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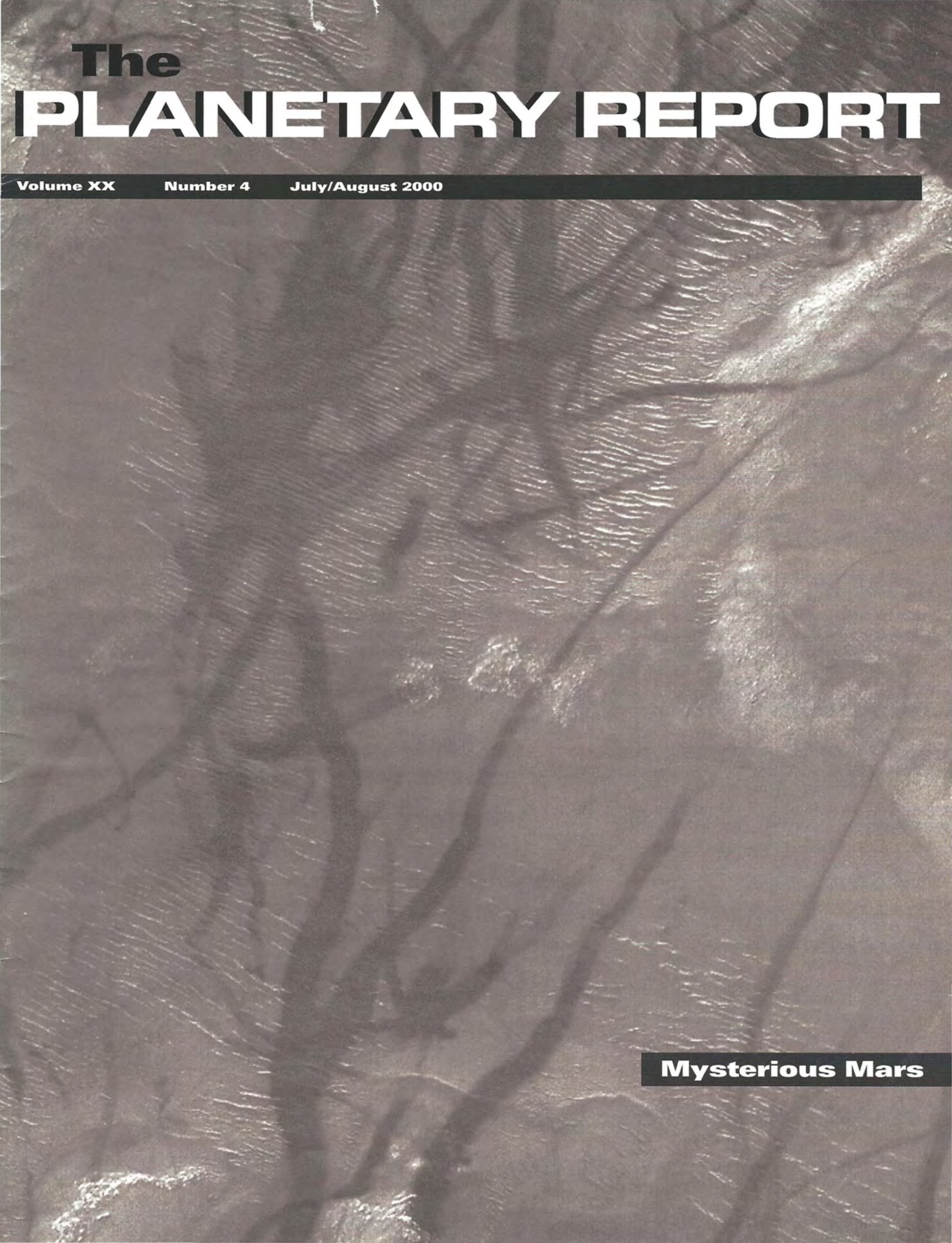

Mysterious Mars

On the Cover:

With each passing glance, Mars continues to surprise and delight. These dark, wild streaks are the trails of dust devils that run over hills, skim straight across dunes and ripples, and dance through fields of house-sized boulders. The Mars Orbiter Camera on *Mars Global Surveyor* imaged this 3-by-5-kilometer (2-by-3-mile) portion of Argyre Planitia on February 21, 2000.

Image: MSSS/NASA

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From The Editor

Mars, Mars, Mars. Everywhere you look in the popular scientific press lately, you see questions about the Red Planet. At the beginning of the year, we read: what went wrong with the *Mars Polar Lander* (*MPL*)? How could NASA have lost *MPL* and the *Mars Climate Orbiter*? What's wrong with the United States' Mars program?

Then, in the spring, four different review panels released their reports (which we summarize in this issue). The questions became: how do we fix what went wrong? Are we trying to do the right things? How do we get back to Mars?

Just weeks ago, another Martian bombshell dropped: Mike Malin and Ken Edgett, who built and operate the camera on the *Mars Global Surveyor*, announced that they had found evidence of possible liquid water on Mars (see pages 12, 13 and 21).

This news has dramatically changed the questions. Instead of concentrating on the nuts and bolts of the Mars program, now there is a rush to go after the water. How do we land near the possible springs? How do we dig through the surface? How do we determine if it really is water and not some other erupting substance?

In our next issue, Bruce Jakosky, who served as an independent voice on the NASA press conference panel, will begin to address these questions. Mars, Mars, Mars; it's filling our pages, too.

—*Charlene M. Anderson*

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Members' **Dialogue**

SETI—A Long Wait

I enjoyed reading "Flash! Optical SETI Joins the Search," in your March/April 2000 issue. Optical SETI is a step in the right direction. However, I've recently read speculation ("Where Are They?" in the July 2000 issue of *Scientific American*) that the lack of SETI results to date indicates a lack of intelligent beings in the galaxy. In spite of speculation about the meaning of the negative SETI results, certain qualitative factors seem to have been overlooked.

People assume that a technological civilization will use linearly increasing amounts of energy, resulting in immensely powerful radio emissions and thermal energy noticeable at interstellar distances. They ignore our own trend toward greater efficiency. For example, in a few decades much, if not all, of our TV broadcasts will be carried by optical cable rather than megawatt level, omnidirectional transmitters. Yet we assume a more advanced civilization would use brute force to communicate, and we would see the evidence of their waste heat and radio energy.

The idea that, given enough time, a civilization will expand to fill the entire galaxy seems deeply flawed. It's entirely possible that diversity of thought, goal, and opinion are essential traits of an aggressive technological civilization. Mass colonization would require stability over a huge period of time, and this may be antithetical to the creativity needed for the enterprise. In fact, the Fermi Paradox (or "why aren't they everywhere?") is based on the assumption that, over time, a sort of "omni civilization" must evolve, colonizing all available space, no matter how inhospitable. Maybe it just never does, for reasons as concrete as those governing the lifetimes of stars.

Interstellar flight may someday be possible, but just not worth it. Our own development in propulsion has lagged behind our imaging technology. Radio and optical telescopes with huge baselines and fantastic resolution are current-day possibilities. Why go, when you can look? This pretty well shoots down the idea of interstellar colonization as a scientific enterprise. If we want to study the ocean floor, we send a robot or a few people for a few hours. We don't send whole families down there to live.

Our current searches are probably similar to a child fishing in the gutter using a bent pin for a hook. It hardly makes sense to conclude that there are no fish anywhere just because the kid doesn't catch one. When SETI consists (I hope) of thousand-mile baseline telescopes, maybe we'll get a little luckier.

—TERRENCE CHURCHMAN,
Pasadena, California

Track those NEOs!

David Jewitt's article, "Astronomy: Eyes Wide Shut," in the May/June 2000 issue of *The Planetary Report* mentions the need for "a massive computer array capable of meeting the huge data-processing demands" of a whole-sky survey on a monthly basis.

For those of us "looking for little green men" by participating in the SETI@home program, "saving the planet" would undoubtedly be embraced as another worthy cause. Couldn't a similar program be used for near-Earth asteroid identification?

—BEV BOURDON,
Maple Ridge, British Columbia, Canada

I recently downloaded my "Certificate of Appreciation" for participating in the SETI@home project. I have it hanging on my office wall.

Perhaps there are other opportunities to use the SETI@home experience to expand our knowledge of the universe. For example, the search for extrasolar planets or "ESP@home."

I know very little about the techniques used to detect distant worlds—the methods may not be suitable for this sort of project. However, over two million PC users from around the globe have demonstrated their eagerness to participate in this sort of endeavor. I'm sure many more people would be just as eager to join similar projects.

Another possibility would be the search for NEOs. In "Astronomy: Eyes Wide Shut," the author suggests that we should be surveying the entire sky for NEOs on a monthly basis. This would require "a massive computer array capable of meeting the huge data-processing demands." That seems tailor-made for a SETI@home-like application.

—GEORGE GOUTHAS,
Dernacourt, Australia

There is only one planet Earth. If there is not a program to continuously monitor the whole sky, the Earth is at risk. Even with such a program, we lack a means of deflecting asteroids or comets from impacting Earth.

NEOs are a world problem requiring international participation. A good start would be to implement the 1994 "order" by the US House Committee on Science to catalog all NEOs within 10 years.

There is a quotation [Solomon, Proverbs] that I believe applies: "Where there is no leadership, the people perish."

—JAMES J. VARGO,
Lynden, Washington

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OPINION:

Contamination from Mars: No Threat

BY ROBERT ZUBRIN

Disease organisms don't hop easily between very disparate hosts (such as humans and plants), making the scenario depicted here a fantasy. Any indigenous Martian host organism would be far more distantly related to humans than are members of the botanical world.

Painting: Remedios Varo (1908 Spain–1963 Mexico City); **Unsubmissive Plant**, *1961. Oil on Masonite. Private Collection.*

Of all the dragons infesting the maps of would-be Mars explorers, one stands out as not only illusory but hallucinatory. This is the "Threat of Back Contamination."

The story goes like this: no Earth organism has ever been exposed to Martian organisms, and therefore we would have no resistance to diseases caused by Martian pathogens. Until we can be assured that Mars is free of harmful diseases, we cannot risk exposing a crew to such a peril, which could easily kill them or, if it didn't, return to Earth with the crew to destroy not only the human race but the entire terrestrial biosphere.

The kindest thing that can be said about the above argument is that it is just plain nuts. In the first place, if there are or ever were organisms on or near the Martian surface, then the Earth has already been, and continues to be, exposed to them.

Over the past billions of years, millions of tons of Martian surface material have been blasted off the surface of the Red Planet by meteorite strikes, and a considerable amount of this material has traveled through space to land on Earth. We know this for a fact because scientists have collected tens of kilograms of a certain kind of meteorites called SNC meteorites and compared the chemical composition of the rocks' entrapped gases with the atmosphere measured on the Martian surface by the *Viking* landers. The perfect match between the two represents an irrefutable fingerprint proving that these materials originated on Mars.

Although each SNC meteorite must wander through space for millions of years before arrival at Earth, it is the opinion of experts in the area that neither this extended period traveling through hard vacuum nor the traumas associated with ejection from Mars and arrival at Earth would be sufficient to sterilize these objects, if they originally contained bacterial spores. Furthermore, on the basis of the amount of SNC meteorites we have found, it has been estimated that these Martian rocks continue to rain down upon the Earth at a rate of about 500 kilograms (more than 1,000 pounds) per year. So, if you're scared of Martian germs, your best bet is to leave Earth fast, because when it comes to Martian biological-warfare projectiles, this planet is smack in the middle of torpedo alley.

The Habitat Needs of Germs

The fact of the matter is that life almost certainly does not exist on the Martian surface. There is no liquid water on the surface—the average surface temperature and atmospheric pressure will not allow it. Moreover, the planet is covered with oxidizing dust and bathed in ultraviolet radiation. Both of these features—peroxides and ultraviolet light—are commonly used on Earth as methods of sterilization.

Views expressed in this article are those of the author and do not necessarily represent those of The Planetary Society.

If there is life on Mars now, it almost surely must be ensconced in exceptional environments, such as heated hydrothermal reservoirs underground.

But couldn't such life, if somehow unearthed by astronauts, be harmful? Absolutely not. Why? Because disease organisms are keyed to their hosts. Like all other organisms, they are specially adapted to life in a particular environment. In the case of human disease organisms, this environment is the interior of the human body or of a closely related species, such as another mammal. For almost 4 billion years, the pathogens that afflict humans today have waged a continuous biological arms race with the defenses developed by our ancestors. An organism that has not evolved to breach our defenses and survive in the microcosmic free-fire zone that constitutes our interiors will have no chance of successfully attacking us. This is why humans do not catch Dutch elm disease and trees do not catch colds. Any indigenous Martian host organism would be far more distantly related to humans than are elm trees.

There is no evidence for the existence of (and every reason to believe the impossibility of) macroscopic Martian fauna and flora. Without indigenous hosts, the existence of Martian pathogens is impossible. And if there were hosts, the huge differences between them and terrestrial species would make the idea of common diseases an absurdity.

Equally absurd is the idea of independent Martian microbes coming to Earth and competing with terrestrial microorganisms in the open environment. Microorganisms are adapted to specific environments. The notion of Martian organisms out-competing terrestrial species on their home ground (or terrestrial species overwhelming Martian microbes on Mars) is as silly as the idea that sharks transported to the plains of Africa would replace lions as the local ecosystem's leading predator.

Sterilized Samples: A Terrible Loss

Not too long ago, I took part in a NASA planning meeting for the upcoming (robotic) Mars Sample Return mission, during which someone seriously proposed that, to allay alleged public concerns, any sample acquired on Mars be sterilized by intense heat before being brought to Earth. While an extremely unlikely find, the greatest possible treasure a Mars Sample Return mission could provide would be a sample of Martian life. Yet certain of those attending the meeting would destroy it preemptively (and a great deal of valuable mineralogical information in the sample as well). The proposal was so grotesque that I countered by asking the assembled scientists, "If you should find a viable dinosaur egg, would you cook it?"

The question is not entirely out of line; after all, dinosaurs are our comparatively close relatives, and they did have diseases. In fact, every time you turn over a shovelful of dirt, you are returning a sample of the Earth's disease-infested past to menace the current biosphere. Nevertheless, paleontologists do not wear decontamination gear.

Just as the discovery of a viable dinosaur egg would represent a biological treasure but no menace, so a sample of live Martian organisms would be a find beyond price but certainly no threat. By examining Martian life, we would have a chance to differentiate between those features of life that are idiosyncratic to Earth and those that are universal. We might be able to observe organisms simpler than bacteria, missing links in the evolution of life from a chemistry whose simplicity could clarify our understanding of the structure and functions of more complex organisms. We could thus learn something fundamental about the very nature of life. Such knowledge could provide the basis for astonishing advances in genetic engineering, agriculture, and medicine.

No one will ever die of a Martian disease, but it might be that thousands of people are dying today of terrestrial ailments whose cure would be apparent if only we had a sample of Martian life in our hands.

Back contamination mavens need to back off. Their warnings have no rational basis and are being used to urge crimes against science.

Robert Zubrin, President of the Mars Society, made his reputation as a cutting-edge planner of solar-system exploration while at Lockheed Martin Corporation. He is the founder and CEO of Pioneer Astronautics and author of two books: The Case for Mars *(Simon and Schuster, 1996) and* Entering Space *(Tarcher-Putnam, 1999).*

Earth is already "contaminated" by Mars: about 15 meteorites found on our world came from the Red Planet. Scientists are certain of the Martian origin because the chemical makeup of gases trapped inside those rocks perfectly matches the measurements of Mars' atmospheric gases taken by the* Viking *landers. All three of these rocks are Shergottites, the most common subgroup of Mars meteorites. The one-centimeter cubes are shown for scale.

Left: This piece of Mars, the Sahara meteorite, was discovered in Libya on May 1, 1998. It weighs a little over 2 kilograms (about 4.5 pounds) and is shaped like a loaf of bread. *Photo: Max Planck Institute for Chemistry*

Middle: This 245-gram (9-ounce) meteorite was found in California's Mojave desert on October 30, 1999. It is one of two parts of the same rock, called collectively the Los Angeles meteorite. *Photo: JPL/NASA*

Right: EETA 79001 was found in Elephant Morraine in Antarctica on January 13, 1980. It's only 180 million years old—very young by solar system standards—and was blasted into space from Mars 600,000 years ago. *Photo: JSC/NASA*

WHAT MIGHT HAVE BEEN: THE *MARS POLAR LANDER* AND *MARS CLIMATE ORBITER*

by Andre Bormanis

Of all sad words of tongue or pen,
The saddest are these: "It might have been!"
—John Greenleaf Whittier

Outer space seemed unusually silent on Friday, December 3, 1999. Early that afternoon, scientists and engineers at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California eagerly awaited the signal that would confirm their *Mars Polar Lander* (*MPL*) spacecraft had safely touched down somewhere near the Martian south pole. Following in the planet-steps of the wildly successful *Mars Pathfinder* mission, *MPL* was to be the second Mars landing in the ambitious Mars Global Surveyor Program and the first landing on the planet's frigid polar terrain.

Piggybacked on the spacecraft were two microprobes that were to be released about 10 minutes before the *MPL* landing. Part of NASA's New Millennium initiative to stretch the limits of spacecraft engineering for planetary missions, the probes were designed to jab into the Martian crust, penetrating several meters below the surface to search for water and make other scientific measurements.

JPL expected silence during *MPL*'s descent. To save money and weight, the spacecraft had not been equipped with a transmitter that could operate during approach and descent to the Martian surface. If all had gone as planned, *MPL* would have reestablished contact with Earth shortly after landing.

The deadline for the expected signal came and went, but not a whisper was heard from Mars. New command sequences were transmitted to *MPL*, but the excruciating silence continued. By the end of the day the mood at JPL and at The Planetary Society's Planetfest '99 was somber. By Sunday night, few expected that anyone would ever hear from *MPL* or its two microprobes.

Engineers continued for several weeks to try to establish contact with the spacecraft. On December 18, and again on January 4, an antenna at Stanford University in Palo Alto, California detected a faint signal that may have come from Mars. Hopes rose that the wayward lander might finally be calling home. But after careful analysis, the engineers concluded that the signal did not come from *MPL*. Little more could be done. Even if the spacecraft had landed intact, its batteries would have been draining to the point that communication (let alone the planned science operations) would soon be impossible.

Mars Climate Orbiter

The failure of the $165 million *Mars Polar Lander* came only three months after the loss of another Mars-bound spacecraft, *Mars Climate Orbiter* (*MCO*). The first interplanetary weather satellite, *MCO* was scheduled to enter Martian orbit on September 23, 1999. It passed behind the planet's limb that day, as intended, but was never heard from again.

In the wake of these discouraging failures, NASA Headquarters ordered investigations of both spacecraft losses and a major review of its ambitious plans for the next decade of Mars exploration. The *MCO* Mishap Investigation Board, led by Arthur Stephenson, director of NASA's Marshall Space Flight Center, convened shortly after contact with that spacecraft was lost. NASA was anxious to discover any problems that might affect its sister spacecraft, *MPL*, well before its scheduled landing.

After *MCO* launched on December 11, 1998, responsibility for its navigation through interplanetary space was transferred to a team of engineers at JPL. Lockheed Martin provided JPL with the telemetry needed to guide the spacecraft to Mars. In order to be captured into Martian orbit, *MCO* had to pass behind the planet at just the right altitude: too high would cause it to slingshot past Mars and back into interplanetary space; too low would cause it to crash or burn. Unbeknownst to the engineers at JPL, software developed by Lockheed Martin was providing crucial thruster data in English units. JPL was expecting the data in metric units.

The Stephenson Report noted that planetary missions are a "one strike and you're out" kind of activity. One minor mistake in hardware, software, or management can be catastrophic. The way to prevent mistakes is through careful oversight, exhaustive testing, and independent analysis. All of these management functions were deemed "deficient" for the *MCO* program, especially in software testing.

The report also concluded that the navigation team in charge of *MCO* after launch was understaffed and inadequately trained and lacked sufficient understanding of critical spacecraft systems. The team detected navigation anomalies several times as *MCO* sailed toward Mars but failed to thoroughly root out the source of these anomalies—which turned out to be the mix-up of English and metric units in the thruster data. As a consequence, the chance to try one final trajectory correction as *MCO* approached Mars couldn't be taken.

MCO probably made its closest encounter of the Red Planet at an altitude of just 57 kilometers (35 miles)—too deep in the atmosphere for the spacecraft to survive. The Stephenson Report identified the units discrepancy as the direct cause of the *MCO* failure. But program management factors—primarily related to the way the missions had been developed and run by JPL and its prime contractor, Lockheed Martin—were cited as the ultimate reason the spacecraft was lost.

After the telemetry-unit snafu was discovered, every line of

LOSSES

All launch photos are beautiful—portraits of raw power, triumphant achievement, and wondrous expectation, they symbolize much of what is great about humanity. But humanity means human beings, who often err—sometimes catastrophically. A trail of critical mistakes led to the loss of Mars Climate Orbiter, *seen here launching from Kennedy Space Center on December 11, 1998.* Photo: NASA

Below: As Mars Polar Lander *underwent a last checkover in a space simulator at JPL, teams of specialists were unaware that the spacecraft held a fatal flaw: its ground-sensing system was too easily activated. Identification of the problem by subsequent investigators will lead to improved design and testing of future missions. In this shot, two of the lander's three legs, the electronics bay, and a propellant tank are visible.* Photo: JPL/NASA

code in the *Mars Polar Lander* software was checked and double-checked. *MPL* would not confuse foot-pounds for newton-meters. Unfortunately, this wasn't enough to save the mission.

Mars Polar Lander

When *MPL* failed, two teams were created to investigate. The Mars Program Independent Assessment Team (MPIAT) was headed by Thomas Young, former president of Martin Marietta (now incorporated into Lockheed Martin). At JPL, a Special Review Board was established. John Casani, a retired JPL chief engineer and former director of flight operations for the laboratory, led that team.

The most likely cause of the *MPL* failure was discovered by accident, according to Edward Euler, the Lockheed Martin program director for the two Mars missions. In early February 2000, engineers were conducting tests on a model of the next Mars-bound lander (a virtual clone of *MPL*). The tests seemed to suggest that sensors on *MPL*'s landing legs could have generated false signals when the legs extended during the final phase of descent. Its onboard computer probably misinterpreted these signals as an indication that the lander had touched down. This in turn led *MPL* to cut off its engines prematurely, some 40 meters above the Martian surface. If this scenario is correct, the lander slammed into the ground at a speed of nearly 80 kilometers (50 miles) per hour, an impact the spacecraft could not survive.

The *MPL* landing system was tested prior to launch, but the landing leg sensors were improperly wired during those tests. The wiring problem was discovered and corrected, but the tests were not repeated. The engineers were confident that, properly wired, the sensors would function as intended. And they probably did function correctly, but the *MPL* computer misinterpreted the shaking and vibrating that accompanied the landing leg deployment as an indication that the spacecraft was on the ground. A simple change to one line of computer code probably would have been enough to distinguish a spurious sensor reading from the real thing. But without any data from atmospheric entry through descent and landing, there is no way to know for sure whether *MPL* survived to the final, fateful 40-meter altitude. If it did, it's almost certain that the engines shut down prematurely.

According to the MPIAT Report, "It is not uncommon for sensors involved with mechanical operations, such as the lander leg deployment, to produce spurious signals. For *MPL*, there was no software requirement to clear spurious signals prior to using the sensor information to determine that landing had occurred. . . . While the most probable direct cause of the failure is premature engine shutdown, it is important to note that the underlying cause is inadequate software design and systems test."

Why Things Went Wrong

The Mars Surveyor Program, initiated by NASA in 1996, is undeniably ambitious. It calls for sending two spacecraft (an orbiter and a lander) to Mars every 26 months. The MPIAT Report notes that under this program, Mars missions must be developed and launched within a variety of rather unforgiving constraints. The launch date for a given mission is determined by the every-26-months launch window, which determines the schedule for completing the spacecraft. The launch vehicle dictates the upper limit of the spacecraft's weight. The suite of instruments that the spacecraft carries determines the scientific goals of the mission. And all of these requirements must be met within the cost caps established by the program budget. With these parameters fixed, only two variables—margins and risk—remain. "If adequate margins are available," the report states, "risk can be effectively managed; if not, risk will grow to an unacceptable level."

You get what you pay for, the saying goes. But how true is it? Although the highly successful Mars Global Surveyor *and* Mars Pathfinder *were inexpensive compared to big missions of the past, the money spent on them was enough to produce two spacecraft that worked. This color-enhanced portrait of Mars is a composite of nine color strips taken by the Mars Orbiter Camera on* MGS *during nine consecutive pole-to-pole orbits over the planet in March 1999.*

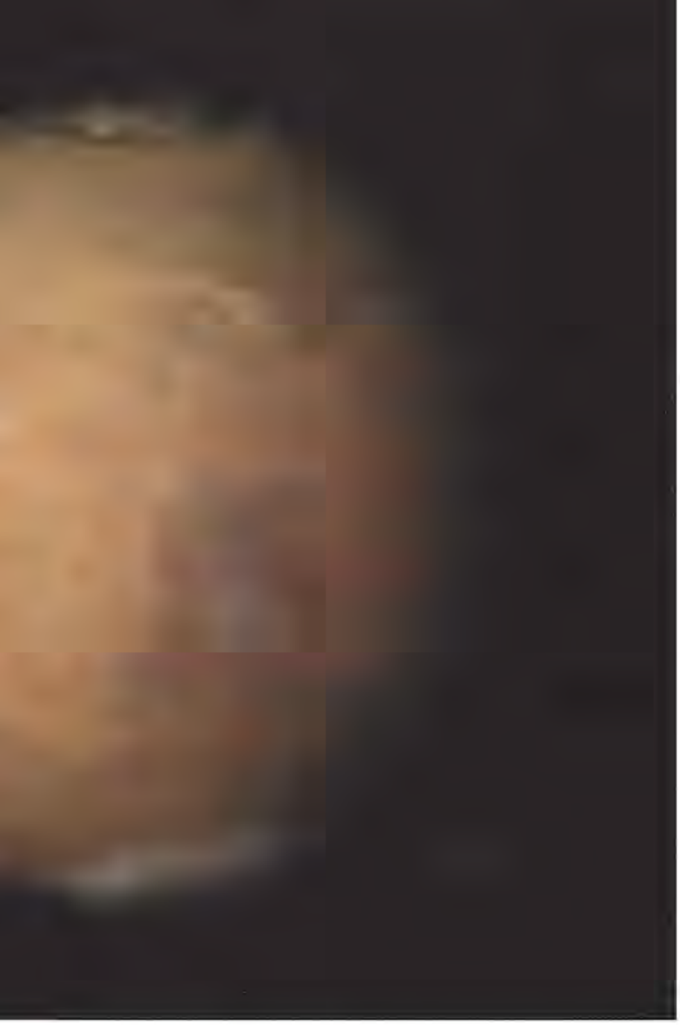
Image: MSSS/NASA

Adequate budget margins were clearly not available for *MPL* and *MCO*. The projects were underfinanced "by at least thirty percent," Young said, which forced JPL and Lockheed Martin engineers to cut corners and take unnecessary risks in order to save money and meet tight deadlines.

Given the challenging goals of the mission, *MPL* was significantly underfunded from the beginning. The highly successful and still functioning *Mars Global Surveyor* (*MGS*) orbiter cost approximately $250 million (including the value of spare hardware inherited from the *Mars Observer* project). The development cost of the *Mars Pathfinder* mission was around $200 million (including the $25 million spent on the *Sojourner* rover). Lockheed Martin claimed it could build *MPL* and *MCO* together for about $190 million, even though the science planned for these missions was considerably more ambitious than that conducted by either *Pathfinder* or *MGS*.

The MPIAT Report emphasizes the importance of exhaustive verification and testing to the success of any deep-space mission. According to the report, the microprobe development program deviated from sound testing principles "to such a degree that it leads to the conclusion that the microprobes were not ready to launch."

The report also cites the absence of a descent-telemetry system on *MPL* as a major mistake. Lacking data from the spacecraft during its descent makes it impossible to evaluate



the performance of *MPL* during this critical phase of the mission and effectively eliminates any possibility of using knowledge gained from the *MPL* loss to prevent similar problems in future missions. According to Young, this is "a prime example of the Mars Program being treated as a collection of individual projects as opposed to an integrated program."

The Future for Mars Exploration

NASA's Mars program management problems haven't escaped notice on Capitol Hill. At a hearing held in March by the Senate Space Subcommittee, Arizona Senator and recent Republican presidential candidate John McCain chastised NASA Administrator Dan Goldin. "The extent of mismanagement noted in these reports is startling," McCain said, as reported by *Aviation Week and Space Technology*. "Some of the overarching themes are apparent—staff complacency, inadequately trained personnel, lack of effective internal communication and staff not following established procedures."

Goldin, however, noted that the "faster, better, cheaper" (FBC—of course it needs an abbreviation) management philosophy he has instituted at the space agency has, on the whole, been remarkably successful. Since he became administrator in 1992, NASA has launched 146 payloads at a cost of roughly $18 billion. "Our total losses amounted to ten payloads, measured at one-half billion dollars, or less than three percent," Goldin said. He did acknowledge that the agency was losing many space veterans to retirement and that "we didn't take the time to adequately train, adequately mentor" the younger engineers. The MPIAT Report concurs. It states that "there are not enough experienced managers for the large number of projects for which JPL is currently responsible. This situation requires significant involvement by senior management to compensate for the lack of experience."

Prior to the loss of *MCO* and *MPL*, Tony Spear, the project manager for the *Pathfinder* mission, was asked to begin an evaluation of the FBC approach. He quickly discovered that there were almost as many definitions of FBC as there were members of his review team! They all agreed, however, that "FBC is not trying to fit a challenging Mission scope within arbitrary schedule and cost caps." But budget and time constraints in the Mars Surveyor Program virtually guaranteed that contractors would have to take enormous risks to save money and stay on schedule.

The scope of the early FBC missions, such as the *Clementine* lunar mission, *Mars Pathfinder*, and the *Stardust* mission to intercept a comet, fit fairly well within the established budget caps. But, the Spear Report notes, "the challenge bar was raised too high" for some of the second-generation missions: that is, *MCO* and *MPL*. Spear concludes, "We need to slow down some, not rush too quickly into important programs and projects, plan and implement them more carefully, and move away from fixations on cost and near term gain." He does, however, endorse the philosophy of continual improvement and innovation in mission technology and management that underlies FBC.

An essential element of any successful engineering team is good communication, and the quality of communication between JPL and NASA Headquarters and between JPL and Lockheed Martin was notably inadequate. JPL managers did not forcefully express their concerns about the parsimonious budget and schedule constraints to Headquarters, and Headquarters was not receptive to bad news from JPL. During a press conference following publication of the MPIAT Report, Ed Weiler, NASA's associate administrator for space science, admitted that "we asked JPL to do the impossible." During a late-March address to JPL employees, Administrator Goldin offered his own mea culpa: "I pushed too hard, and in so doing, stretched the system too thin."

All of the recommendations made in the MPIAT Report have been or are being implemented. G. Scott Hubbard, who currently leads the astrobiology program at NASA Ames, has been named Mars Program Director and will serve as the single "point of contact" for all Mars missions at NASA Headquarters. A Mars Program Office has also been created at JPL to coordinate mission planning and execution with Hubbard's office.

Unfortunately, the budget for the Mars Surveyor Program will increase by only 2 or 3 percent at most over the next five years. Given the budget, NASA's plan to launch two major missions to Mars every 26 months is probably unrealistic. The next Mars landing mission, which was scheduled for launch in 2001, has already been delayed indefinitely, and a sample return mission—the ultimate goal of the Mars Surveyor Program—won't happen before the end of the decade.

The exploration of Mars will certainly continue, albeit not at the pace envisioned when the Mars Surveyor Program was established. Smaller and cheaper are not always compatible with faster in the exploration of the solar system. Patience may be, as Ambrose Bierce once noted, a minor form of despair disguised as a virtue. But when budgets are tight and the risks are high, it may also be a necessity.

Andre Bormanis is a special consultant to The Planetary Society.

MARS GLOBAL SURVEYOR: PERFORMING DAILY, 687 DAYS A YEAR

Illustration: JPL/NASA

by Jennifer Vaughn

In planetary exploration, success doesn't come easily, but successful moments, when they happen, capture the attention and awe of the world. Think back to the *Mars Pathfinder* landing and how the world was enthralled when the spacecraft began returning images of its new home. Tragic moments capture attention too. We don't need to think back very far to find an example (or two). But what about ongoing success—a spacecraft that delivers day after day after day? After years, the accomplishment may begin to seem lackluster—even commonplace. For *Mars Global Surveyor* (*MGS*), now entering its second Earth-year of global mapping, this seemed to be the case, until an extraordinary finding—possible liquid water on Mars—finally turned the spotlight to this tireless explorer.

Launched in November 1996, *Mars Global Surveyor* was the first of NASA's Mars Surveyor missions. With the intention of creating a long-term, cohesive plan to explore the Red Planet, the Mars Surveyor Program proposed a series of missions, one building on another, that would develop an overall understanding of Mars' history and climate evolution and search for indicators of past or present life there. Other missions in the program included the lost *Mars Climate Orbiter*, *Mars Polar Lander,* and the now-canceled *Mars Surveyor 2001* lander. Fortunately, the *Mars Surveyor 2001* orbiter is still set to launch in April 2001, and plans for a 2003 mission are still under way.

One of NASA's earliest "faster, better, cheaper" missions, *Mars Global Surveyor* gave many of the instruments originally on board *Mars Observer,* lost in 1993, a second chance to investigate Mars. Indeed, five of *Mars Observer*'s seven instruments were rebuilt and reflown on *MGS*. Malin Space Science Systems' Mars Orbiter Camera, Arizona State University's Thermal Emission Spectrometer, Goddard Space Flight Center's Magnetometer/Electron Reflectometer and Mars Orbiter Laser Altimeter, and Stanford University's Radio Science analysis facilities compose *MGS*'s suite of instruments, which together provide a global, composite view of Mars. By the time mission operations conclude next February, *MGS* will have compiled an extensive record of the nature and behavior of the Martian surface, atmosphere, and interior—necessary information for planning more specialized missions to the Red Planet, such as sample returns or even human landings.

A SHAKY, YET MEMORABLE ENTRANCE

After a nine-month cruise through space, *MGS* did have a moment in the spotlight, when a broken damper-arm and weakened yoke threatened one of the spacecraft's solar panels. The malfunction was confirmed as the spacecraft began lowering its orbit through a process called aerobraking, in which the craft skims the atmosphere, creating drag and thus slowing itself down. Engineers feared the weakened solar panel would not survive if they went ahead with the original plans for aerobraking. After pinpointing the problem and running numerous tests, the team developed a slower and safer aerobraking schedule, which delayed the mission one year. *MGS* achieved its final mapping orbit, a near-circular orbit approximately 367 kilometers (228 miles) from the surface, in February 1999, and the official mapping mission began weeks later.

Even while *MGS* was in elliptical orbit, waiting to begin the global mapping mission, the instruments on board were busily at work. The Mars Orbiter Camera (MOC) looked deep within canyons and craters and peered down into the Arizona-sized volcano Olympus Mons. During an encounter with Mars' inner moon, Phobos, Thermal Emission Spectrometer (TES) data, showing extremely fast heat loss, combined with close-up MOC images to reveal that the moon is covered by a layer of fine powder at least a meter deep, most likely formed from millions of years of meteoroid impacts.

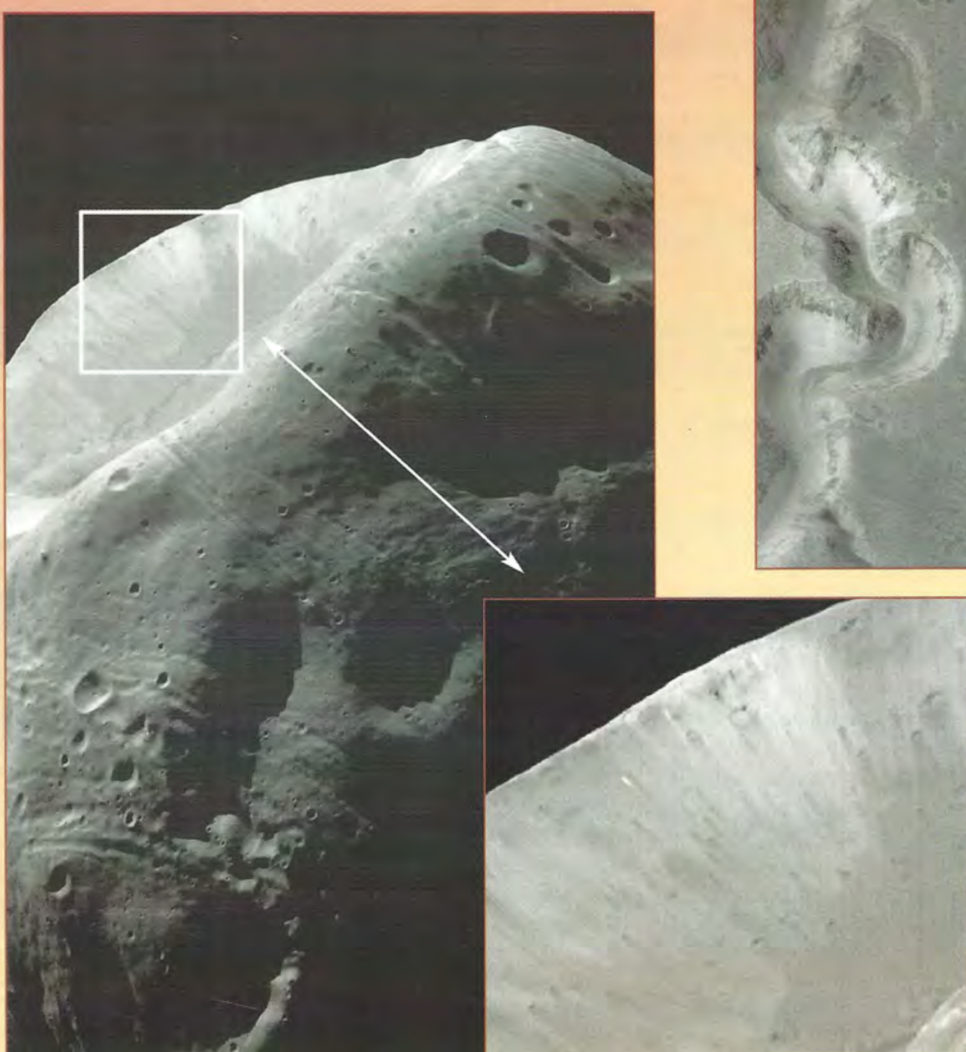
Extended time in aerobraking orbit delivered a great surprise for *MGS*'s Magnetometer team—evidence suggesting past movement of the Martian crust. Banded patterns of magnetic fields pulling in opposition on the Martian surface appear to be

Since the discoveries of* Mariner 9 *in 1972, we have known that water may once have flowed on Mars, carving a variety of canyons, valleys, and channels. Some of this water appears to have gushed across the landscape in sudden, massive floods. Other valleys appear to be the result of water that flowed underground, sometimes causing the ground to collapse and sediment to be transported away. But one puzzle has remained for more than 20 years—did any of these valleys experience flows of liquid water over long periods?

Top: This MOC image shows a portion of the wall and floor of an ancient impact crater in Noachis Terra. The image reveals* V*-shaped depressions on the crater wall that are characteristic of water seepage from an underground layer. The image also shows a smooth, dark surface on the crater floor that might be interpreted as the remains of a pond or lake. There are two types of dark surfaces on the floor of this 50-kilometer-diameter (31-mile) crater. One dark surface shows a rippled texture and is known from* Viking *images to be a field of windblown dunes. The other is a relatively smooth surface with "islands" of bright material within it. The boundary between the dark floor materials and the lighter materials of the crater wall suggests, by the formation of bays and peninsulas, a "ponding" relationship.

Left: MOC captured this image on January 8, 1998, showing a portion of the meandering canyons of the Nanedi Valles system—one of several valleys that cut through the smooth and cratered plains of the Xanthe Terra region of Mars. Within the floor of the 2.5-kilometer-wide (1.6-mile) valley is a small, 200-meter-wide channel, seen in the upper right corner of the image. The channel suggests that the valley might have been carved by water flowing through this system, maybe in the form of a river, for an extended period of time.

Images: MSSS/NASA



This high-resolution MOC image of Mars' larger moon, Phobos, captures a 10-kilometer-diameter (6-mile) crater called Stickney, which is almost half the size of Phobos itself. Light and dark streaks trail down the slopes of the bowl, suggesting that even in a gravity field about 1/1,000th of the Earth's, debris still travels downhill. ***Images: MSSS/NASA***

similar to patterns seen in the crust of the Earth's seafloors and could indicate an early era of plate tectonics. On Earth, the seafloor slowly spreads apart at midoceanic ridges as new crust flows up from Earth's interior. The direction of Earth's magnetic field reverses occasionally, resulting in alternating stripes in the new crust, similar to the magnetic stripes found on Mars. In order to call the pattern on Mars a definite crustal spreading, researchers will need to find a point of symmetry, where the pattern on one side matches the pattern on the other. Another possible explanation for the stripes is fracturing of a uniformly magnetized crust due to volcanic or tectonic stresses from the rise and fall of neighboring terrain.

The aerobraking orbit was essential in finding the magnetic stripes because the lowest point of each elliptically shaped orbit dipped below the planet's ionosphere, allowing the magnetometer to gather better-than-planned regional measurements. If the mission had gone just as planned, the spacecraft's orbit would have been more than 320 kilometers (200 miles) high, and the magnetometer would have had too much magnetic interference to detect the stripes.

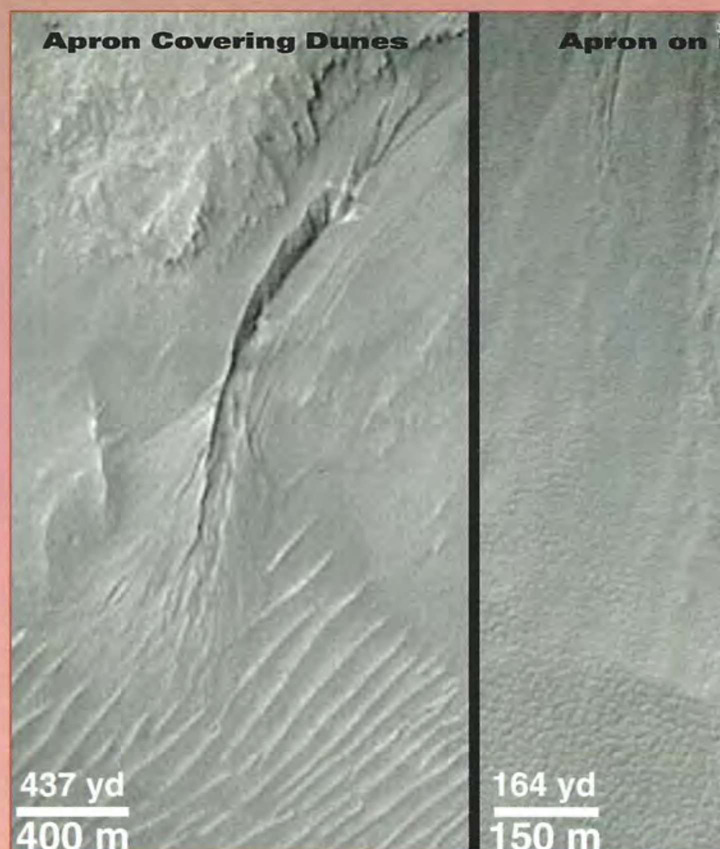
MGS also began uncovering clues to Mars' warmer, wetter past well before reaching circular orbit. Early MOC images suggesting ancient riverbeds and ponding within craters began what is now a large portfolio of images chronicling Mars' water. While the spacecraft was still in orbital hiatus, TES data also revealed the first clear evidence of an ancient hydrothermal system. Around Mars' equator, TES found an unusual accumulation of the mineral hematite, crystallized grains of ferric (iron) oxide that typically originate from thermal activity and standing bodies of water. And nearly a year before its official mission began, the Mars Orbiter Laser Altimeter (MOLA) was collecting more than 50,000 measurements of the north polar ice cap, revealing canyons and spiral troughs in the pole's water and carbon dioxide ice.

FOLLOWING THE WATER

Mars is the only other planet in our solar system known to have water, an atmosphere, and a history resembling present-day Earth. The Mars Surveyor Program, striving to learn more about these characteristics, highlighted three primary goals for its missions to Mars: life, climate, and resources; one common thread linked the goals together—water. We know that water existed on the now dry and barren Mars. Finding where the water was will guide us to interesting places to look for life (past or present). Understanding what happened to the water is essential to understanding Mars' climate history. And discovering traces of current water, either underneath the surface or at the poles, will be invaluable for future human explorers.

Just a few weeks ago, *MGS* made headlines with images suggesting liquid water may have flowed on Mars very recently. MOC images captured numerous "alcoves," or recesses, in the sides of craters, valleys, and pits. Beneath the alcoves are gullies resembling terrestrial channels cut by flowing water. Near the floors of the craters and valleys are debris aprons formed when the flow stopped and laid down its load of rocks and soil (for more about the Martian gullies, see Factinos, page 21).

The visual evidence, although compelling, challenges the experts' understanding of Mars. With temperatures well below freezing and an atmosphere 100 times thinner than at sea level on Earth, how could liquid water be stable long enough to



flow downhill? Certainly, much effort will be made by *MGS* and by future missions to Mars to answer this question and to determine whether or not liquid water exists there today.

The carved gullies are not the only evidence of water that *MGS* has collected. Topographic data and a variety of MOC images suggest that the northern lowlands resemble an ocean basin. Elevation measurements from MOLA and radio-science measurements of gravity, collected to create a crustal map of Mars, reveal a thinned crust below the northern lowlands and evidence of a system of now-buried channels that could have fed a great northern ocean.

The discovery was largely due to *MGS*'s Radio Science (RS), which measures the varying pull of gravity from different regions on Mars. Areas with channels filled with sediment have lower gravity. The RS data supported the existence of large channels, possibly 200 kilometers (125 miles) wide, thousands of kilometers long, and at least 1 to 3 kilometers (0.6 to 1.9

Gravity data from Radio Science and topography data from the Mars Orbiter Laser Altimeter combine in this global slice of the crustal structure of Mars along 0° longitude. In the figure, the north pole is at the far left and the south pole is at the far right. The crustal structure under the northern plains is about 40 kilometers (25 miles) thick, while at the high southern latitudes it is about 70 kilometers (45 miles) thick (for illustrative purposes, the figure is vertically exaggerated). The sloping region under part of the southern highlands (yellow/orange) versus the region of uniform thickness under the northern lowlands (blue) and Arabia Terra (green) represent two distinct crustal provinces, with the boundary occurring at the lowlands/Arabia Terra (blue/green) transition. Analysis of the topography and gravity indicates that the northern lowlands were likely a zone of high heat-flow early in Martian history. Rapid heat loss in this region could have released gases trapped within the planet to the atmosphere and underground ice or water to the surface, helping to produce a warmer, wetter climate than present on Mars today.

Figure: MGS RS and MOLA Science Teams

In June 2000, Malin Space Science Systems announced that the Mars Orbiter Camera (MOC) had collected evidence of possible liquid water on Mars. MOC has captured more than 120 examples of possible water-formed gullies in craters, troughs, and valleys. Close examination of these images revealed the gullies must be geologically young. Relative to Mars' 4.5 billion years of history, the gullies may be only a few million years old, or less. This estimate is based on the lack of impact craters on the alcoves, channels, and aprons of these features. However, other evidence hints at even more recent formation—in fact, some gullies may be actively seeping water today.

At the bottom of "Apron Covering Dunes" is a series of evenly spaced, almost parallel ridges. These ridges are dunes created by windblown sand. The fanlike deposit, called an apron, at the lower end of the deep channel covers some of the dunes, indicating the apron of debris from the channel is younger than the dunes. The dune field has no impact craters, so it is geologically young. The even younger apron probably formed within the past few centuries.

"Apron on Polygons" shows aprons deposited at the base of the south-facing slope in an impact crater. The slope and plains surrounding the apron materials have a bumpy pattern of evenly spaced polygons. Polygonal patterns on Earth are formed by seasonal and daily freezing and warming cycles of ice in the ground. Such polygons on Earth are usually only several thousand to tens of thousands of years old, at most. The fact that an apron of debris covers the polygons and no new polygons have formed on top of the apron suggests that the apron may be less than a few tens of thousands of years old.

"Fresh, Dust-Free Surfaces" shows small, dark channels eroded into one of the gully alcoves. Two aspects of this picture indicate that the processes involved in Martian gully formation—liquid water seepage and downslope movement of debris—have probably occurred recently, only a few years or even days before the picture was taken. One is the sharp contrast between dark-toned and light-toned surfaces. On Mars, fine, bright dust settles out of the atmosphere and eventually coats surfaces, erasing the contrast between dark and light terrains. If dust had settled over time on the alcoves and small channels shown here, they would not appear so dark relative to the surrounding terrain, which is dust-covered and bright. The other attribute suggesting relative youth is the preponderance of boulders and their sharp, crisp relief. The boulders have not been broken down into finer debris, and they are not covered by sand and dust. *Images: MSSS/NASA*

miles) deep. Such channels would have brought enormous amounts of water to the northern plains, enough to create and sustain an ocean. MOC high-resolution images suggest the origins of such channels would not have been due to rainfall, but rather they would have been created by "sapping" or possibly by a continental ice sheet below the surface. While the evidence is strong, some experts are still skeptical, pointing out that the new ocean hypothesis is far from proven.

Continuing the search for water and resources, *MGS* examined the Martian poles and discovered that the two poles have distinctly different characteristics. The north polar cap is mostly water ice, while TES determined the south residual cap has regions composed of coarse-grained carbon dioxide ice, possibly in the form of a slab. High-resolution MOC images found unusual shapes and landforms on the south polar cap that do not appear on the north polar cap, suggesting the poles have had different climates and histories for thousands, or even millions, of years. Large pits, troughs, and flat mesas on the south polar cap do not seem to appear anywhere else on the planet, leading scientists to think the distinct landforms may have something to do with the amount of frozen carbon dioxide in the region.

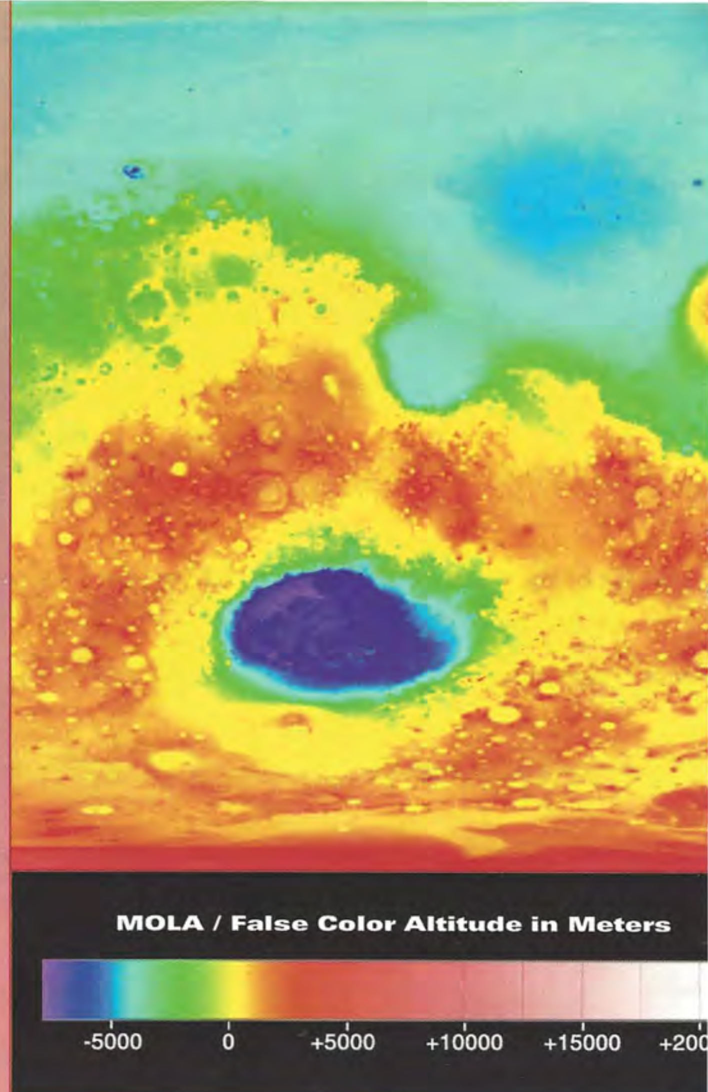
READING THE ROCKS

Last year, data compiled from MOLA were used to create the first-ever global 3D view of Mars. The map represents 27 million elevation measurements gathered in 1998 and 1999. The elevation points are known with an accuracy of 13 meters in general; large areas of the flat northern hemisphere are known with precision better than 2 meters. The map reveals a striking difference between the planet's low, smooth northern hemisphere and the heavily cratered southern hemisphere, which sits about 5 kilometers (3 miles) higher than the north. The difference in elevation between the hemispheres results in a slope from the south pole to the north, a major influence on the flow of water in Mars' early history. Scientific models of watersheds using the new elevation map show that the northern lowlands would have drained as much as three-quarters of the water on the Martian surface.

The 3D map (image at right) highlights the massive Hellas impact basin in the southern hemisphere. Nearly 9 kilometers (5.5 miles) deep and 2,100 kilometers (1,300 miles) wide, the impact crater could easily swallow Mount Everest. Surrounding the basin is a ring of material rising about 2 kilometers (1.25 miles) high and stretching out to 4,000 kilometers (2,500 miles) from the impact center. This ring of material, most likely the result of an asteroid impact, has a volume equivalent to a 3.5-kilometer-thick (2-mile) layer covering the continental United States and contributes significantly to the high topography in Mars' southern hemisphere.

TES data reveal that the dark (low-albedo) areas on Mars are generally basaltic in nature. After years of speculation, the new TES data confirm the composition of Mars' dark rocks. Furthermore, TES data show these rocks are not heavily weathered, despite their great age, suggesting that chemical weathering on Mars might be much less extensive than previously thought. No areas of carbonate, sulfate, or quartz have been found, although the area near the equator appears to be rich in hematite.

MOC's hawkeyed view continues to reveal layers of Mars' history. The camera, which records the planet's surface one strip at a time, has exposed layers in canyons and troughs, in both the north and south polar caps, on the tops of volcanoes, and in the pits of impact craters. Eventually, these layers will tell us the story of Mars' geologic history. MOC's narrow-angle telescope, with resolution at approximately 1.5 meters per pixel, shows objects on the surface the size of a school bus. Never before has Mars' surface been seen from orbit in such detail, and geologists are finding that many surfaces have no obvious analogs on Earth, raising new questions for future missions to examine.



A CHANGING FACE

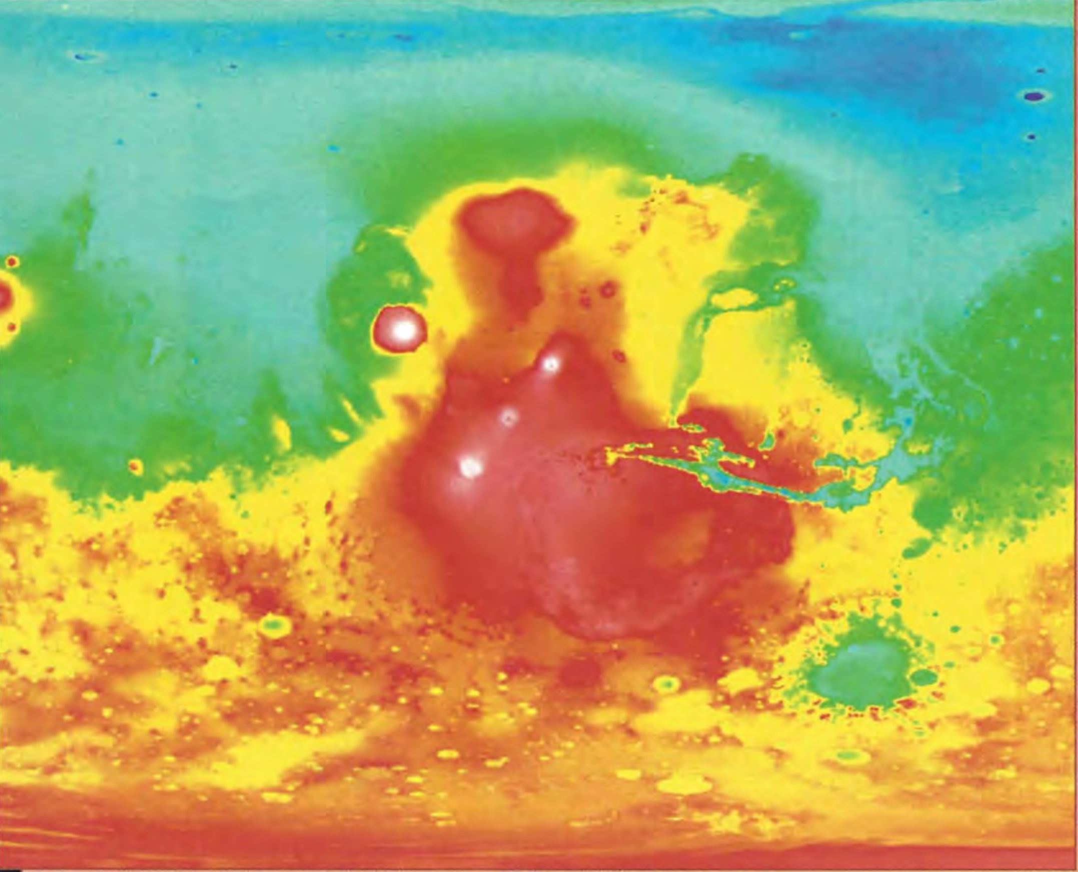
MGS's two-hour circular orbit allows the instruments on board to monitor the constant reshaping of Mars by the forces of nature. Dust devils, dune formation, and landslides rearrange Mars' dusty facade. Seasons change, ice caps grow and retreat, clouds form over high-elevation areas, and dust storms kick up, then disappear.

MOC monitors Mars' weather daily, just like weather satellites monitoring Earth. Radio Science uses Doppler shifting in the radio frequency to determine the pressure and temperature of Mars' atmosphere with more accuracy than if we had a weather balloon there. Researchers have collected tens of thousands of temperature and atmospheric pressure readings, documenting the daily and seasonal changes on the Red Planet.

One particularly interesting weather feature on Mars is the dust devil, which results from vortices of air that arise when the ground is heated. On Earth, they are relatively small features, but on Mars, the average dust devil may carry several tons of dust within its height of 2 kilometers (1.2 miles)—so much dust that dust devils could be responsible for giving the Martian sky its unearthly brownish color. As the dust devils pick up surface dust, they leave behind dark streaks, which were a mystery to scientists until MOC caught some dust devils "in the act" last December. Although these vortices are sufficient to raise and carry tons of dust, the slow-moving dust devils have much less power than tornadoes on Earth, which develop under very different conditions.

MOC captured evidence of shifting sands in dune fields that were first seen in *Mariner 9* pictures from the early 1970s. Closer observation of the moving dunes could allow scientists to measure the rates of wind erosion on Mars. Scientists are paying special attention to the dark dune fields isolated within large impact craters, because these dunes appear to be free of the dust layer that covers much of the Martian surface. By watching sand dunes, scientists are also developing new insights into how the polar caps retreat as seasonal warming begins. MOC images taken at the end of Martian winter in both 1998 and 1999 reveal patches of dark sand poking through fields of carbon-dioxide frost. Although the images closely resemble aerial photographs of dunes on Earth, these features in the Martian environment perplexed scientists at first. Some thought the dark spots on the ice could be the result of small explosions, but new MOC images show the dark spots continuing to grow and spread as spring approaches, until eventually the frost disappears, revealing the dune field underneath.

(continued on page 16)



This high-resolution map, generated by MGS's Mars Orbiter Laser Altimeter, represents 27 million elevation measurements gathered in 1998 and 1999. Image: MOLA/NASA

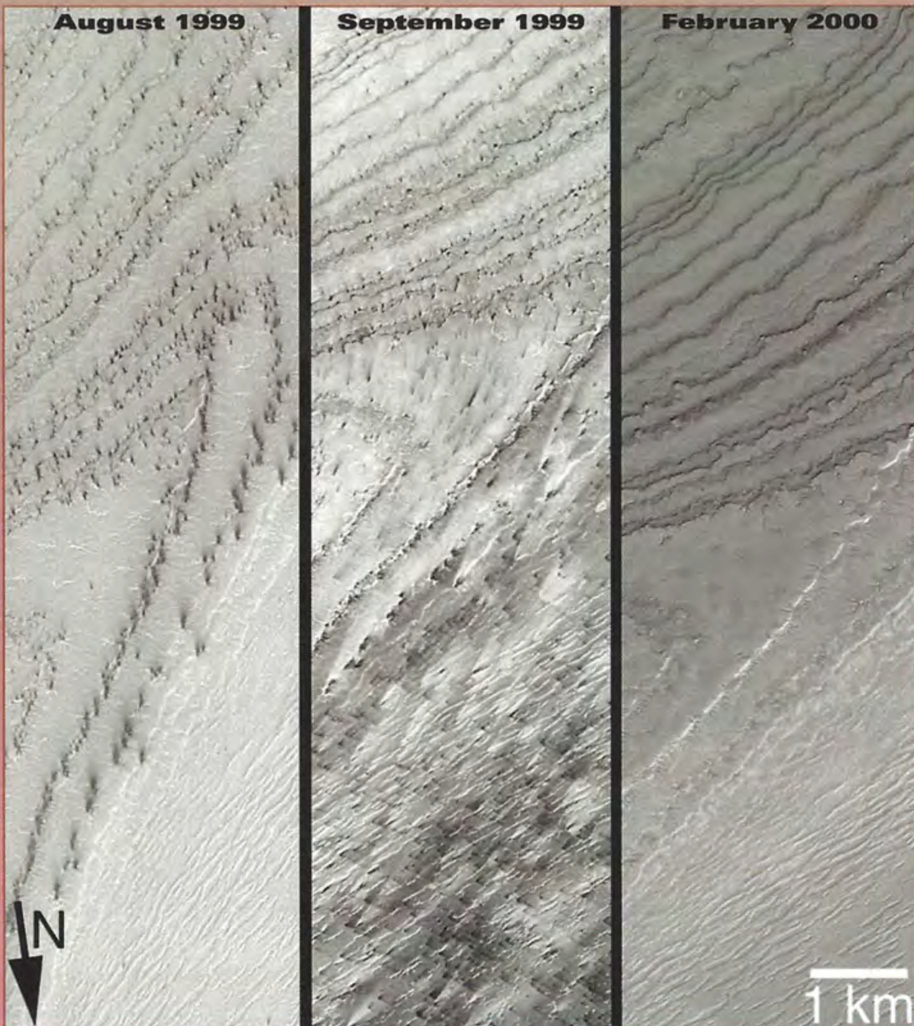
Dark streaks on the steep, downwind slopes of sand dunes in Rabe Crater in the Helles Pontus/Noachis region are visible at several locations in this MOC image. Sand dunes move forward by the combined action of wind that drives sand up the shallow slope on the windward side of the dune (in this case, the slopes that face toward the lower right) and the avalanching of this sand down the steeper, leeward slope. The dark streaks indicated by arrows are evidence of sand avalanches that occurred within a few months or years of when the picture was taken (March 1999).

Image: MSSS/NASA

Top: During northern summer in April 1999, MOC looked down at the north polar cap and saw a relatively flat surface covered by small pits, cracks, bumps, and knobs, giving it a cottage cheese look. The pits, estimated to be less than about 2 meters deep, probably developed over thousands of years of successive spring and summer seasons. The north polar residual cap is thought to contain mostly water ice because its summertime temperature is usually near the freezing point of water and because Viking data show water vapor rising off the cap in summer.

In contrast, this image of the south polar cap (right), with its flat-topped mesas with inset circular depressions, looks more like Swiss cheese. The largest mesas here stand about 4 meters high and may be composed of frozen carbon dioxide and/or water. Nothing like this has ever been seen anywhere on Mars except within the south polar cap, leading to some speculation that these landforms may have something to do with the frozen carbon dioxide (dry ice) thought to be in the south polar region.

Images: MSSS/NASA



Left: Here are three views of the layered terrain near the Martian south pole. Together, these three views document changes that occurred between August 1999 and February 2000. Each view is 3 kilometers (1.9 miles) wide. The wavy, almost parallel lines in the upper half of each picture are exposed layers of the south polar layered terrain. As the terrain began to defrost in early August 1999, dark spots appeared. Wind occasionally picked up some of the dark material and blew it across the landscape, creating dark streaks. By late September, much of the scene was covered with these dark spots and narrow, dark windstreaks. By February, all of the frost and dark spots were gone, revealing the underlying layered terrain.

Image: MSSS/NASA

(continued from page 14)

ENCORE PERFORMANCES?

At this point, *Mars Global Surveyor* is still only halfway through its 687-day primary mission. Maybe there's an extended mission in the wings. Whatever its future, *MGS* has demonstrated superbly how one successful mission can reshape our understanding of a neighbor in space.

Each of the *MGS* science teams proudly shares its findings on the Internet. Recently, Malin Space Science Systems unveiled a web-based data bank of MOC images—all 25,000 of them!

There will come a day when this dependable spacecraft will stop sending its observations from Mars, and it will be up to the next mission to teach us more. Until then, *MGS* continues to give us a closer, deeper, and truer view of Mars' character, day after day after day. Now that deserves a standing ovation.

Jennifer Vaughn is Managing Editor of The Planetary Report.

Follow the *Mars Global Surveyor* mission on the Internet:

Mars Global Surveyor home page
http://marsweb.jpl.nasa.gov/mgs

Malin Space Science Systems' Mars Orbiter Camera
http://www.msss.com

Right: A variety of geologic features stand out in this high-resolution MOC image of the eastern edge of the Gigas Sulci, approximately 750 kilometers (470 miles) northwest of the Pavonis Mons volcano and 350 kilometers (220 miles) southeast of Olympus Mons. The Gigas Sulci consist of steep, somewhat mountainous terrain, but the valleys and some of the slopes between the hills appear smooth and mantled (perhaps by dust). Small, parallel ridges on some of the valley floors are probably windblown dunes. The edge of the hilly terrain is cut by a deep trough, caused by faulting and down-dropping in the center of the valley. The slopes of this valley exhibit dark streaks caused by small landslides. Boulders the size of small buildings perch on some of the slopes. The deep trough and another, shallower one to the south (lower left) cut across lava flows, indicating that the troughs formed after the lava flows were emplaced, cooled, and hardened.

Image: MSSS/NASA

World Watch

by Louis D. Friedman

Usually we "watch" the world's government space programs in this column. But what about privately funded space exploration?

So far, all missions exploring the solar system are or have been government funded. The United States has sent missions to the Moon, to all the planets except Pluto, to many planets' satellites and to several asteroids, and, currently, two spacecraft are on their way to comets. The European Space Agency (ESA) has flown to Halley's comet and has flights planned to Mars and to a rendezvous with a comet in 2011. Germany, partnering with the United States, has launched a Sun-observing mission. Japan has sent spacecraft to the Moon, to Halley's comet, and to Mars. The Soviet Union explored the Moon, Mars, Phobos, Venus, and Halley's comet.

Despite the number of past programs and others still in planning, we receive mail suggesting "we could do more missions to other worlds if only governments would get out of the way," or "why not support private space exploration?" Responding to the latter is easy: The Planetary Society is happy to encourage and offer financial support to private missions, assuming they are credible and our members support the project.

In response to the first suggestion, while we might encourage private missions, we remind people that the experiment of getting governments out of the way has been done. Governments got out of the way of lunar missions for 20 years after the last *Apollo* mission in 1972. With Mars, after *Viking* in 1975, governments got out of the way for nearly as long. During that time, nothing happened—no private enterprises stepped in to fill the gap.

Private interests need financial returns. Missions to gain knowledge, inspire people, or provide incentives for education don't motivate private investors. Nor does the record of space failures; space, as we have learned repeatedly, is a difficult place. Perhaps after the way is paved by government missions, the road to space will be easier, and privately funded missions may become more appealing for investors.

A number of private companies and interests are exploring possibilities now. One of the most notable is the effort led by the Open University in Great Britain, which has won approval to attach a lander to ESA's *Mars Express* mission in 2003. The lander, *Beagle 2,* is only partially privately funded, with some of its support coming from the British government. Of course, the ESA mission is government funded, although ESA deserves great credit for accepting this piggyback.

One company, Celestis, has developed a business of carrying the cremated remains of people into space—a business perhaps, but hardly a venture in exploration. A sister company, Encounter 2001, is seeking to launch a spacecraft into interstellar space carrying people's DNA (in the form of hair samples) and names.

Several companies are rumored to be engaged in a new Moon race. LunaCorp, SpaceDev, TransOrbital, and Applied Space Resources, Inc. are four US companies that have announced their intent to conduct lunar missions. LunaCorp recently announced a one million dollar sponsorship from Radio Shack (far less than required to conduct a space mission but still noteworthy). A fifth company, being started by an Internet incubator of companies, is also reported to be developing a lunar mission. In addition, SpaceDev has announced that it is seeking investors for a mission to a near-Earth asteroid.

These companies have specialized business plans for returning a profit or at least paying for the costs of their missions. In some cases, the ideas are straight from science fiction. Some companies propose to mine asteroids, claim property, or build hotels on the Moon; others are thinking of displaying billboards or commercials in space. Similar goals drive a private space venture in Earth orbit: MirCorp plans to provide private funding to commercialize the operations of the Russian *Mir* space station. Private space ventures are also looking to the dot com and entertainment worlds to enable their efforts.

But there's something more to consider about these new companies, something more important, in my opinion, than their business plans. What are their plans in the event of failure? As numerous government missions have shown and nascent private rocket companies have learned the hard way, something always goes wrong in space.

Perhaps I sound negative, but I'm just trying to be realistic. I believe private missions are possible—in fact, just this past spring I dropped everything for a few weeks in an attempt to make a private mission happen. Despite setbacks, I haven't given up. The time may be coming for a credible private mission, but don't let anyone tell you that governments should get out of the way to space. There is no one ready to pass them.

Meanwhile, The Planetary Society has led the way for private funding of space missions. Our Mars Microphone on the *Mars Polar Lander* was the first privately funded instrument sent to another world. On the Russian *Mars '96* mission, we launched the first private message to the future with our *Visions of Mars* CD. And our Red Rover Goes to Mars project, which was originally set to have flown on the *Mars Surveyor 2001* lander, could potentially fly on the 2003 mission. This Planetary Society project, as a joint educational venture with LEGO Company, may mark the first commercial participation on a planetary project.

We will keep leading the way. We have a microphone ready to go to Mars again, and Red Rover will continue its travels. The Planetary Society is ready and willing to explore new worlds. We do this without government money or aerospace industry funds. Our only criteria for undertaking projects are their value and credibility—and our members' support. With that, we know we will fly again and again.

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

Human Exploration of Space:

There is a story told in Hollywood . . . Two young screenwriters brought to Clint Eastwood, the iconic Western actor and filmmaker, a script they had just completed. They felt it would be a perfect film for him to star in and direct. It told the tale of a loyal band of retired test pilots, once cheated of the chance to become astronauts, who are recalled to space to save civilization from almost certain catastrophe.

Eastwood was impressed by the young men's efforts and believed the script would make an exciting movie, but the idea that old "fuds" past retirement age would be allowed to fly into space was just too implausible. So he rejected the script.

Then NASA announced that 77-year-old former astronaut John Glenn would return to space as a crew member on STS-95, a flight of the space shuttle *Discovery*.

Truth had become stranger than fiction. Eastwood changed his mind.

Space Cowboys, starring Eastwood, James Garner, Tommy Lee Jones, and Donald Sutherland, will open in theaters this summer.

Space exploration and science fiction enjoy a symbiotic relationship, and sometimes the line between truth and fiction is hard to discern. Much of science fiction grows out of the human desire to imagine what it would be like to be freed of the bounds of Earth. Many of the scientists and engineers who work to turn such imaginings into reality were inspired by science fiction. And, in turn, their achievements and discoveries provide new ideas and themes to be tackled by science fiction writers.

This summer The Planetary Society is examining this relationship in a National Public Radio (NPR) special called *Human Exploration of Space: Fact and Fiction*. Hosted by Larry Mantle of radio station KPCC and produced by the Ken Mills Agency, the show will be fed to NPR stations on August 29 and September 26. (Check with your local NPR station for its broadcast plans.)

Many Planetary Society friends, Advisors, and Directors take part in the show, sharing their memories and experiences in traversing the regions between fact and fantasy. As a preview, we have selected excerpts from their radio interviews. We hope you enjoy their perspectives.
—Charlene M. Anderson, Associate Director

Author Ray Bradbury,
remembering when *Viking* landed on Mars:
Roy Neal of NBC interviewed me on TV and radio that morning, and he dared to say, "Mr. Bradbury, how does it feel, now that you've been writing about Mars all these years and you put a civilization up there—you colonized it with all kinds of people. How does it feel now that we've landed there and you discover there is no civilization, and there are no Martians?"

I said, "Fool, fool . . . there are Martians on Mars, and it is us. We are the Martians from this day forward. We Earthmen have become Martians, and we will live there, and we will survive there. Now, no more questions like that!"

Film critic F.X. Sweeney,
commenting on *2001: A Space Odyssey*:
[*Star Wars* turned] back the clock from Kubrick's authentically sterile view of outer space, of just clean, white light falling on clean objects that are moving along between the planets. When you die in outer space, there is no sound, and that's the terrifying part. I was quite appalled to discover that space felt cold: I actually had to zip up my jacket watching this film. That coldness was a representation of what space really is. It was to call upon those mythic stirrings within us that would help us face our fears before going into outer space by saying, "This is what you can expect."

***Right:* Sometimes an old "fud" is the best man for the job, as a space cowboy attaches a booster rocket to an errant satellite. Clint Eastwood almost didn't make this film; he thought the idea of older people flying in space was too outrageous until John Glenn proved him wrong.**

***Below:* In the Clint Eastwood film *Space Cowboys*, some over-the-hill test pilots prove they still have the right stuff by mastering the new technologies of space, including the shuttle maneuvering arm.** Photos: WB & Village Roadshow Film Limited ©2000

Fact and Fantasy

by Charlene M. Anderson

Planetary Society President Bruce Murray, imagining a film:
Suppose you could script a multimedia production of the *Voyager* mission . . . the first close-up look at Jupiter, at the four Galilean satellites; then on to Saturn, its major moon Titan; on to Uranus and Neptune . . . using a trajectory, an opportunity, that comes only every 175 years. Think about the drama; it's incredible. That will go down in history as one of the real high points of the 20th century. It will be there with *Apollo*, for different reasons. The mission was launched in 1977, got to Jupiter in 1979. These were not periods when we were clear about what we were doing as a country, but we did that. That spirit of reaching out, that exploration spirit, empowered the Congress to back us when they could have not. It empowered NASA to stay behind it, and it certainly empowered the public to support it.

Left: The return of 77-year-old John Glenn to space in 1998 proved the old adage that truth is stranger than fiction. His adventure inspired a movie based on retirees returning to active duty and flying a space shuttle mission. Glenn is seen here being prepared for a training session on a centrifuge that would subject him to three-g forces. Photo: NASA

Engineer Donna Shirley, on the frontier and fiction:
There's a real problem in the human psyche, because we don't have any frontiers anymore that the average person can get to. In the early days of the Americas, if you wanted to saddle your horse or pack everything on your back and walk out into the wilderness, you could. Now it's so expensive to get to the only frontier left, space, a lot of people are frustrated. So there is an awful lot of vicarious adventure that science fiction allows us to participate in.

Bill Nye the Science Guy, expanding on the influence of *Star Trek*:
The Prime Directive can guide us in our exploration on other worlds, most notably and contemporaneously, the exploration of Mars. We should go to Mars and dig around, look for underground water, look for evidence of living things or evidence of past living things. If we decide that the surface of Mars, or the subterranean spaces on Mars, if they exist, are without life, then we can go ahead and build our Mars habitats.

On the other hand, if we find living things on Mars, then the Prime Directive gives us pause for thought. Perhaps we should leave that world alone and see how life evolves there. You can't really state the question that you should think about more clearly than the Prime Directive used on *Star Trek*.

Majel Barrett Roddenberry raises a question:
I'm enamored of the idea of mankind in space. I want to see it happen so badly. But I do want it to be done the right way: I want it done intelligently and with kindness and with thought and with the expectation that whatever we find out there is not going to be like us. Are we prepared to live with this?

***Apollo 11* astronaut Buzz Aldrin, on the lingering effects of his landing on the Moon:**
It wasn't the rocks that we brought back or the questions we answered, or what somebody said here or there. It was the impact that that had on millions of people around the world who participated and, by watching, had a sense of involvement in that experience, so much so that it froze in their memory where they were, all the circumstances around that event.

Now, when I run across these people, I rejuvenate the thought of that moment. They feel compelled to tell me where they were at that time. People recall things that happened, whether their tragedies or major significant achievements. Ours happened to be a significant achievement that had its roots in the dreams of centuries. ❍

Questions and Answers

On Earth, wherever there's an aqueous medium—even a super salty or highly acidic one—we find living things. This photo of acid-loving bacterial slime streamers was taken in a tunnel at an unused copper mine in northern California. The one-meter-wide stream is inhabited by a previously unknown Archean species, which thrive in this pool of concentrated sulfuric acid laced with arsenic and other toxic metals. The growing ranks of "extremophiles" we are finding on Earth bolster the theory that life might exist in Europa's salty seas. Photo: K.J. Edwards, Woods Hole Oceanographic Institution

On Earth, there are geological mechanisms which remove salt from seawater that cannot be present on Europa. Is it not realistic to assume very high salinities for Europan water, making life unlikely?
—Rindert Bolt,
Utrecht, The Netherlands

Your point about high salinities being likely in Europa's ocean appears to be valid. The salinity of Earth's ocean is regulated over geologic time by several mechanisms. One is reduction of sulfates to form less soluble sulfide minerals in the oceanic crust. Another is evaporitic precipitation of salts, which accumulate in continental crust. Europa may or may not have the first type of regulatory mechanism, but it certainly has no continents, so evaporite processes can't work as they do on Earth.

There appear to be great differences between Earth and Europa in the quantities of salt-forming elements in each body's crust. Most of our planet's sulfur and chlorine supplies have been sequestered within the metallic core, whereas a much larger fraction of Europa's sulfur and chlorine may exist in its crust, as chloride and sulfate salts. This difference has to do with their different bulk compositions when these bodies formed and with the way global differentiation occurred.

Europa's ocean is probably saturated in salts—it may well be 10 times saltier than Earth's ocean or more. So could life exist in such an environment? Although on Earth the saltiest brines tend to have low biodiversity (the Great Salt Lake and the Dead Sea are good examples), they also sport some of the most luxuriant densities of microorganisms known from natural lake environments. For organisms adapted to such conditions, it seems the saltier the better. There are no fundamental laws of life that would rule out life in Europa's ocean, even if it is as hypersaline as some models would suggest, or even if it is a concentrated ocean of sulfuric acid solution, as other models suggest.

What are the needs for life? 1. There must be an energy source, such as chemical disequilibria, that can be exploited by organisms. 2. There must be nutrients, including a source of organic carbon or a biochemical means to reduce carbon from inorganic sources. 3. And there must be liquid water.

These needs seem to be met by a wide variety of models of Europa's ocean. The wording of the classical requirement for "liquid water" may well be replaced by "a polar solvent containing polar or ionic solutes." This could include hypersaline aqueous solutions or sulfuric acid solution. The standard requirement for an aqueous medium (and physical conditions that allow the stability of such a medium) does not mean that life is possible only above 273 kelvins (0 degrees Celsius or 32 degrees Fahrenheit), where pure liquid water is stable.

The more we look for life in extreme environments, like seemingly frozen sea ice and sulfuric-acid drainage from mines (see photo at left), the more we have come to realize that wherever liquid water is in nature (water redefined as above), life is likely to exist and thrive. Low rates of biodiversity in hypersaline and highly acidic environments may reflect the fact that these conditions are not the norm on Earth; such environments tend to be transient on geologically significant time scales on our planet, and so evolution may not have produced as many successful natural experiments and as many species that can cope in such extreme environments. On Europa, such conditions may have been the norm for billions of years, and so there is no telling how evolution may have progressed.

On the other hand, it is possible that there are some fundamentals (though not "laws") that tend to make life less likely or less diverse or somehow very different in hypersaline or super-acidic environments compared to more "normal" environments. High solute abundances may favor high densities of microorganisms here on Earth, because with evaporitic concentration of salts one normally also has evaporitic concentration of nutrients. These large amounts also mean high abundances of toxic heavy metals, which must be dealt with, thus requiring some means to either precipitate the metals or to live with them. If a chemical system is at the ice point, then high solute abundances also mean low temperatures, which imply low rates of metabolic activity and generally low ionic diffusion rates. If organisms contain significantly lower solute abundances internally than those in the external environment, then there also exist high osmotic pressures, which can destroy cells.

Scientists haven't studied whether these and other factors mean that life is less or more likely to get started, and we don't know yet whether they influence rates of biological evolution. However, it is clear that hypersaline conditions do not eliminate prospects for life, and it is tempting to imagine how multicellular organisms might evolve.

High solute abundances and low temperatures mean a high viscosity of the aqueous medium. If an organism is a swimmer, it might be shaped differently from common swimmers on Earth—it might swim more slowly, might eat, grow, and generally live more slowly. With lower temperatures and lower metabolic rates, life spans there could be far longer than for Earth life, and so the number of generations over geologic time far fewer; hence the extent of biological evolution might be lower.

But who knows? The point is that almost anywhere we look on Earth, anywhere an aqueous medium exists, we find life. It seems improbable that with all its complex abiotic aqueous chemistry and geologic processes, Europa would not also have developed biological systems. Consider the variety and richness of life on our own planet now or in any geologic age in the past.

The most ludicrous thought is that we can imagine correctly the nature of any European life. Let's go there and find out how much more incredible nature is than our best dreamers can imagine.

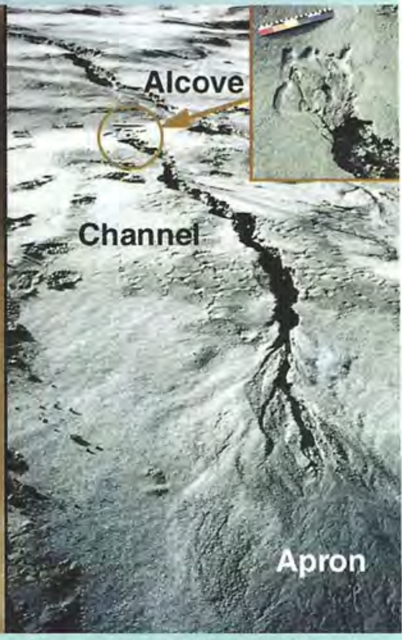
—JEFFREY S. KARGEL,
United States Geological Survey

Factinos

Mike Malin and Ken Edgett of Malin Space Science Systems in San Diego may have discovered evidence of liquid water on Mars. While poring over recent images (at right and on pages 12 and 13) returned by the *Mars Global Surveyor* (*MGS*), the scientists found features that suggest there may be springs of liquid water on or just below the surface of the Red Planet. These new pictures show the smallest features ever observed from Martian orbit—about the size of a sport utility vehicle. Malin and Edgett compare the structures to those left by flash floods on Earth. They reported their findings in the June 30, 2000 issue of *Science*.

"We see features that look like gullies formed by flowing water and the deposits of soil and rocks transported by these flows. The features appear to be so young that they might be forming today. We think we are seeing evidence of a groundwater supply, similar to an aquifer," said Malin, principal investigator for the Mars Orbiter Camera on *MGS*. "These are new landforms that have never been seen before on Mars."

The gullies observed in the images are on cliffs, usually in crater or valley walls, and are made up of a deep channel with a collapsed region at its upper end (an "alcove") and, at the other end, an area of accumulated debris (an "apron") that appears to have been transported down the slope.



These pictures show the similarities between gullies on Mars and on our own planet. On Earth (right), rainwater flowing under and seeping along the base of a recently deposited volcanic ash layer has created a gully. On Mars, we don't see the water but infer it was there from the landforms and their likeness to examples here at home. The MOC image at left, taken on July 3, 1999, covers an area 1.3 by 2 kilometers (0.8 by 1.2 miles). Mike Malin took the picture of Mount St. Helens in the 1980s. The colored bar in the inset is 30 centimeters (1 foot) long.

Images: MSSS/NASA

"We've come up with a model to explain these features and why the water would flow down the gullies instead of just boiling off the surface," explained Edgett. "When water evaporates it cools the ground—that would cause the water behind the initial seepage site to freeze. This would result in pressure building up behind an 'ice dam.' Ultimately, the dam would break and send a flood down the gully." At first, Edgett was skeptical that water formed the strange features. "I was dragged kicking and screaming to this conclusion, but the visual evidence linking groundwater discharges as the cause was too strong," he said.

Most of the gullies are in Mars' southern hemisphere, but a few are in the north. "What is odd about these gullies is that they occur where you might not expect them—in some of the coldest places on the planet," noted Malin.

The water supply is believed to be about 100 to 400 meters below the surface and limited to specific regions across the planet. Each flow down each gully may have had roughly 2,500 cubic meters (about 90,000 cubic feet) of water—or enough to fill seven community-size swimming pools. The process that starts the water flowing remains a mystery, but the team believes it is not the result of volcanic heating.

"I think one of the most interesting and significant aspects of this discovery is what it could mean if human explorers ever go to Mars," said Malin. "If water is available in substantial volumes in areas other than the poles, it would make it easier for human crews to access and use it—for drinking, to create breathable air, and to extract oxygen and hydrogen for rocket fuel or to be stored for use in portable energy sources."

—from the Jet Propulsion Laboratory and NASA Headquarters

Society News

Wanted: Explorers and Adventurers

We want you to be the first to know about an upcoming expedition to Belize and Mexico to search for evidence of the asteroid or comet that ended the age of the dinosaurs.

This will be The Planetary Society's fourth expedition to the Yucatan peninsula to collect and study samples of ejecta blanket material from the Chicxulub impact crater. In fact, our last expedition discovered a significant outcrop of ejecta material, the closest of all known samples to the point of impact.

Our team leaders, Adriana Ocampo and Kevin Pope, are currently on reconnaissance in the Yucatan region assessing future sites to explore. Although dates have not been finalized, we're planning for the expedition to take place sometime during the first quarter of 2001. Using past expeditions as a guideline, we expect this one to last 11 to 13 days and cost approximately $2,500 per person, excluding airfare.

For more information on previous expeditions, check out the July/August 1995 and 1996 issues of *The Planetary Report* or visit the NEO section of our website.

Call Lu Coffing at (626)793-5100 or e-mail her at **tps.lc@planetary.org** for more information or for an application to join the expedition.

—Lu Coffing, Financial Manager

More News on Our Website—In More Ways Than One

The Society's website continues to improve and expand. We're pleased to announce that the site is now hosted and supported by Zoomwerks, where it seems most of the staff are long-time, enthusiastic Society members. With this major step, we're confident you'll be seeing—and hearing!—many exciting new features online.

One of them has already begun. "The Executive Director's Report" features Louis Friedman's personal updates on the latest Society activities, as well as our take on the state of planetary exploration, SETI, and much more. These brief audio reports can be heard by anyone with either the RealPlayer or Windows Media Player plug-ins installed in their web browser.

We hope to bring you many more "streaming" media presentations, including conversations with our distinguished advisors and board members and reports from other individuals at the forefront of exploration. It may not exactly be KTPS Radio, but we think you'll like what you'll hear. Visit us soon at **planetary.org**.

—Mat Kaplan, Web Editor

LEGO Donates Red Rover, Red Rover Systems

The LEGO Company, cosponsor of the Society's Red Rover, Red Rover and Red Rover Goes to Mars projects, donated Red Rover, Red Rover systems to 26 institutions around the world. With Red Rover, Red Rover, students build robotic rovers using LEGO blocks, then practice controlling the rovers via teleoperation.

The recipients of the systems were chosen by a random drawing that took place at The Planetary Society last April. Systems went to India, Poland, the United States, Australia, Honduras, Vietnam, Venezuela, Denmark, and the United Kingdom.

Around the globe, students are competing for a chance to be part of the Student Scientist and Student Navigator teams with our Red Rover Goes to Mars project. The donated systems will permit many more students to participate in the Student Navigator selection going on now.

—Linda Hyder, Education Manager

Planned Giving

Estate planning can be complicated, confusing, and intimidating to even the most sophisticated business person. Whether your estate is worth $500 or $5,000,000, whether you are 25, 50, 75 years old or older, estate planning is important for you and your heirs. In the United States, charitable contributions from wills, insurance policies, and trusts can make a significant difference in the amount of your taxable estate.

Over the years, bequests have allowed The Planetary Society to pay off a second mortgage (when we first purchased Society headquarters), fund special projects, and pay for much-needed equipment. Gifts can be restricted to special projects or unrestricted to be used at the Society's discretion.

If you would like more information about estate planning, call or e-mail Lu Coffing at (626)793-5100 or **tps.lc@planetary.org**. *—LC*

Create Your Own Solar System

Would you like to have your own planet? How about a whole solar system?

The Planetary Society has entered into a partnership with UBUBU ("you-be-you-be-you"), which has developed the UBUBU Universe™, where users can create their own customized collection of 3D planets.

The company's goal is to make your computer and the Web a much friendlier, more intuitive place. You create a virtual solar system that acts as a desktop replacement and browser interface. Place 3D Objects on a planet to represent websites, e-mail, PC files, applications, streaming video, MP3s, or anything else you access with your computer. Navigate by flying to a planet and rotating it to reveal the Object you want.

The Planetary Society's Object is our familiar sailing ship. Sail it on one of your oceans, or put it on top of a mountain if you like—we won't care. Wherever it goes, it will provide a direct link to our website. You can download Earth and other planets, including actor Patrick Stewart's. Stewart is one of UBUBU's creative partners and personally selected the Society as an Object on his planet.

To learn more, or to get your solar system started, visit the Society's home page at **planetary.org**. *—MK*

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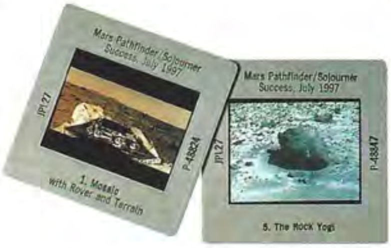

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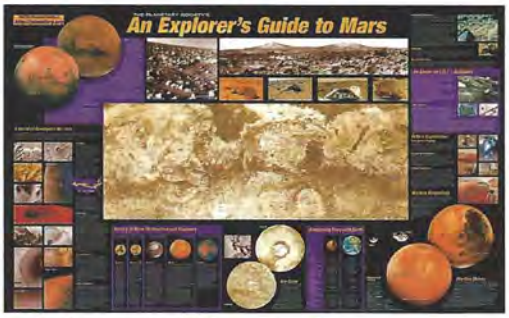

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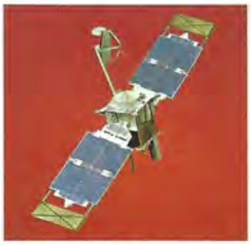

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A dreamy, early evening light suffuses Mars' Valles Marineris in this painting by Ludek Pesek. Born in 1919, Pesek was a member of that small group of space art pioneers who showed us other worlds in our solar system before we had the close-up spacecraft images that we take for granted today. This painting is one of a series called The Planet Mars, which he produced in the 1970s. Ludek Pesek died on December 4, 1999.

Ludek Pesek's space art first came to the attention of American viewers with his spectacular debut of 15 paintings in an article called "Voyage to the Planets," published in the August 1970 issue of *National Geographic*. The magazine soon followed with "Journey to Mars," a feature that included a poster-sized reproduction of Pesek's painting of a Martian dust storm. Pesek illustrated an assortment of books on space for children and adults. He also wrote the science fiction novels *Log of a Moon Expedition* and *The Earth Is Near*. Several of his artworks are part of the permanent collection of the Smithsonian Institution's National Air and Space Museum.

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