millimeter-size, lightly shocked fragments of granite.

Furthermore, blocks up to a meter in diameter from the uppermost limestone layer surrounding the 24-kilometer-diameter (15-mile) Ries impact crater in southern Germany have been found nearly 200 kilometers away in Switzerland. Although they were not actually ejected from Earth, these blocks again show a combination of low shock damage (less than 10 kilobars, 10,000 times Earth's atmospheric pressure at sea level) and high ejection velocity (1.4 kilometers per second or about 3,000 miles per hour). Thus, current theory, experiment and observation all agree in indicating that a small quantity of material near the surface surrounding the site of an impact is ejected at high speed while suffering little shock damage.

Impacts such as the one that created the 180-kilometer-diameter (110-mile) Chicxulub crater in Yucatán 65 million years ago (and incidentally caused a profound extinction that wiped out the dinosaurs, among others) may have launched millions of rock fragments 10 meters (30 feet) or more in diameter into interplanetary space. Of these fragments, a small fraction, perhaps 1 in 500, would have been so lightly shocked that internal temperatures remained below 100 degrees Celsius (212 degrees Fahrenheit). Higher temperatures would presumably kill any microorganisms present in the rock, but a few thousand of the ejected rocks, those originating nearest the free surface, could have carried viable organisms into interplanetary space. Although such impacts are fortunately rare at the present time (the only comparable craters known are the 1.85-billion-year-old Sudbury crater in Ontario and the 1.97-billion-year-old Vredefort crater in South Africa), the much higher cratering rate early in solar system history during the period of late heavy bombardment that lasted up to about 3.8 billion years ago would have made ejection of microorganisms a much more common occurrence at that time.

The most lightly shocked rocks ejected at high speed are necessarily those closest to the free surface. The surface is also the place where biological activity is highest, so that a large impact on Earth, or on an earlier life-harboring Mars, would be very likely to throw rocks that might contain microorganisms into interplanetary space. Larger organisms, even if present, would be unlikely to survive the 10,000 g accelerations accompanying the launch process.

Current cratering calculations indicate that large impacts even on Venus, despite its dense atmosphere, could eject surface rocks into interplanetary space. Meteorites from Venus have not yet been discovered, but there appears to be no reason why they might not someday be found on Earth. Large impacts on all of the terrestrial planets are thus capable of ejecting lightly shocked surface rocks into interplanetary space. If there should be microorganisms on the surfaces of these planets, then they too have a chance of journeying to another planet.

Between the Planets

Ejecta from even the largest, fastest impacts do not travel fast enough to make a direct trip from one planet to another. In general, the quantity of ejecta is largest at the lowest ejection velocities, so most planetary ejecta move relatively slowly with respect to the planet they escape (naturally, a much larger quantity of ejecta moves still more slowly and ends up falling back onto the planet of origin). The way that an ejecta fragment from, say, Mars eventually reaches Earth is by a series of encounters with Mars as it and the fragment orbit the Sun. Occasionally such a fragment comes too close to Mars and ends up falling back onto the planet after some time in space. However, it is much more likely to miss Mars and recede into interplanetary space, but not before Mars' gravity has deflected the fragment and changed its orbit.

After a long series of such encounters, a few fragments' orbits get "pumped up" sufficiently to cross Earth's orbit. Then the more massive Earth takes over this cosmic volleyball game, changing the orbit still more, until the fragment may become Venus crossing. Sometimes the fragment is deflected all the way out to Jupiter or Saturn, which themselves may eject it from the solar system entirely. At any stage of this random walk through the solar system, the fragment may actually hit one of the planets, ending its journey.

Natural orbital perturbations thus supply the means for rocks ejected from one planet to spread throughout the solar system and eventually fall onto another planet (or leave the solar system entirely). This is presumably how the SNC meteorites reached Earth. Any microorganism contained in these rocks would thus have an opportunity to colonize the new planet, if it was able to survive both the journey and the fall to its destination.

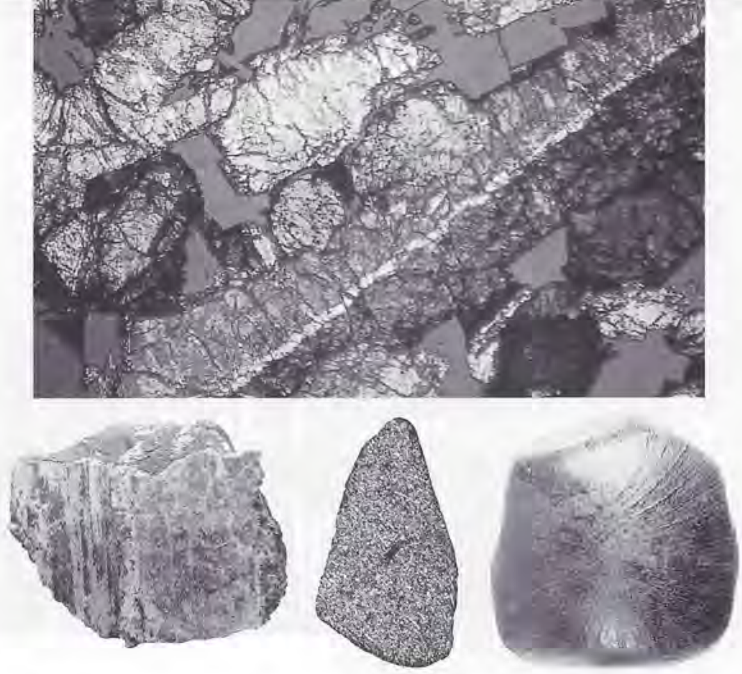
Surviving the Journey

Can microorganisms survive long exposure to the space environment? This question is of paramount importance for the transfer of viable microorganisms from one planet to another, since even dormant organisms might not be able to survive a long trip. Furthermore, cosmic rays, ultraviolet light or even radiation from the enclosing rocks might kill the organisms along the way.

Many microorganisms stand up surprisingly well to the space environment. Subjected to high vacuum, some bacteria quickly dehydrate and enter a state of suspended animation from which they are readily revived by contact with water and nutrients. Medical laboratories routinely use high vacuums for preservation of bacteria. Viable microorganisms were recovered from parts of the *Surveyor 3* camera system after three years exposure to the lunar environment. However, these instances of preservation have only been tested over times approaching decades, not over the tens to hundreds of millions of years necessary for interplanetary travel.

Nature, however, has been kind enough to give us several instances of really long-term preservation of viable microorganisms. Chris McKay of NASA Ames Research Center has extracted microorganisms preserved for perhaps as long as 3 million years from deep cores in the Siberian permafrost. Even more impressive is the discovery of bacteria that were preserved for some 255 million years in salt beds of Permian age discovered at a site in New Mexico. Dehydrated by contact with salt and protected from radiation by the salt's low content of radioactive elements, these ancient bacteria demonstrated their viability by causing the decay of fish that had been packed with the salt.

Living bacteria can tolerate extremely high radiation doses, far higher than any multicellular organism can withstand. They can resist the effects of radiation largely because of active DNA repair systems. It is less clear that a dormant bacterium could tolerate large amounts of radiation. However, if the microorganisms happened to be living in cracks or pores of rocks that were ejected as large blocks, the rock itself might provide adequate shielding against both cosmic rays and ultraviolet light. Since it requires about 3 meters (about 10 feet) of rock to shield against high-energy galactic cosmic rays, if the impact event were to throw out rock fragments of about 10 meters (30 feet) diameter or larger, a significant interior volume would be protected against this radiation. Ultraviolet light can be screened by only a few microns of silicate dust, so the interiors of large ejecta blocks might be excellent havens for spacefaring bacteria.



We think that rocks have traveled from Mars to Earth because we have examined examples in our laboratories with characteristics that link them to the Red Planet. The Shergotty meteorite, seen in a photomicrograph at top and at bottom center, fell in India in 1965. Researchers tried to identify its origin for years. The bottom piece shows the orientation of pyroxene grains, which suggest that this rock formed at the bottom of a magma chamber on another planet: Mars. At left is a martian meteorite, Allan Hills 84001, found in Antarctica several years ago but correctly classified only this year. It contains complex carbonates that may hold clues to Mars' climate history. At right is Lafayette, which shows the scars of ablation from its fall through Earth's atmosphere. *Photographs (clockwise from top): J. Berkley; Smithsonian Institution; Smithsonian Institution; Johnson Space Center*

Entering a New World

When a meteorite strikes the surface of an airless body like the Moon at high speed, it creates a shock wave in both the target rocks and in the meteorite that converts most of its initial kinetic energy into heat, melting or even vaporizing the original meteorite. Organisms inside such a meteorite would have little chance of surviving the impact. However, if the planet has an atmosphere, the meteorite might be slowed sufficiently that it strikes the ground at terminal velocity, perhaps only a few hundred meters per second, which microorganisms could easily survive.

The fate of a meteorite entering a planetary atmosphere depends largely upon its initial size and speed. Small meteorites, smaller than a few centimeters, burn up in Earth's atmosphere. Very large ones, a kilometer or more in diameter, traverse it without slowing and make craters. Meteorites of intermediate sizes, a few meters to tens of meters, however, are significantly slowed by the atmosphere. Buffeted by kilobars of aerodynamic pressure, they break up in the atmosphere (as did the famous Peekskill meteorite that disintegrated over the eastern United States on October 9, 1992) and may eventually fall to the ground in a shower of small fragments. Even on the modern Mars, with its tenuous atmosphere, meter-size meteorites are greatly slowed before striking the surface.

This scenario of slowing and breakup of intermediate-size meteorites is nearly ideal for the dispersion of microorganisms onto the new planet. Whether or not these organisms can survive and multiply depends, of course, on conditions at their new home. It seems unlikely that terrestrial organisms arriving on the modern Mars or Venus would survive. However, in the past conditions may have been much more hospitable on Mars at least, and perhaps at that time microorganisms from Earth found a home on Mars, or vice versa.

The current impact-exchange rates among the terrestrial planets are relatively low. However, during the era of heavy bombardment, when most of the visible craters on the Moon and Mars formed, cratering rates were thousands of times higher than current rates. Blue-green algae were apparently present on Earth as early as 3.5 billion years ago, and life may have been present even earlier, overlapping the period of heavy bombardment. Given the possibility of exchange of life among the planets by large impacts, we may have to regard the terrestrial planets not as biologically isolated, but rather as a single ecological system with components, like islands in the sea, that occasionally communicate with one another.

Although this scenario is highly speculative, it may be testable: If sample returns from former lake deposits on Mars should contain evidence of the existence of a microbiota, it may be possible to extract organic molecules from the samples. If familiar terrestrial molecules such as DNA, RNA and proteins are discovered, and especially if a genetic code similar to that of terrestrial organisms is found, then it would provide very strong verification of the idea that Earth and Mars have exchanged microorganisms in the past. Naturally, any such test requires that we be very careful not to contaminate the samples beforehand with terrestrial organic molecules.

H. Jay Melosh is a professor of planetary science at the Lunar and Planetary Laboratory at the University of Arizona. His latest book, Impact Cratering: A Geologic Process, *has been published by Oxford University Press.*

Anticipating the Reaction:

Public Concern About Sample Return Missions

by Margaret S. Race

Space scientists and engineers will plan missions to return samples from other worlds to Earth before they have answers to questions about the possibility of life on those worlds. We know Mars as well as, perhaps better than, any other extraterrestrial planet in our solar system, yet we cannot say for certain whether life ever existed there, or if it still does. Consequently, the spacefaring nations will continue to impose planetary protection controls on missions to avoid the risk of alien organisms contaminating Earth or terrestrial organisms invading other worlds.

Before official protection requirements are established for Mars sample return missions, we must consider a variety of social and political issues as these missions are planned. If ignored, these issues could become serious impediments.

When the *Apollo* astronauts returned to Earth with samples of the Moon, their mission planners faced a different, and in some ways more innocent, world. In the intervening years, public attitudes about technological hazards have shifted, causing public policies to change. Let's look at four particularly noteworthy shifts that have implications for sample return missions:

1. A dramatically different legal and regulatory environment. Laws and government institutions have changed to encourage public participation in the decision-making process. At the same time, imposing and complex new regulations about health, environment and safety have been instituted.

2. Institutionalized public vigilance. Today, public vigilance is maintained by well-funded, highly organized, nongovernmental watchdog groups. As we've seen with the challenges to launching *Galileo* and *Ulysses,* which carried plutonium power plants, opponents can scrutinize missions for perceived or actual environmental, health and safety risks. They can use a variety of legal avenues in attempts to stop a mission.

Mission planners will also have to consider the policies of international groups, such as the United Nations and the World Health Organization, which have addressed concerns about protecting Earth and minimizing risk to populations from space exploration activities.

3. Politicization of technological debates and shifts in the nature of public decision-making. Since *Apollo* times, there has been a gradual but significant shift in the nature of public decision-making, from unquestioning acceptance of closed-door, unilateral decisions by experts to the expectation of open communication among government agencies, experts and the public. If concerns about risk thrust technical discussions about planetary protection into the public realm, such discussions will be complicated by questions that are difficult or impossible to answer with scientific data.

4. A risk-averse public combined with mass media coverage focusing on hazards and disasters. The public is less willing to accept risk and more wary of technology, and expects experts to prove in advance that activities will pose no risk. Mass media coverage, which often focuses on potential accidents and disasters, powerfully shapes perceptions about risk. Sensationalized media coverage about planetary protection and sample return missions could intensify public anxiety.

While it's impossible to predict exactly how the public will respond to sample return proposals, it's advisable to anticipate complications. As people with demonstrated interest in planetary exploration, Planetary Society members will be among those who will weigh the benefits and the risks.

The Ice-Minus Experience

One way to anticipate problems is to scrutinize past controversies. A good case is the public debate over genetic engineering in the mid-1980s centering on a new organism created by recombinant DNA technology. Although it did not involve extraterrestrial organisms, this so-called ice-minus experiment illustrates the kinds of concerns and controversies possible for planetary sample return missions.

The ice-minus controversy involved the first intentional release of a genetically engineered organism into Earth's environment. A team of university researchers sought government permits for a small-scale field test of a mutant bacterium to determine the strain's effectiveness in preventing frost damage to agricultural plants. Opponents characterized the experiment as reckless because it used an organism not naturally found in the environment. They claimed it might cause drastic problems if released.

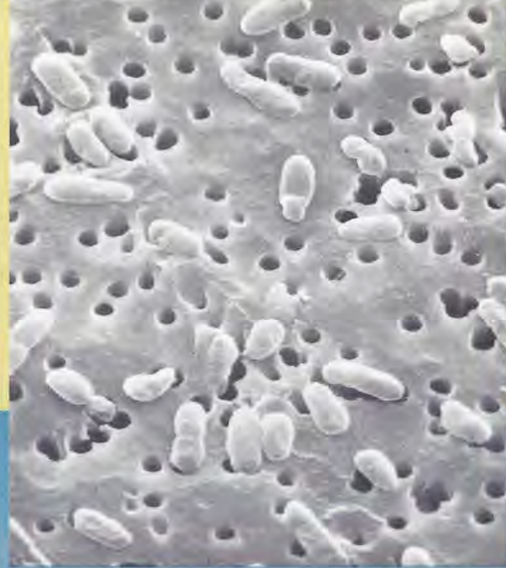
Through a succession of legal challenges and public policy maneuvers, opponents maintained a lengthy public debate over genetic engineering. By the time the experiment was done—without incident—nearly five years later, the controversy had involved federal, state and local government agencies; legislative bodies and the courts; public hearings and environmental impact documents; and intense media coverage.

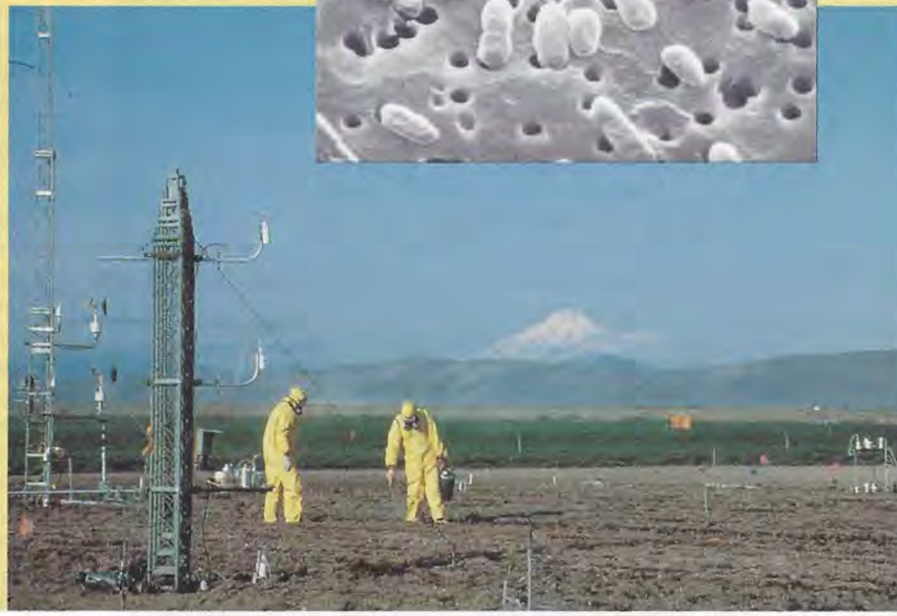
Let's examine some similarities to possible sample return scenarios, focusing on a Mars mission.

New Life-forms

Like the ice-minus experiment, a sample return mission could involve the deliberate handling and importation of new life-forms under experimental conditions.

The ice-minus experiment was spurred by basic scientific





ABOVE: NASA and other space agencies around the world are considering Mars sample return missions. The agencies know how to handle engineering designs and scientific experiments, but the possible public reaction to bringing pieces of another world back to Earth may be more difficult to address. This is a mock-up of a recent design. Illustration: NASA

TOP RIGHT: The ice-minus bacteria are seen in a scanning electron micrograph. Photograph: Kit Galvin, courtesy of Steven Lindow

RIGHT: The bacteria were first released outdoors at Tulelake, California, in May 1987. Scientists were required to wear protective garb, and the US Environmental Protection Agency set up meteorological equipment in towers to monitor the bacteria's dispersal. No adverse effects were detected. Photograph: Gary Anderson, courtesy of Steven Lindow

questions, with only indirect benefits to society in the form of frost protection for crops. A sample return mission will be based on scientific questions about the nature of the planets and life in the universe, with no predictable societal benefits except the generation of new knowledge.

Experts were divided in their opinions of the risks of the ice-minus organism, but the majority judged the experiment to be of low risk. Despite extensive testing under quarantine before the actual experiment, opponents remained unconvinced and continued to challenge it. Today, most scientists expect that martian soil samples are unlikely to contain life, although they continue to debate whether life exists on Mars or would pose a risk to terrestrial organisms. Even if Mars samples were handled under stringent quarantine, the public might still view the possibility of escape, however low, as a threat to the terrestrial biosphere.

Finally, the ice-minus experiment was constrained by a seasonal window. Mars sample return missions are limited by launch windows a few weeks long that occur only every two years. Legal challenges, public controversy or indecision could translate into delays and added costs. As with ice minus, scientists' practical concerns about reaching a decision to proceed could be misinterpreted as forcing a questionable decision on an unwilling public.

The Perception of Risk

The public may raise many concerns that are difficult or impossible to address factually. Proposals to import martian soil samples could face claims of dreaded or even catastrophic consequences, such as uncontrollability, irreversibility and global effects for present and future generations. As with ice minus, the public may question both the value of the benefits and a perceived inequitable distribution of risks and benefits. Space scientists and engineers could be seen as reaping the benefits, but the general or local population could incur the risks if an accident occurred.

Because of the complexity of the debate, it is questionable how well the mass media will convey information. Their coverage is likely to range from accurate information to mild analogy to sensationalism bordering on science fiction.

Who'll Call the Shots?

The initial legal challenges to ice minus came, in part, from assertions that guidelines for handling genetically engineered organisms were imposed by a federal organization that did not have the authority to either write or enforce regulations under existing laws. From the earliest days, planetary protection controls have been based on nonstatutory guidelines from COSPAR (the Committee on Space Research of the International Council of Scientific Unions), a nongovernmental organization concerned with cooperative international space research. The ice-minus experiment remained in the public spotlight for years until areas of legal uncertainty were resolved through legislative and public hearings, agency deliberations and the courts. For Mars sample returns, lawyers have already pointed out that legal obstacles could arise from uncertainty about control and authority, international treaty obligations, constitutional concerns about quarantine and environmental impacts.

During the *Apollo* program, a specially established Interagency Committee on Back Contamination (ICBC) handled the decisions about back-contamination controls, quarantine protocols and facilities. Similarly, the federal Interagency Biotechnology Science Coordinating Committee was established to resolve complex genetic engineering questions. It may be necessary to set up an interagency body to handle questions about planetary protection, especially in the face of today's more complex environmental, health and safety laws.

Typical Mission Profile for a Robotic Mars Sample Return

For Russia, the United States and the other spacefaring nations planning to explore Mars, a sample return mission is high on their agendas for early in the next century. These are the major features of a possible mission. This mission profile reflects current engineering designs and incorporates a set of constraints addressing planetary protection concerns.

- Two spacecraft, a Mars lander (subjected to *Viking*-like sterilizing treatment) and orbiter, are launched by a single rocket.
- The spacecraft fly to Mars (approximately nine months).
- Lander is targeted to predetermined site.
- Rover collects samples of rocks, soil and crust.
- Pure atmospheric samples are taken.
- All samples are stored in canisters under near-Mars conditions.
- Mars ascent vehicle with canisters launches into Mars orbit.
- Vehicle and orbiter rendezvous.
- Sample canisters are transferred to sterile vault on orbiter without contaminating the sample return capsule.
- Vault is sealed to provide biological containment.
- Orbiter fires engines to return to Earth.
- Sample return capsule separates and directly reenters the atmosphere.
- Capsule is retrieved by helicopter air snatch.
- Sample vault is opened under sterile conditions in a high-containment facility.
- Samples are tested for living organisms, biological hazards, and toxicity with a quarantine protocol.
- Samples are released for multidisciplinary analyses.

Recognizing the Right to Know

For a high-profile mission like a Mars sample return, the international space agencies will need to do everything in their power if they are to avoid criticism and ensure success. They must treat societal concerns about such missions seriously from the start.

In NASA, for example, there is a tendency to concentrate on hardware, technology and mission architecture, with nontechnical topics seen as undesired add-ons that complicate the mission and increase costs. For sample return missions, relegating social, environmental and nonscientific issues to a later stage of planning may ultimately prove more costly, both economically and otherwise.

With any sample return mission, the space agencies will face unavoidable legal requirements. For example, the international Outer Space Treaty requires that appropriate measures be taken to ensure that space activities are conducted to avoid harmful contamination of celestial bodies or adverse changes in Earth's environment.

In the United States, NASA has interpreted the National Environmental Policy Act as requiring "consideration of the possible environmental effects of any NASA actions at the earliest stages of study and planning" in order for recommendations and decisions to be made with full knowledge and understanding of the likely environmental effects. NASA will also have to respond to government regulatory agencies with authority over quarantine, environmental or safety areas.

Considering the quarantine problems during the *Apollo* missions and the recent failures of *Challenger*, the Hubble Space Telescope and *Mars Observer*, the regulatory agencies and the public may accept nothing short of comprehensive analysis and full disclosure as required by law. It is almost certain that NASA will face public challenges about sample return risks long before launch time.

For sample returns from space, the public concerns will undoubtedly be centered on back contamination. These same concerns are likely to generate the most media attention. Just as with the ice-minus experiment, scientists' explanations of technological design and their reassurances of exceedingly low risk will not deter people from challenging the mission.

Ultimately, it is for citizens to determine the types and degrees of risk they will accept. Thomas Jefferson wrote, "I know of no safe depository of the ultimate powers of the society but the people themselves, and if we think them not enlightened to exercise their control with a wholesome discretion, the remedy is not to take it from them, but to inform their discretion."

That is precisely what the space agencies of Earth must do during every phase of mission planning and sample return from other worlds.

Margaret S. Race is an environmental policy analyst and assistant dean in the College of Natural Resources at the University of California, Berkeley.

Where No One Has Gone Before . . . *(continued from page 5)*

of Earth by organisms from elsewhere, are addressed by the policy. In the case of forward contamination, the problem is not just that organisms will be *transported* to other places in the solar system (that is unavoidable, given the prevalence and tenacity of life on Earth). The constraints are intended to prevent the *growth* and *spread* of Earth organisms on other solar system bodies.

Likewise, we don't really worry that putative extraterrestrial organisms will turn out to be human pathogens, causing disease. It is very hard to survive in the rest of the solar system as a human pathogen. A greater concern would be potential, unanticipated environmental effects of a new form of life on Earth. In the long run, the greatest concern for back contamination control may be protecting the public from confusing other biological phenomena (for example, unexplained diseases) with some imagined biological insult from space.

For any given mission, constraints are based on our knowledge about the target body at the time that a mission matures into the final stage of planning and preparation. In the COSPAR policy, individual missions are placed in different categories depending on the type of mission and the nature of the mission's target. Requirements vary from Category I, for missions to bodies of no biological interest (for example, the Sun), to Category IV, where a spacecraft will land on a planet of potential biological interest. Category V is reserved for missions that visit another solar system body (other than the Moon) and return to Earth.

The *Galileo* mission, for example, was classified by NASA as Category II, reflecting a low level of concern for the contamination of Jupiter. Nonetheless, Jupiter and its system of moons are of considerable interest in relation to studies of organic material in the solar system, and the Category II classification mission ensured that documentation about the spacecraft's eventual location will be available to future investigators. An additional provision will protect Jupiter's moons from inadvertent contamination.

Despite the conditions discovered by *Viking,* Mars remains one of the most clement solar system bodies. Although the probability of growth for Earth organisms on Mars was thought to be extremely small after the *Viking* missions, the *Mars Observer* mission was assigned a Category III classification to reflect a concern for biological contamination by an orbiting spacecraft that would eventually crash into the planet.

The mission's planetary protection plan required cleanroom assembly of flight hardware, limited the amount of time the spacecraft could orbit in the lower atmosphere of Mars and required the spacecraft's eventual placement in a high and stable orbit to prevent it from hitting Mars prior to 2038. These requirements had a cost associated with them (extra fuel for the spacecraft to achieve the final orbit, the extra mission analyses required and so on), but the failure of the mission highlighted a need to take a conservative approach in protecting Mars from the unintended consequences of a mission.

Future Applications

The planetary protection policy described does not dictate static requirements but is designed to accommodate our changing understanding of the solar system, and the potential for life on other solar system bodies. With it, spacefaring nations can deal with a broad array of future missions.

As for developing methods to implement planetary protection requirements, clever engineering can compensate to some degree for scientific ignorance. For example, by having a disposable surface coating on a returning sample canister, the chain of contact between the surface of Mars and an Earth-return spacecraft could be broken,

Sinuous channels cut by running water cross the martian surface in many places. This feature, Parana Vallis, may contain ancient lake deposits that would be good targets for sample return missions. *Image: JPL/NASA*

and issues associated with reversing the contamination of the return sample canister could be ignored.

In like measure, as we learn more about conditions on other solar system bodies and the ability of Earth life to deal with those conditions, we can modify the implementation requirements to reflect that new knowledge. The Space Studies Board has, in fact, recommended a less intensive set of requirements for Mars lander missions. In particular, future landers that do not carry life-detection experiments will not need to be sterilized throughout because we no longer think Earth life could grow anywhere on the martian surface. These new requirements for Mars will be presented to COSPAR for consideration at the upcoming 1994 meeting in Hamburg, Germany.

John D. Rummel is the director of research administration and educational programs at the Marine Biological Laboratory in Woods Hole, Massachusetts, and previously was the deputy chief of the Mission From Planet Earth Study Office at NASA headquarters. Michael A. Meyer is the exobiology discipline scientist and the planetary protection officer in the Solar System Exploration Division at NASA headquarters in Washington, DC.

Readers' Service

Our Readers' Service is an easy way for Society members to obtain newly published books about the science and adventure of voyages to other worlds.

We make these books available at the lowest possible prices. Each title is offered for six months, or three issues of *The Planetary Report*. We keep rotating our stock so that the titles we offer are always fresh.

Moon Shot: The Inside Story of America's Race to the Moon

By Alan Shepard and Deke Slayton; Turner Publishing, Atlanta, 1994, 383 pages.
Retail price: $21.95
Member price: $19.00

Out of the braggadocio of Cold War confrontations in the 1950s and 1960s, the Soviets and Americans fell into a splendid displacement activity. Rather than risk the lives of their respective populations, they entered into a race to the Moon. The gigantic efforts in both countries engaged thousands of anonymous engineers and technicians. But at the tips of the pyramids a handful of men—astronauts and cosmonauts—became instant celebrities.

Their stories have already been told and dramatized, but *Moon Shot* recalls what it was like from the points of view of two of the original American team—Alan Shepard and Deke Slayton. With the help of journalists Jay Barbree and Howard Benedict, they describe a remarkable friendship. *Moon Shot* is also an elegy for Slayton, who died of brain cancer in the summer of 1993.

The *Apollo* story conjures up a vanished America of white family men with patriotic, self-effacing wives who seemed as focused as their husbands on winning for America. The authors of *Moon Shot* are not interested in scientific or engineering feats but dwell, instead, on the astronauts' personal strengths, including the courage to overcome disappointments.

Shepard and Slayton describe the overwhelming euphoria of weightlessness, the surprise of hearing the first "concert of the spacecraft," a strange and unexpected mechanical orchestra of whirling gyroscopes, humming cameras and crackling radios that broke into the soundlessness of space.

They recall John Glenn's awe when he first saw "tiny light motes from some fable of fairyland," come right up to his window as his spacecraft emerged from night into day, "a mass of thousands of very small particles that are brilliantly lit up like they're luminescent . . . the size of a firefly on a real dark night." (The motes were probably bits of water ice and paint flecks.)

Space travel drew Shepard and Slayton as surely as the sea called to Ulysses. But they were not their own masters and both were felled, Shepard after his first flight, Slayton before he had even one turn, by medical setbacks. (Shepard developed Ménière's syndrome, damage to the inner ear; Slayton's heart began beating irregularly.) Grounded and longing to fly, they stayed on the team.

Moon Shot is at once about friendships among astronauts and the ties that connected the Americans with their Russian competitors. Both nations, the authors point out, when under pressure to win took foolhardy shortcuts that resulted, in 1967, in the *Apollo 1* inferno and, 86 days later, the destruction of *Soyuz 1*. The two disasters left four spacefarers dead—three Americans and one Russian. There was a pause to reconfigure the teams—and the race continued. The story takes us past *Apollo*, with its triumphant display of American know-how and a cursory look at the Moon, to a sudden change in diplomatic temperature, Soviet–American cooperation, and a meeting in space. After keeping the faith, both Shepard and Slayton finally got clean bills of health in time for another chance to ride the rockets—Shepard on *Apollo 14* and Slayton on the *Apollo/Soyuz* test project.

Written in multiple voices, *Moon Shot* is at once a double autobiography and group recollections from men who were exactly what their country needed in a very special time and place.
—Reviewed by Bettyann Kevles

Still Available: *Universe Down to Earth*

By Neil de Grasse Tyson.
This collection of lively essays explores ideas of science rarely examined in the popular literature.
(Reviewed March/April 1994.)
Retail price: $29.95
Member price: $25.00

Stardust to Planets: A Geological Tour of the Solar System

By Harry Y. McSween, Jr.
Take a quirky cruise by the planets with an idiosyncratic geologist who's willing to share the excitement he feels for our neighboring worlds.
(Reviewed May/June 1994.)
Retail price: $22.95
Member price: $20.00

To Place Your Order:

Please send a check or money order, made out to The Planetary Society, for the price of the book (in US dollars) plus, for each book, a shipping and handling charge of $2.50 for the US, Canada and Mexico, $5.00 for other countries. Address your envelope to Readers' Service, 65 North Catalina Avenue, Pasadena, CA 91106-2301.

For faster service, order by telephone with your Visa, MasterCard or American Express card. Call (818) 793-1675 from 9:00 a.m. to 5:00 p.m. Pacific time.

All books sent postpaid. Please allow 4 to 6 weeks for delivery in the US, Canada and Mexico, 12 weeks for delivery to other countries.

World

Watch

by Louis D. Friedman

Washington, DC—Will the United States undertake a Mars exploration program? By the time you read this, that question may be answered. The US Congress is considering the proposed Mars Surveyor program—a series of missions to explore Mars from orbit and on its surface. These are its guidelines:

- Cost not to exceed $150 million per year, including the launch vehicle.
- Two launches at every Mars opportunity, every 26 months.
- Lighter, smaller spacecraft, both to drive technology and to increase the number of spacecraft possible within cost and mass constraints.
- Use of a new launch vehicle, called Med-Lite, for lower cost, lighter weight launches.
- Continuous orbiter presence at Mars, providing communications for landers and carrying remote sensing instruments. The first two orbiters, called Global Surveyors, would be launched in 1996 and 1998. They would carry out the science objectives of the lost *Mars Observer*.
- Landers will be launched at every Mars opportunity. Using miniaturization technology, they will be even smaller than *Pathfinder*, already approved for a 1996 launch.
- International cooperation would be introduced whenever possible.

We asked Society members in the US to contact Congress in support of the program. As we go to press, Mars Surveyor appears to be receiving favorable consideration.

Moscow—The other shoe has dropped: *Mars '94* has now slipped to 1996. Some of the key spacecraft components and instruments were not totally ready for launch this year, prompting the postponement.

The European space agencies and NASA support the new schedule. Project personnel from Russia and other countries (principally France and Germany) are now reevaluating hardware and software delivery and their test schedules. NASA's Jet Propulsion Laboratory (JPL) has a Mars oxidant experiment set to fly on the lander. The Planetary Society also has an experiment—the *Visions of Mars* CD-ROM. Its label carries a microdot bearing our members' names and a microelectronics and photovoltaics experiment provided by JPL. (See the November/December 1993 *Planetary Report*.)

The Netherlands—The International Mars Exploration Working Group (IMEWG) has recommended an internationally coordinated strategy for Mars exploration over the next decade. The group, set up by the world's major space agencies, considered national agency plans, bilateral arrangements and political support for Mars missions in reaching the new strategy.

The strategy involves launching an extraordinary number of spacecraft—21—to Mars from 1996 to 2003. American, Russian, European and Japanese launch vehicles would be used to carry spacecraft built with the cooperation of several nations.

Meanwhile, new US–Russian cooperation is possible as a result of recent NASA–Russian Space Agency (RKA) talks and the start-up of joint studies. They are specifically studying a joint 1998 mission. If the Mars Surveyor program is approved, the US participation would be enabled. In the suggested mission, the Russians could launch the orbiter. This would help the Surveyor program meet cost constraints and build more robust landers for surface exploration.

As part of a long-standing relationship with Russia, the French are building the Mars Balloon with its Planetary Society–designed Snake guide-rope, which was to fly on *Mars '96*. A recent Russian–French bilateral agreement supports the move of the mission, which involves an orbiter, a rover and a balloon, from 1996 to 1998.

Pasadena—A Planetary Society workshop, "Exploring Mars Into the 21st Century," produced a strong case for international cooperation in the nascent Mars Surveyor program. A crucial recommendation was to use the highly capable Russian *Proton* launch vehicle in the Surveyor launch strategy. The workshop also recommended that work begin on US–Russian cooperation in a unified 1998 plan.

The workshop was attended by representatives from the US, European, Russian and Japanese programs. This international character strengthened the final report's influence among the space agencies. Its recommendations very closely resemble those that emerged later from the NASA–RKA talks and those of IMEWG.

As an additional note, the NASA–RKA talks also have resulted in the study of a new joint Pluto mission, as an earlier Society study recommended. The Society is playing an effective role in encouraging planetary exploration missions.

Louis D. Friedman is Executive Director of The Planetary Society.

News and Reviews

by Clark R. Chapman

Before the invention and widespread use of photography, explorers conveyed their visual impressions of distant lands with ink and paint. Although John Wesley Powell carried cameras during his explorations of the Colorado River more than a century ago, his reports to the public (*Canyons of the Colorado*) were more lavishly illustrated by the artist's hand than by the camera's lens.

Now the camera goes everywhere—everywhere we can go, that is. One realm cameras had not gotten to by the 1940s was outer space. The cosmos was then, and remains today, the modern arena of exploration, and space artists have shown us the way. The findings of scientists about worlds out there, and the spaceship designs of engineers who were to get us there, might well have remained obscure and forgotten were it not for the visual translations of artists like Chesley Bonestell.

The Dean of Space Artists

I recall as a boy being thrilled by *Life* magazine's "The World We Live In," and by the series of lavishly illustrated articles about space travel in *Collier's*. It was Bonestell's vision of craggy peaks on the Moon, of sleek interplanetary spaceships and of distant places like the double-star system Beta Lyrae that shaped much of my own conception of the cosmos. It was thus wonderful to see many of Bonestell's pictures again in the May 1994 issue of *Scientific American*.

Ron Miller, a space artist himself, presents a "Science in Pictures" essay about Bonestell's life, illustrated with 17 of Bonestell's portrayals of the planets, painted from the late 1940s through the early 1960s. Bonestell, certainly the preeminent space artist of his time (he died in 1986 at the age of 98), was best known for his glossy magazine works and for his books (such as *Conquest of Space*, with author Willy Ley). But his work also shaped the planetary vistas of planetariums around the world and the scenes in such science fiction films as *Destination Moon*.

Shortly before his death, The Planetary Society honored Bonestell by naming asteroid 3129 after him, through the cooperation of the asteroid's discoverer, Eleanor Helin. The back-cover artist's space of the May/June 1986 *Planetary Report* presents a 1976 Bonestell painting of an international mining operation on a near-Earth asteroid. His paintings have graced many other pages of this magazine.

Bonestell's long life was not lived wholly in the firmament. He contributed artistically to such landmarks as the 17-Mile Drive in Pebble Beach, the Golden Gate Bridge and the film classic *Citizen Kane*.

Where Cameras Have Not Been

Spacecraft now carry cameras to distant planets but the cosmos will always remain fertile ground for the artist's imagination. Whether extraterrestrial images are rendered in traditional paints or through the high-tech media of the future (á la Industrial Light and Magic), the popular imagination will need the translation from the limited information we actually have to the possibilities of unworldly vistas that may await us. Recently, space artists have helped scientists and the wider public alike to visualize comet Shoemaker-Levy 9's crash into Jupiter's back side, as epitomized by Don Dixon's Jupiter Watch poster (available from The Planetary Society). We await *Galileo*'s CCD (charge-coupled device) images of the impacts to see how we did in our predictions, just as Bonestell learned from the early lunar spacecraft that the Moon's mountains were not the craggy spires he had depicted.

For life here on Earth, we no longer require the artist to show us the rudimentary, objective outlines of reality. The camera can do that. The artist embellishes on the basics, interprets the world for us, connects us with multiple layers of reality. Where no camera has ever been—out in interplanetary and intergalactic space—it remains for the artist to perform the basics of the camera and add whatever embellishment or fantasies may be required by his or her imagination.

Many scientific measurements, models and theories remain incomplete until they are visualized. A few researchers, like my colleague William K. Hartmann, are artists themselves and use their art to crystallize their own interpretations of nature. Many more scientists require scientific illustrators or artists to translate their concepts into visual forms that their colleagues, the wider scientific world and the lay public can relate to.

The space sciences are unique, however, in the degree to which space art must play a major role between the limited data we have about faraway worlds and our ability to conceptualize those worlds and understand them. That was the niche that Chesley Bonestell carved out for himself half a century ago, and it is a pleasure to witness an ever growing, international community of space artists following in his footsteps.

Clark R. Chapman drew many pictures of the planets as seen through his telescope, but his first painting of planet Earth (a desert scene near Las Cruces, New Mexico) was to be his last.

Society News

Rover Update: Beagle Set to Prowl on Mars

On March 22, 1994, The Planetary Society announced that James Byrne had won the Name the Rover Contest. Byrne, a 12-year-old student from Vancouver, British Columbia, suggested the winning name for the Russian Mars rover prototype: Beagle.

Society judges selected Beagle (named after Charles Darwin's ship) and nine other finalists out of more than 400 entries from all over the world. The names were then submitted to Russian officials, who made the final decision. The other finalists and their authors are:

- Audax (*bold* in Latin)—Emily Darlington, Browns Mills, New Jersey
- Darganfod (*discovery* in Welsh)—Rosie Afzal, Mid-Glamorgan, South Wales
- Diomed (a Greek hero)—Olga Gnatuchenko, Desnogorsk, Russia
- Divni (*prodigy* in Russian)—Ivan Shevchenko, Dmitrievskoe, Russia
- Gerakl (a Greek hero)—Alecha Smirnikh, Armeiskaya, Russia
- Mechta (*dream* in Russian)—Polina Sharova, St. Petersburg, Russia
- Putnik (*voyager* in Russian)—Alecha Smirnikh, Armeiskaya, Russia
- SEEKER (acronym for Surface Explorer, Excavator, Knowledge Extractor and Reporter)—Simone Colgan, Scottsdale, Arizona
- Silamir (*force* and *peace* in Russian)—Marina Biblya, Dmitrievskoe, Russia

We congratulate these individuals and all the students who entered the contest and are looking forward to being tomorrow's explorers.

—Louis D. Friedman, Executive Director

Looking at the Future of Interstellar Flight

On August 30, noted authors and scientists will gather at the United Nations' Dag Hammarskjöld Hall in New York City to debate the future of robotic spaceflight. Open to the public, this special panel discussion is part of a Planetary Society–sponsored conference called "Practical Interstellar Robotic Flight: Are We Ready?"

At this event science fiction authors Robert Forward, David Brin and others are scheduled to speak about interstellar flight. Jet Propulsion Laboratory scientists Michael Klein and Richard Terrile will discuss the search for extrasolar planets.

For more information, contact me at Society headquarters, 65 North Catalina Avenue, Pasadena, CA 91106-2301.

—Susan Lendroth, Manager of Events and Communications

Members' Dialogue

Focus on Success

It was both interesting and annoying to read Nicholas Wade's essay in *The Planetary Report* (March/April 1994). Apart from a passing reference to *Galileo*'s images of the asteroid Ida, Wade mentioned only NASA's recent problems—the loss of *Mars Observer*, the Hubble Space Telescope's fuzzy images and *Galileo*'s malfunctioning high-gain antenna.

He might, instead, have highlighted NASA's recent success stories, such as the completion of *Magellan*'s radar mapping of the surface of Venus and the first successful attempt at aerobraking a spacecraft (also *Magellan*).

All too often, people find it easier to emphasize the failures over the successes of both individuals and organizations. The argument seems to be that one must be either successful all of the time, or not at all. However, I hope that NASA will seriously consider the observation that sending spacecraft in pairs significantly increases the chances of success for planetary missions.

—THOMAS G. FEWER,
Waterford, Ireland

Don't Dilute

I am concerned about the implications of Louis D. Friedman's letter in the March/April 1994 Members' Dialogue. Given the mood of Congress and the general populace regarding budgets and space missions, the Society has a formidable task before it in promoting planetary exploration. To become involved in "the spectrum of social issues" would dangerously dilute our resources and efforts.

As complete human beings, we need to be concerned about all issues that affect our society and our planet. But should these issues "be in the mainstream of Society activity"? I say emphatically not! Let's keep our goals in sight and not allow ourselves to be distracted.

—JOSEPH S. POTTS,
Irwin, Pennsylvania

Any attempt to transform The Planetary Society into a "liberal activist" organization will dilute our message and lead to an immediate loss of membership—starting with mine. The Society's mission is neither liberal nor conservative in nature. Most of the people I know who are interested in space tend toward the conservative side politically. Dumping them would not serve our purpose.

I belong to a number of special interest organizations including the National Rifle Association, Planned Parenthood and the Nature Conservancy. This includes groups that have been strongly identified as "conservative," "liberal" and "moderate." I find no inconsistency in this as each group espouses a particular point of view with which I agree.

I do not want to lose those members who may be anti-gun or pro-life just because I disagree with their positions on those unrelated issues. If they are pro-space, then I welcome their support on that issue.

—RICHARD D. THURSTON,
Spanaway, Washington

Questions and Answers

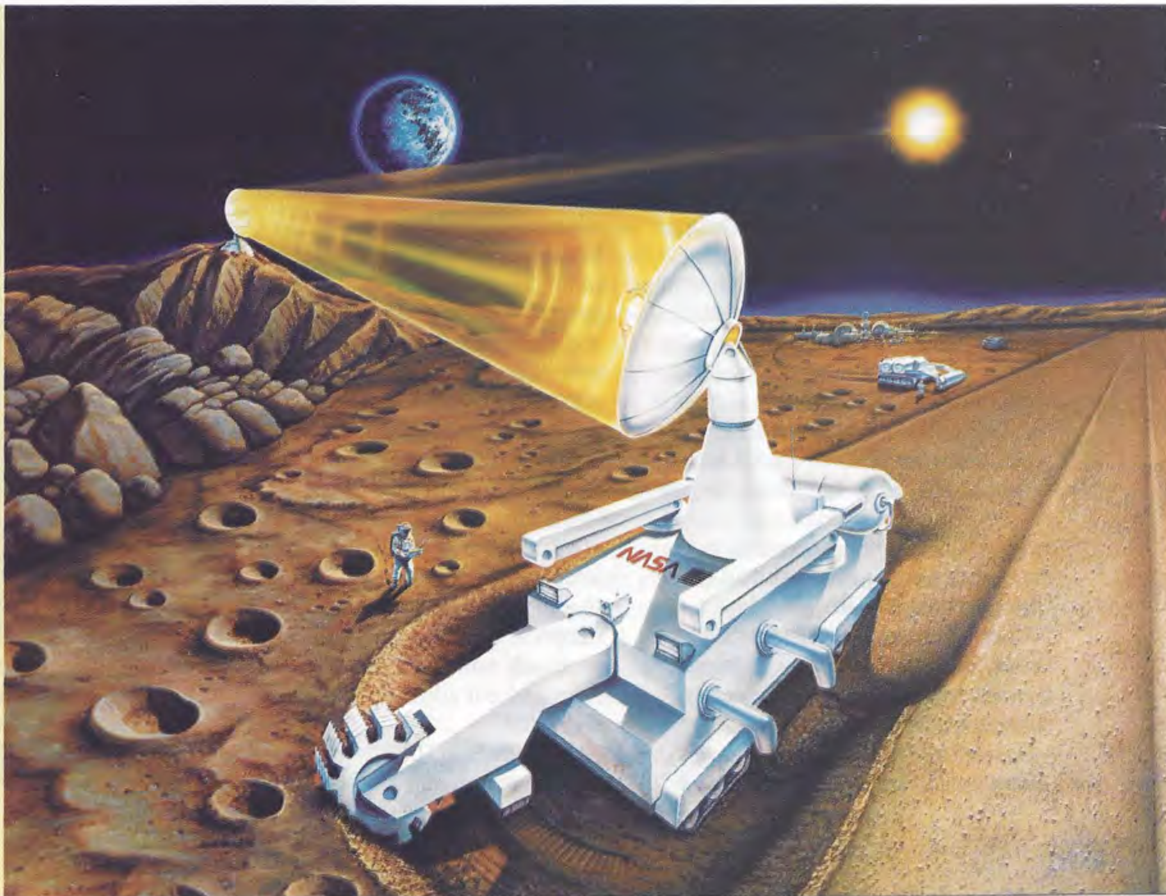
I recently learned that the far-thinking and oil-poor Japanese are already designing equipment to mine helium 3 on the surface of the Moon, working hard to solve the design problems of toroidal fusion reactors and discussing a Moon transport shuttle with Russia.

The basis for all of this is a claim that a single shuttle load of helium 3, when fused with deuterium, will yield sufficient energy to replace Japan's oil consumption for a year. Is this correct? Are the United States and any other nation working on this or similar energy sources?
—Ian G. Child, Winter Park, Florida

The possibility of using helium 3 to make electricity in fusion reactors has been known to scientists in the US and elsewhere for more than 20 years. Work in this area has recently increased as it has become evident that fusion devices operating on the helium-3 fuel cycle would be cleaner, safer and in many cases more economical than those using the more common deuterium–tritium (DT) fusion cycle. We also found that the plasma temperatures in a helium-3 reactor would have to be about four times higher than we have already achieved in the laboratory. Since we have managed to experimentally increase the plasma temperature by a factor of about 1,000 in the past 30 years, we feel that another factor of 4 is achievable in the next 10 years.

The main problem with the use of helium 3 to generate large amounts of electrical power is that the easily accessible resources of this isotope on Earth are small (less than 1 metric ton). It should be noted that 1 metric ton of helium 3 fused with deuterium will produce about 10,000 megawatt-years (equal to 10,000 megawatts for one year) of electrical energy and the United States' use of electricity in 1993 was about 330,000 megawatt-years. To produce all of the electricity in the US in 1993 would have required about 33 metric tons of helium 3.

Fortunately, samples of lunar regolith from the US *Apollo* and the Soviet *Luna* missions revealed that there were considerable amounts of helium 3 deposited on the surface of the Moon by the solar wind. In 1986 we discovered that about 1,000,000 metric tons of helium 3 still reside on the lunar surface and that this could (even accounting for inefficiencies in recovery rates) provide for the present electricity needs of the world for thousands of years to come.



The Mark II Lunar Volatiles Miner, designed by students at the University of Wisconsin, would use the Sun's energy to heat the lunar soil to 700 degrees Celsius (about 390 degrees Fahrenheit). This temperature is high enough to evolve helium 3, as well as hydrogen, nitrogen, carbon monoxide, methane, helium 4, carbon dioxide and water from the reaction of hydrogen and the oxygen in the soil. The spent fine-grained material, depleted of its volatiles, is dropped back onto the surface of the Moon.

Illustration: John Andrews, courtesy of G. Kulcinski

The thermal energy equivalent of all the oil used in Japan (in 1992) would be equal to about 7 metric tons of helium 3. This amount of liquified helium 3 could easily fit into the cargo bay of a shuttle-sized spacecraft.

As to the future of this energy source in the US, it should be noted that all research in this area was recently terminated by NASA's Commercial Development Division because it is "too long range." Evidently, the Japanese do not share this view and they plan to place themselves in the position of developing this energy source for the 21st century.
—GERALD L. KULCINSKI,
Fusion Technology Institute, University of Wisconsin

How does the mass of our planet's atmosphere compare with that of its oceans?
—Carlo Piscicalli-Taeggi, Milan, Italy

Earth's atmosphere contains about 5.2 x 10^{18} kilograms of air, as compared to 1.4 times 10^{21} kilograms of water in the oceans. Thus, the ocean is about 270 times as massive as the atmosphere. The pressure that Earth's atmosphere exerts at sea level is a little over 1 bar. That's much less than the surface pressure on our sister planet, Venus, which has a 93-bar atmosphere consisting mostly of carbon dioxide.

The reason our atmosphere is relatively thin is that most of the volatile (gas-forming) compounds other than nitrogen, oxygen and water are locked up in rocks. Carbon dioxide in Earth's crust, for example, is nearly as abundant as that on Venus. This crustal inventory would produce a carbon dioxide pressure of 60 bars were it all present in the atmosphere.

But because Earth has liquid water, most of its carbon dioxide has been converted to carbonate rocks, and the atmospheric carbon dioxide pressure is only 0.00035 bar. The fact that Earth has lots of water at its surface and only a little carbon dioxide, as compared to just the opposite on Venus, is a consequence of their different distances from the Sun and their correspondingly different evolutionary paths.
—JAMES KASTING,
Pennsylvania State University

During the* Mariner 10 *mission, Mercury was found to have a significant magnetic field. The project scientists had two theories on how a planet with a slow rotational period could possess a magnetic field: intrinsic generation by a huge metallic core or by induction from the solar wind.

Has the question ever been resolved?
—Alex R. Blackwell, Wahiawa, Hawaii

Mariner 10 made three passes by Mercury. One of these was a distant pass on the dayside of the planet and did not penetrate the planet's magnetic field, but the two nightside passes did enter that region.

The orientation of an induced magnetosphere is controlled by the orientation of the magnetic field of the solar wind that changes on timescales of hours. The orientation of an intrinsic magnetic field is controlled by the fluid motions in the electrically conducting core that change on timescales of thousands of years. The orientation of the solar wind's magnetic field was quite different during the two nightside passes of *Mariner 10* but the orientation of the planetary magnetic field was the same. Hence it is now commonly accepted that Mercury's magnetic field is intrinsic to the planet and not of solar wind origin.

This question is very timely. After 20 years of neglect, at least two different groups are preparing to submit plans to NASA for a return to Mercury. One of these missions would resemble *Mariner 10*. The other, called *Hermes,* would orbit Mercury and complete the optical and magnetic survey begun so long ago.
—C.T. RUSSELL, *University of California, Los Angeles*

Factinos

In late March, NASA released the first-ever photograph of the moon of an asteroid (see photo at right). *Galileo* captured the image last August 28 as it flew past the asteroid 243 Ida. The picture was not transmitted to Earth until recently because the spacecraft is returning data very slowly. According to scientists at the Jet Propulsion Laboratory, the image, together with data from *Galileo*'s near-infrared mapping spectrometer, provides the first conclusive evidence that natural satellites for asteroids do exist.

Galileo project scientist Torrence Johnson said, "It was previously thought that natural satellites of asteroids could form, but they probably weren't common. Having found one fairly quickly, we can say that they're probably more common than previously thought."

Scientists estimate that the satellite is about 1.5 kilometers (1 mile) across in this view and it appears to be about 100 kilometers (60 miles), plus or minus 50 kilometers, from Ida's center. Ida itself is about 56 by 24 by 21 kilometers (35 by 15 by 13 miles) in size.
—from the Jet Propulsion Laboratory

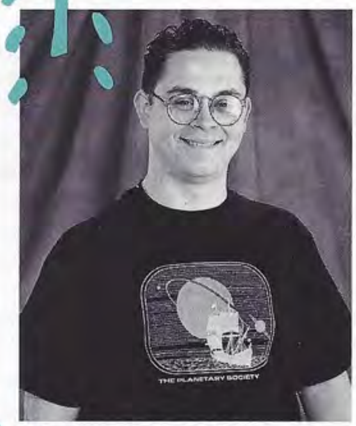
Alexander Wolszczan, an astronomer from Pennsylvania State University, has found "irrefutable evidence" of at least two planets orbiting a nearby star—the first confirmed observation of planets outside our solar system. (See the March/April 1992 issue of *The Planetary Report*.) The star, known as PSR B1257+12, is one of just 21 known stellar objects, called millisecond pulsars, that spin thousands of times faster than typical stars, broadcasting powerful radio pulses as they revolve.

In the past, news of planet discoveries has been followed quickly by retractions when errors in the data were discovered or when others could not confirm the initial sighting. But Wolszczan's findings, which were published in the April 22 issue of *Science,* seem to convince many skeptical astronomers.

Wolszczan used the 305-meter (1,000-foot) radio telescope at the Arecibo Observatory in Puerto Rico to measure the arrival times of the pulsar's energy pulses. Using statistical analyses and detailed observations of the pulsar's radio signals, Wolszczan was able to detect the infinitesimal wobble caused by the gravitational pull of the planets whirling around the central star.
—from Robert Lee Hotz in the *Los Angeles Times*

Far-out

Surf Titan



Shown left to right:

Climb Olympus T-Shirt
Rising 25 kilometers above the surrounding plain, the martian volcano Olympus Mons is the highest in our solar system. Only the boldest climbers will ever attempt its summit. Will you? 100% cotton. White. S, M, L, XL. 1 lb.
#517 $14.00

Surf Titan T-Shirt
Saturn's moon may well be the interplanetary "hang ten" vacation spot of the future! Waves of liquid hydrocarbons will give adventurous surfers the rides of their lives! 100% cotton. Navy blue, long sleeve. S, M, L, XL. 1 lb.
#651 $20.00

Dive Europa T-Shirt
Why "Dive Europa"? This moon of Jupiter may conceal a vast global ocean beneath its cracked, icy surface. In the distant future, explorers may use special diving gear to help unlock the secrets of this world. 100% cotton. Gray and white. S, M, L, XL. 1 lb.
#568 $14.00

Ski Mars T-Shirt
Ready to hit the slopes on the Red Planet? A properly space-suited skier could glide down the martian polar caps, whether they're regular water or dry ice. 100% cotton. White. S, M, L, XL. 1 lb.
#553 $14.00

Planetary Society T-Shirt
Evoking the age-old spirit of exploration, the Society's caravel sets sail for new worlds against a midnight sky. 100% cotton. Black. S, M, L, XL. 1 lb.
#665 $16.00

SOFTWARE

Space Adventure
IBM-compatible software—requires hard drive and VGA monitor. Mouse and most popular sound cards are optional. (Please specify 3 1/2" or 5 1/4" disks.) 2 lb.
#748 $49.00

Dance of the Planets
Q.E.D. edition. IBM-compatible software—requires 80x86 CPU, DOS 3.X or higher, 640K RAM, EGA or VGA graphics, hard drive. Math co-processor required. (3 1/2" disks only.) 2 lb.
#715 $175.00

EZCosmos
IBM/Tandy-compatible software—requires DOS 3.2 or greater, EGA or VGA graphics, 640K RAM. Mouse optional. (Please specify 3 1/2" or 5 1/4" disks.) 2 lb.
#503 $55.00

SimEarth
IBM-compatible software—requires a hard drive and 640K RAM; Macintosh software—requires a hard drive and 1 MB RAM for black and white or 2 MB RAM for color. 2 lb. **$55.00**
#740 IBM-Compatible
#741 Macintosh

Murmurs of Earth: The *Voyager* Interstellar Record
This two-CD set, playable on any standard CD player, also includes the book *Murmurs of Earth* by Carl Sagan and the *Voyager* record team. With a CD-ROM drive, you can display images on your PC. Image accessing requires IBM-compatible computer with 640K RAM, Super VGA graphics card for 640x480, 256 colors, multisync monitor and PC-compatible CD-ROM drive. Or Apple Macintosh LC or II series, with system 6.0.5 or greater and 2 MB available memory, a 12- or 13-inch color monitor and Macintosh-compatible CD-ROM drive. 3 lb.
#725 $54.00

COLOR REPRODUCTIONS

Portrait of the Milky Way
40" x 27" poster. 2 lb.
#330 $15.00

Solar System in Pictures
Nine 8" x 10" mini-posters. 1 lb.
#336 $10.00

An Explorer's Guide to Mars
40" x 26" poster. 1 lb.
#505 $6.00

Solar System Chart
39" x 25" poster. 1 lb. **#338 $6.00**

Moon Laser Prints
20" x 16". 1 lb. **$8.00 each**
#311 Full Moon
#312 Moonscape
#315 Earthrise

Planets Laser Prints
20" x 16". 1 lb. **$8.00 each**
#323 Mars **#322 Jupiter**
#337 Uranus **#340 Venus**
#305 Earth

Jupiter/Saturn/Uranus Poster Set
Three 22 1/2" x 29" posters. 1 lb.
#327 $15.00

***Galileo*—Earth and Its Moon**
18" x 24" poster. 2 lb. **#318 $8.50**

Space Shuttle Laser Prints
16" x 20". 1 lb. **$8.00 each**
#344 Day Launch
#345 Night Launch

BOOKS

The Grand Tour
By Ron Miller and William K. Hartmann. 208 pages (soft cover). 2 lb.
#166 $13.50

Fashions

Solar System T-Shirt
Learn about the solar system the fun way! 50/50 cotton/poly blend. White.
Children's S, M, L. 1 lb.
#668 $11.00
Adults' S, M, L, XL. 1 lb.
#667 $14.00

Mars Rover

Mars Balloon

Mars Team T-Shirts
Show your enthusiasm for the Mars Team! Wear one of these two distinctive designs—or wear both! One T-shirt depicts the Mars Balloon flying above the planet's surface with The Planetary Society-designed Snake guide-rope attached. The other shirt displays the rover on Mars-like terrain. 100% cotton. White.
S, M, L, XL. 1 lb. **$14.00 each**
#532 Mars Rover **#630 Mars Balloon**

Mars T-Shirt
Get your facts straight. Wear our Mars T-shirt, which shows off the most popular facts and figures for the Red Planet. (Front of shirt pictured at left; back of shirt at right.) 100% cotton. Black.
S, M, L, XL. 1 lb.
#530 $18.00

Mirror Matter: Pioneering Antimatter Physics
By Robert L. Forward and Joel Davis.
262 pages (hard cover). 2 lb.
#133 $16.00

Exploring Planetary Worlds
By David Morrison.
240 pages (hard cover). 2 lb.
#111 $29.00

Space Age
By William J. Walter.
325 pages (hard cover). 3 lb.
#182 $25.00

The Search for Life in the Universe
By Donald Goldsmith and Tobias Owen.
530 pages (soft cover). 2 lb.
#181 $30.00

The History of Earth
By William K. Hartmann and Ron Miller.
260 pages (hard cover). 2 lb.
#123 $32.00

Starsailing: Solar Sails and Interstellar Travel
By Louis Friedman. Each copy autographed by the author.
146 pages (soft cover). 1 lb.
#157 $9.00

The Starflight Handbook: A Pioneer's Guide to Interstellar Travel
By Eugene Mallove and Gregory Matloff. 274 pages (hard cover). 2 lb.
#186 $20.00

The New Solar System
Edited by J. Kelly Beatty and Andrew Chaikin. 326 pages (soft cover). 4 lb.
#180 $21.00

OTHER ITEMS

***Planetary Report* Binder**
2 lb. **#545 $12.00**

Spacecraft Science Kits
1 lb. **$14.00 each**
#525 Hubble Space Telescope
#538 *Magellan*
#560 *Voyager*
#524 *Galileo*

Planetary Society Note Cards
Set of 16 cards (envelopes included).
1 lb. **#544 $10.00**

Solar System Postcards
Set of 16 cards. 1 lb. **#547 $8.00**

Hugg-A-Planet
#526 Earth 3 lb. **$15.00**
#528 Mars 2 lb. **$13.50**
Special Offer— Order both for $25.00!

Planetary Society Mug
2 lb. **#580 $7.00**
Special Offer— Four mugs (8 lb.) for $24.00!

Planetary Society Pin
1 lb. **#670 $3.00**

Planetary Society Key Ring
1 lb. **#677 $4.75**

Puzzle—A View to Earth
2 lb. **#502 $16.00**

Puzzle—Portrait of the Planets
3 lb. **#556 $11.95**

Use the form bound inside the magazine to order through the mail. For credit-card orders, or for more information on the items listed on these pages, just phone our sales office at 818-793-1675.

Jupiter Watch!

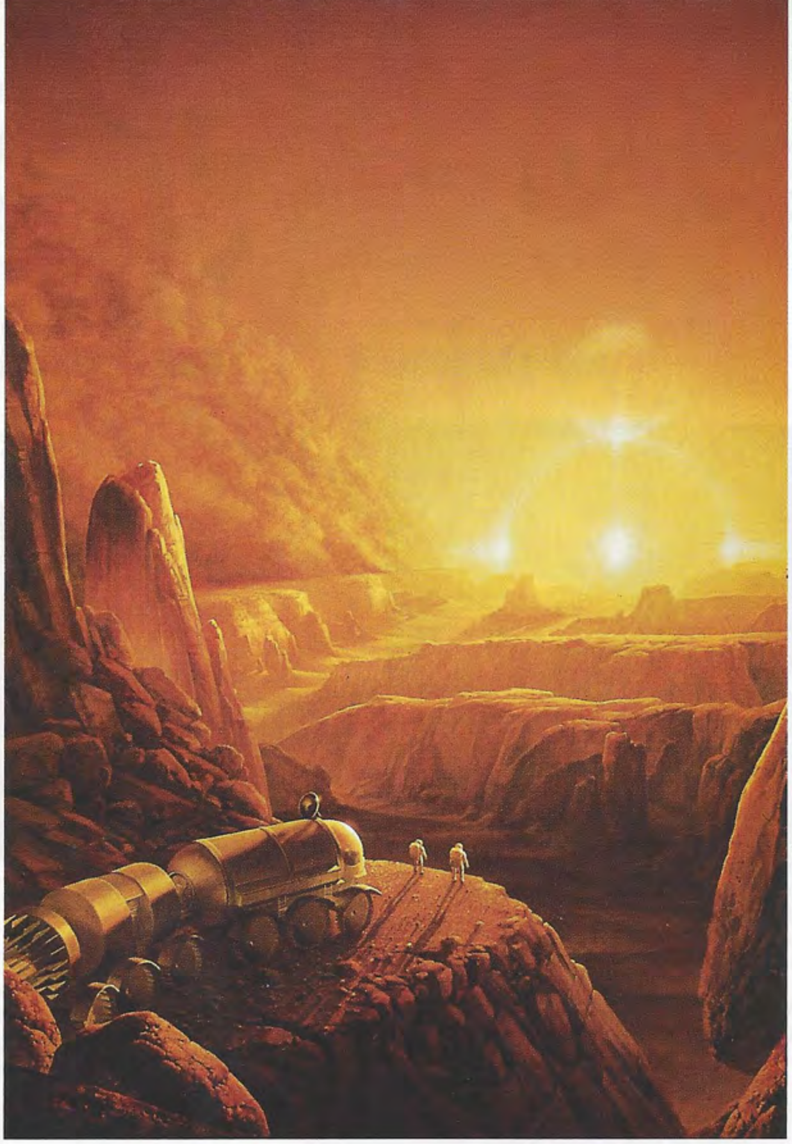
The Quest for Comets: An Explosive Trail of Beauty and Danger NEW
By David H. Levy. This unforgettable book, written by one of comet Shoemaker-Levy 9's discoverers, captures the excitement of comet hunting. 280 pages (hard cover). 2 lb.
#140 $21.50

Jupiter Watch Guide
16 pages. 1 lb. **#680 $5.00**

Jupiter Watch Button
1 lb. **#683 $1.00**

Jupiter Watch T-Shirt
50/50 cotton/poly blend. Black.
L, XL. 1 lb. **#681 $9.00**

Jupiter Watch Poster
18" x 24". 1 lb.
#682 $5.00



These future explorers watch a dust storm gathering along a distant martian rift. They have stationed their land-roving habitation vehicle on the outskirts of the planet's south pole. Humans have long dreamed of walking on Mars, but before we set foot on that planet, we will need to answer the question of whether our presence could endanger martian life-forms—if any exist—or if they could harm us. The painting, "Mars," originally appeared on the cover of Ben Bova's novel of the same name.

Pamela Lee's paintings, which speculate on humankind's eventual presence throughout the solar system, have been exhibited in numerous museums worldwide. She is the first American artist to have paintings flown on both the United States' space shuttle and the Russian space station *Mir.*

THE PLANETARY SOCIETY
65 North Catalina Avenue
Pasadena, CA 91106-2301

PRINTED ON RECYCLED PAPER
Printed in USA