The PLANETARY REPORT

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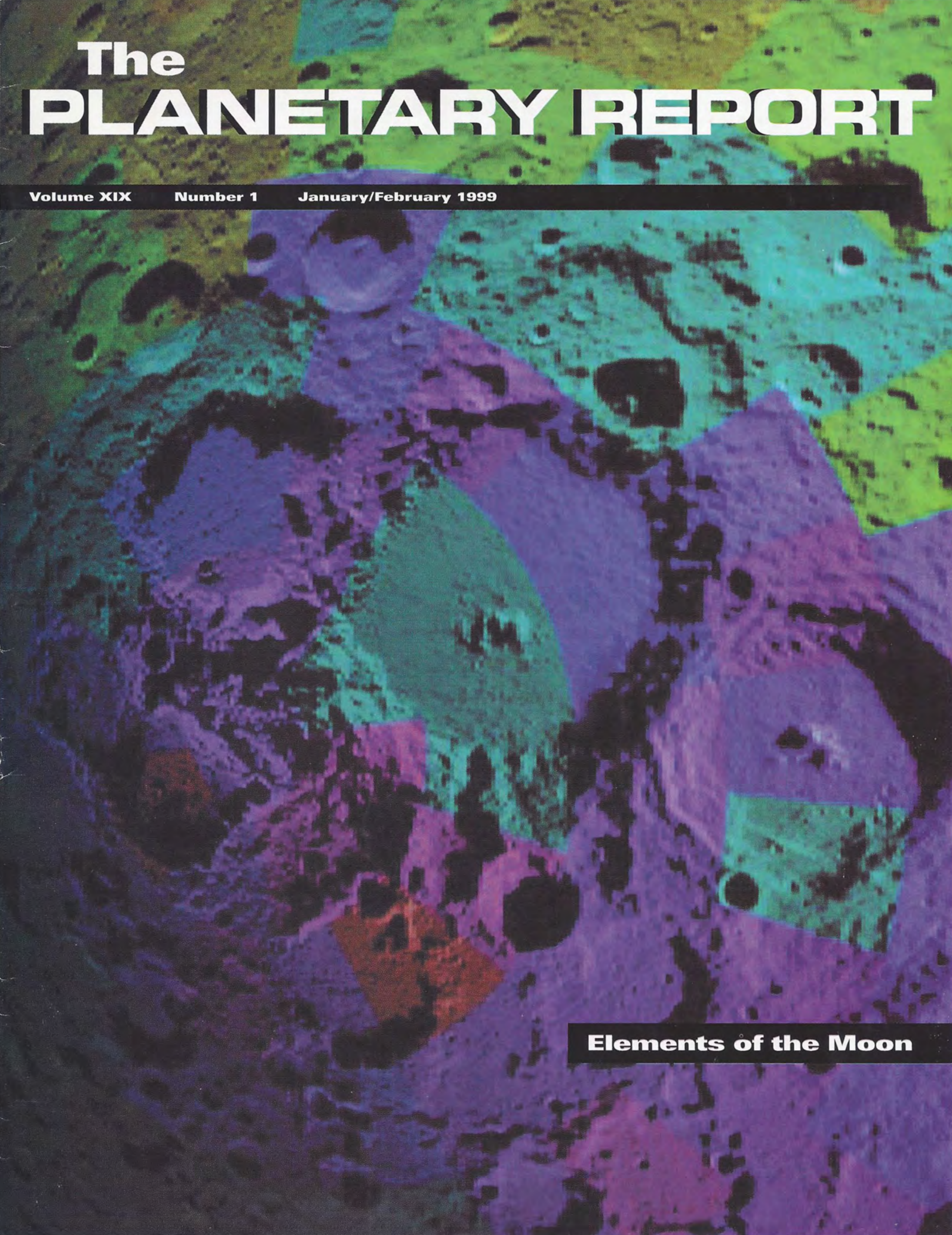

Elements of the Moon

On the Cover:

Looking from Earth, with eyes that see only in a limited spectrum, humans have not been able to determine if deposits of water lie hidden on the Moon. This compound, so abundant on our planet, once seemed absent from Earth's satellite. But the *Lunar Prospector* spacecraft, carrying instruments that see differently than our eyes, has found evidence of water ice in places near the poles that never feel the Sun's light. In this image of the north pole, compiled from neutron spectrometer data, the places most likely to hold water ice are dark blue and magenta; orange-red marks the places least likely to have it.

Image: Ames Research Center/NASA

From The Editor

How will you make the passage of a millennium? Is your party planned? At the Planetary Society, we're working on one grand bash—Planetfest '99, to begin on December 3, the day the *Mars Polar Lander* is scheduled to reach its destination.

Tens of thousands of people will help us begin our millennial festivities as the spacecraft touches down. Although Planetfest will be in Pasadena, people around the world will join the party over the Internet. And we hope to begin the celebrations a little early by holding smaller events around the world throughout 1999 and 2000.

The coming of the Mars Millennium will be our theme. The exploration of the Red Planet—by robots and humans both—is the goal we so ardently promote, and the first two decades of the next thousand years look to be filled with missions of discovery. And we'll wonder what the centuries to follow will bring. Planetary Society members will enter the next millennium knowing that they played a role in shaping the explorations to come.

Consider how far we've come since the last millennial change. In the year 1000, the epitome of exploratory craft was the Viking longboat. With that, humans explored a so-called new world. Now we can reach truly new worlds. We have much to celebrate.

—Charlene M. Anderson

Table of Contents

Volume XIX
Number 1
January/February 1999

Features

Departments

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Members' Dialogue

Pioneers' Paths

In a correction to Questions and Answers in the September/October 1998 issue, distinguished physicist James Van Allen writes:

Loss of contact with *Pioneer 11* was not the result of inadequate onboard power but of inadequate sensitivity of its Sun sensor. The function of the Sun sensor was to provide a roll index (reference point for attitude control) so that at intervals of about six months the reorientation jets could be fired in a rapid sequence of short bursts to precess the axis of the rotating spacecraft and its high-gain antenna to point accurately at Earth. In the absence of a roll reference signal from the Sun sensor, there was no knowledge of how to time the firing of the jets. Hence, the axis of the antenna could no longer be precessed appropriately and the received radio-frequency signal became progressively weaker as this axis drifted slowly away from Earth. The last usable telemetry data from *Pioneer 11*'s scientific instruments were received on January 23, 1995, when the spacecraft was 42.4 astronomical units (AU) from the Sun. An astronomical unit is the mean distance between Earth and the Sun.

NASA announced that the formal end of *Pioneer 10*'s extended mission would be March 31, 1997. However, the Deep Space Network has continued to track *Pioneer 10* and receive clean telemetry data from it on an informal, not-to-interfere-with-newer-missions basis. And through the courtesy of the NASA Ames Research Center's *Lunar Prospector* team, the telemetry data are being processed in the usual way. The latest precession maneuver of *Pioneer 10* was conducted successfully on July 20, 1998. As of December 1998, Ames continues to provide clean, valuable cosmic-ray data to the University of Iowa's investigators and will probably be able to do so through at least 1999. On December 31, 1998, *Pioneer 10* was at a heliocentric radial distance of 71.7 AU or 10.7 billion kilometers (6.7 billion miles), still within the outer heliosphere but gradually escaping from the solar system in the antapex (the point of the celestial sphere from which the solar system is moving) direction.

—JAMES A. VAN ALLEN,
Iowa City, Iowa

Mars or Moon?

Besides the great cost of getting to Mars with *present* technology, we have the more vexing question: why go there? A trip to the Moon has the advantage of affording us shelter from radiation and meteors (once we have "dug" in); "free energy" (photovoltaic); adequate water (if the polar water finding proves out); easy communications with Earth; constant distance from Earth (unlike Mars); interesting resources (helium-3); the ultimate location for a "super" telescope (in a crater on the [far] side); easy travel [to and from] Earth, including tourism; low-gravity hospital care, which is irreplaceable for some therapy; mineralogy and geology on a grand scale with easy com-links to central control and/or Earth satellites; and potential communication systems and other "quick" commercial return-on-investment possibilities. If most people don't know that the first (and last) world voyage by Magellan actually yielded a *profit*, I assure you that the Spanish government of the time did. Of course, all of this is in addition to the overriding advantage of lunar exploration: quick and easy return to Earth with crew rotation, supplies, and medical resources available as needed via robotic or manned ships.

The 1960s saw the greatest scientific accomplishment of humankind, the *Apollo* program, achieved and then frittered away with no infrastructure being established and no lasting presence. We must not make the same mistake again. We must return to the Moon in force for the sake of science, commerce, and humankind (tourism as well as the important psychological factor of escape from our single world). Upon proving out the systems we need to conquer that body (the Moon), we will also be proving out the systems needed for Mars.

Once the systems for Mars are proven on the Moon, we can resurrect the dream of not just traveling to but conquering Mars. To do this, we must have ships that can be launched from the Moon (perhaps accelerated on a linear ramp) or, at a minimum, that can sustain 1-*g* acceleration until deceleration for Mars orbital insertion. That will require advanced fusion, ion, plasma, and/or "zero-point" energy systems, which are now conceived but not fully on paper, let alone in metal.

To "leap" for Mars without planting our "foot" firmly on the Moon is foolhardy and can only lead to problems—problems which we cannot even foresee at this time.

—JAMES BOSHNACK,
Concord, California

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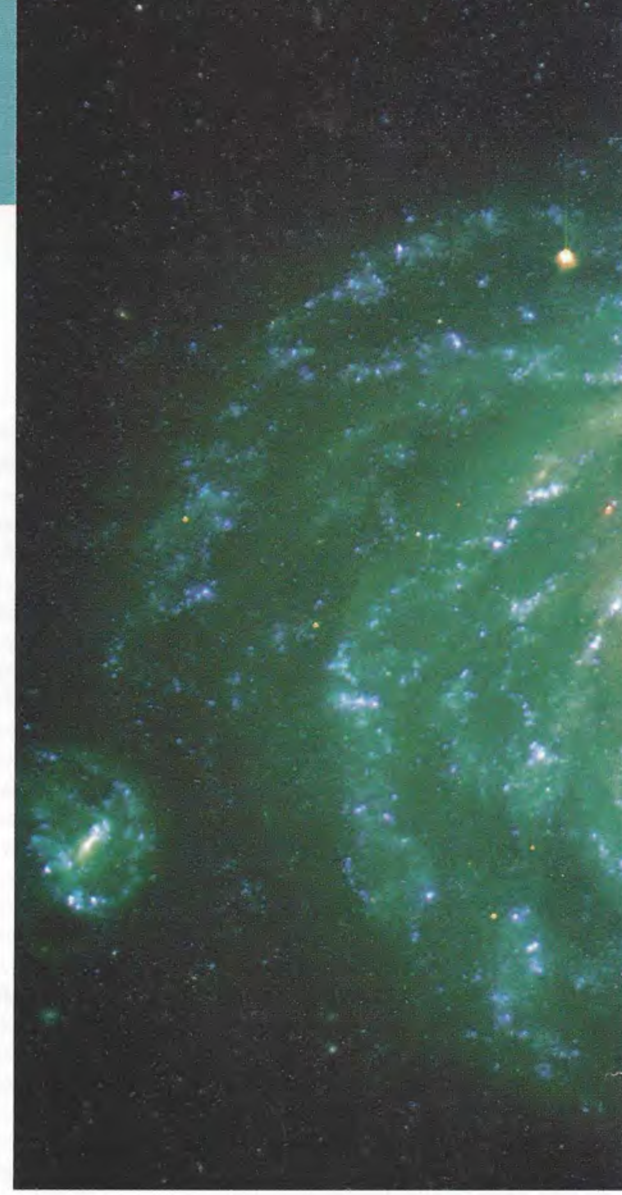
OPINION

Space: You Can't Get There From Here

by Neil de Grasse Tyson



Is humanity destined to become a multi-planet species? What is our future in space? There is no unanimity in answering those questions even from the Board of Directors of the Planetary Society. A friendly bet between directors Neil de Grasse Tyson and Louis Friedman became a topic for Neil's Universe column in* Natural History. *Lou responded with a letter to the editor of that magazine. We've adapted their exchange for members of the Planetary Society, and we hope it will provoke more discussion among our members.
—Charlene M. Anderson

From listening to space enthusiasts talk about space travel, or from watching blockbuster science-fiction movies, you might think that sending people to the stars is inevitable and will happen soon. Reality check: it's not and it won't—the fantasy far outstrips the facts.

Space is vast and empty beyond all earthly measure. When Hollywood movies show a starship cruising through the galaxy, they typically show points of light (stars) drifting past like fireflies at a rate of one or two per second. But the distances between stars in the galaxy are so great that for these spaceships to move as indicated would require traveling at speeds up to 500 million times faster than the speed of light.

A line of reasoning among those who are unwittingly wishful might be: "We invented flight when most people thought it was impossible. A mere 65 years later, *Apollo 8* journeyed to the Moon. It's high time we journeyed among the stars. The people who say it isn't possible are ignoring history."

My rebuttal is borrowed from a legal disclaimer often used by the investment industry: "Past performance is not an indicator of future returns." Analysis of the problem leads to a crucial question: what does it take to pry money out of a population to pay for major initiatives? A quick survey of the world's famously funded projects reveals three common motivations: praise of person or deity, economics, and war. Expensive investments in praise include the Great Pyramids, the Taj Mahal, and opulent cathedrals. Expensive projects launched in the hope of economic return include Columbus' voyage to the New World and Magellan's round-the-world

Humans easily imagine traveling from star system to star system. But comprehending the actual distances involved and figuring how to traverse them is a much more difficult matter. It takes light more than four years to reach us from the nearest star system. It takes almost 100,000 years for light to cross our galaxy. And even a relatively nearby galaxy, such as NGC 1232 seen here, is 100,000 light-years away. The light that became this image left its source when dinosaurs, not humans, dominated Earth. *Image: European Southern Observatory*

voyage. Expensive projects with military or defense incentives include the Great Wall of China, which helped keep out the Mongols; the Manhattan Project, which designed and built the first atomic bomb; and the *Apollo* space program.

When it comes to extracting really big money from an electorate, pure science—in this case, exploration for its own sake—doesn't rate. Yet during the 1960s, a prevailing rationale for space travel was that space was the next frontier; we were going to the Moon because humans are innate explorers. In President Kennedy's address to a joint session of Congress on May 25, 1961, he waxed eloquent on the need to reach the next frontier. The speech included these oft-quoted lines:

> I believe that this nation should commit itself to achieving the goal, before the decade is out, of landing a man on the Moon and returning him safely to the Earth. No single space project in this period will be more impressive to mankind or more important for the long-range exploration of space, and none will be so difficult or expensive to accomplish.

These words inspired the explorer in all of us and reverberated throughout the decade. But nearly all of the astronauts were being drawn from the military—a fact I could not reconcile with the rhetoric.

Only a month before Kennedy's Moon speech, Soviet cosmonaut Yuri Gagarin had become the first human to be launched into Earth orbit. In a rarely replayed portion of the same Kennedy address, he adopted a military posture:

> If we are to win the battle that is now going on around the world between freedom and tyranny, the dramatic achievements in space which occurred in recent weeks should have made clear to us all, as did *Sputnik* in 1957, the impact of this adventure on the minds of men everywhere who are attempting to make a determination of which road they should take.

Had the political landscape been different, Americans (Congress in particular) would have been loath to part with the money (more than $200 billion in 1998 dollars) that accomplished the task.

A trip to the Moon through the vacuum of space had been in sight, even if technologically distant, ever since 1926, when Robert Goddard perfected liquid-fuel rockets. This advance in rocketry made flight possible without the lift provided by air moving over a wing. Goddard realized that a trip to the Moon was finally possible but that it might be prohibitively expensive. "It might cost a million dollars," he once mused.

Calculations that were possible the day after Isaac Newton introduced his law of universal gravitation show that an efficient trip to the Moon—in a craft exiting Earth's atmosphere at a speed of 7 miles per second and coasting the rest of the way—takes about a day and a half. Such a trip has been taken by humans only nine times—all between 1968 and 1972. Otherwise, when NASA sends astronauts into "space," a crew is launched into Earth orbit a few hundred miles above our 8,000-mile-diameter planet. Space travel, this isn't. What if you had told John Glenn, after his historic three orbits and successful splashdown in 1962, that in 36 years NASA was going to send him into space once again? You can bet he would never have imagined that the best we could offer was to send him back into Earth orbit.

The distance to the Moon is 10 million times greater than the distance flown by the original *Wright Flyer*, and this difference in scale is important. The Wright brothers were two guys with a bicycle repair shop. *Apollo 11*, on the other hand, was two guys with $200 billion and 10,000 scientists and engineers and the mandate of a beloved, assassinated president. These are not comparable achievements.

✻

Space. Why can't we get there from here?

Let's start with money. If we can send somebody to Mars for less than $100 billion, then I say let's go for it. But I have a friendly bet with Louis Friedman, Executive Director of the Planetary Society, that we are not going to Mars any time soon. More specifically, I bet him that there will be no funded plan by any government before the year 2005 to send a manned mission to Mars. I hope I am wrong. But I will only be wrong if the cost of modern missions is brought down considerably, compared with the cost of missions in the past. The following note on NASA's legendary spending habits was forwarded to me by a Russian colleague:

The Astronaut Pen

During the heat of the space race in the 1960s, the US National Aeronautics and Space Administration (NASA) decided it needed a ballpoint pen to write in the zero gravity confines of its space capsules. After considerable research and development, the Astronaut Pen was developed at a cost of approximately $1 million US. The pen worked and also enjoyed some modest success as a novelty item back here on Earth. The Soviet Union, faced with the same problem, used a pencil.

Unless there is a reprise of the geopolitical circumstances that dislodged $200 billion for space travel from taxpayers' wallets in the 1960s, I will remain unconvinced that we will ever send *Homo sapiens* anywhere beyond Earth's orbit. I quote a Princeton University colleague, J. Richard Gott, a panelist who spoke a few years ago at a Hayden Planetarium symposium that touched upon the health of the manned space program: "In 1969, [space flight pioneer] Wernher von Braun had a plan to send astronauts to Mars by 1982. It didn't happen. In 1989, President George Bush promised that we would send astronauts to Mars by the year 2019. This is not a good sign. It looks like Mars is getting farther away!"

To this I add the observation that as we approach the millennium, the only correct prediction from the 1968 sci-fi classic *2001: A Space Odyssey* is that things can go wrong.

The Moon is far away compared with where you might go in a jet airplane, but it sits at the tip of your nose compared with anything else in the universe. If Earth were the size of a basketball, the Moon would be the size of a softball some 10 paces away—the farthest we have ever sent people into space. On this scale, Mars (at its closest) is a mile away. Pluto is 100 miles away. And Proxima Centauri, the star nearest to the Sun, is a half-million miles away.

Sending people very far away involves certain technological dilemmas. Suppose one of our spacecraft with a shipload of astronauts crash-lands on a distant, hostile planet. The astronauts survive, but the spacecraft is totaled. The crew adopts the spirit of 16th-century explorers. Problem is, hostile planets tend to be considerably more dangerous than anything faced by the hardiest explorers in human history. The planet

Human Explorers—Worth the Costs

by Louis D. Friedman

It may be hard to get there, and it may be expensive, but Mars is a reachable destination for human explorers. We can do more than simply imagine the technology to take us there—we have the knowledge and capability to build it and use it. But when we will decide to take that step remains a question. *Illustration: Johnson Space Center/NASA*

Since Neil Tyson has made our bet public, I'd like a chance to explain why I think I will win.

He raises two issues, one of which, interstellar flight, can be addressed very readily. At a recent interstellar-flight conference, cosponsored by the Planetary Society, I noted that we are as far away from sending humans on interstellar flights as Leonardo da Vinci was from the airplane. The next day Freeman Dyson, renowned physicist and author, opined that I was a little too pessimistic—we might be only 200 to 300 years away. In any case, it isn't something we will resolve in the next few decades.

As to the second issue, the future of human flight to other planets in our solar system, Neil hits the nail on the head. There are real questions about whether people still share the ambition to travel to other worlds—and the willingness to pay the bill.

If a human Mars mission cost (by some magic) $1 billion dollars, we wouldn't debate it—we would just do it. If it might not have air. And what air it does have may be poisonous. And if the air is not poisonous, the atmospheric pressure may be 100 times higher than on Earth. If the pressure is okay, then the air temperature may be 200 below zero. Or 500 above zero. None of these possibilities bodes well for our astronaut explorers, but perhaps they can survive for a while on their reserve life-support system. Meanwhile, to sustain themselves, all they would need to do is mine the planet for raw materials; build another spacecraft from scratch, along with its controlling computers (using whatever parts are salvageable from the crash site); build a rocket fuel factory; launch themselves back into space; and then fly home. I needn't dwell on the absurdity of this scenario.

Perhaps what we really need to do is to engineer life-forms that can survive the stress of space and still conduct scientific experiments. Actually, such "life" forms have already been created. They are called robots. You don't have to feed them. They don't need life support. And most important, they won't be upset if you don't bring them back to Earth. People, however, generally want to breathe, eat, and eventually come home.

It's probably true that no city has yet held a ticker-tape parade for a robot. But it's probably also true that no city has ever held a ticker-tape parade for an astronaut who was not the first (or the last) to do something or go somewhere. Can you name the two *Apollo 16* astronauts who walked on the Moon? Probably not. It was the second-to-last Moon mission. But I'll bet you have a favorite picture of the cosmos taken by the orbiting robot known as the Hubble Space Telescope. I'll bet you remember the images from the Mars robotic lander *Pathfinder* and its deployed rover, *Sojourner*, which went "six-wheeling" across the Martian terrain. I'll further bet that you remember the *Voyager* images of the Jovian planets and their zoo of moons.

In the absence of a few hundred billion dollars in travel money, and in the presence of hostile cosmic conditions, what we need is not wishful thinking and science-fiction rhetoric inspired by a cursory reading of the history of exploration. What we need, but may never have, is a breakthrough in our scientific understanding of the structure of the universe, so that we might exploit shortcuts through the space-time continuum—perhaps through a wormhole that connects one part of the cosmos to another. Then, once again, reality will become stranger than fiction.

Neil de Grasse Tyson, an astrophysicist, is the Frederick P. Rose Director of New York City's Hayden Planetarium and a visiting research scientist at Princeton University. His latest book, Just Visiting This Planet, *was recently released by Doubleday.*

Reprinted with permission from *Natural History*, September 1998, published by the American Museum of Natural History

cost $500 billion (the cost that President Bush's 1989 initiative got tagged with), then there is again no debate—we won't do it. When the cost is estimated to be somewhere between those two numbers, we will debate and decide on the value of this initiative compared to the cost. Given that a mission to Mars would be a pathway to glory, a major step in the expansion of our species, and a demonstration of the technological prowess of human civilization, I think its value and cost are getting close—and will be close enough for the next US president to take the initiative. As Neil noted about President Kennedy and the *Apollo* program, the Mars initiative will most certainly be taken in the context of some political and social purpose—for example, as a technological challenge, as a means to international cooperation, or as an alternative to ever-more-elaborate weapons programs.

In the meantime, robotic evolution is moving along, and maybe someday robots will be so capable as to supplant the desire of humans to go themselves to other worlds. But with the limitations inherent in even the most wonderful planetary rovers, it seems clear to me that we will feel the need to send human explorers at least until we have been on other worlds, at least until we set foot on Mars.

The long-standing allure of Mars reasserts itself whenever people contemplate our place, as a living planet, among the other worlds of the solar system, in part because of the possibility that life got started there and might even persist today (we humans suspected Mars of harboring life long before we had good reason to). Mars fascinates. Witness the excitement surrounding *Pathfinder* and *Sojourner*'s 1997 adventures. The excitement, above and beyond the science that justifies and rewards exploration, is why we have a US space policy calling for missions to Mars every two years, with plans forming for a sample-return mission in the first decade of the new millennium.

Within the next six years, the International Space Station will be in orbit and the astronauts aboard will be advancing our spaceflight capability. Eight more spacecraft will be exploring Mars, perhaps even taking the first steps toward robotic sample return. We can be sure that the attention of the public and the media will descend on the question of when will humans go to Mars.

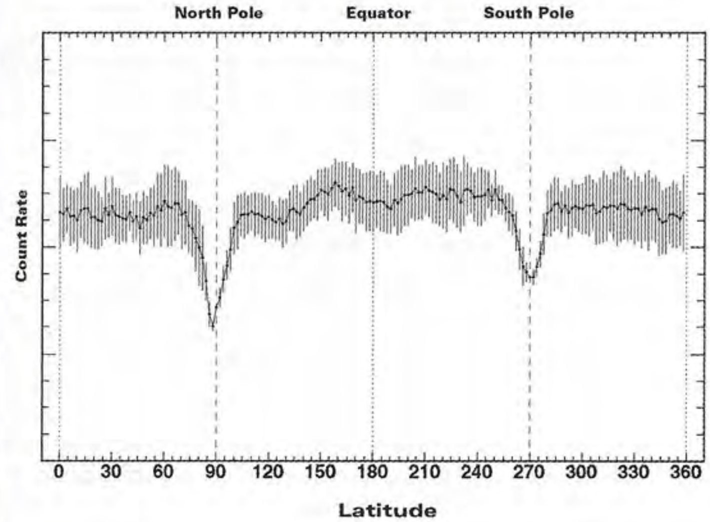
The debate over costs versus benefits will take place. NASA has been very successful lately at doing more for less—and studies of spaceflight now suggest the cost of a human mission to Mars might be significantly less than the cost of *Apollo*. And if the cost is less than one of those strategic-defense systems the military enthusiasts are always proposing, we have a chance to win the debate.

For our future in space, the most daunting point, which Neil does not raise, is today's geo-social context: in an overpopulated world, struggling with poverty, retreating to fundamentalism, mired in ethnic rivalries, the affirmation implicit in a space program falls under a shadow. The state of our world matters to exploration, because only a productive and creative society can hope to reach beyond itself. I must admit, sometimes I feel less than certain about my bet with Neil. But I'm an optimist, and my confidence returns. I am betting the people of Earth will win a bet on themselves.

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

Lunar Prospector: Reviving Interest in the Moon

by James D. Burke



In data from Lunar Prospector*'s neutron spectrometer, the dips in higher-energy-neutron count rates show that some of the neutrons emitted from the lunar surface have been slowed by collisions with low-mass nuclei, most likely hydrogen nuclei. Concentrations of hydrogen in polar cold regions suggest the presence of water ice.*

Illustration: NASA/Ames Research Center

Dawn over Tranquility Base and the Taurus-Littrow Valley begins another two-week day in the regions visited by the first and the last humans to have explored the lunar surface. This telescopic image was captured on December, 15, 1996.

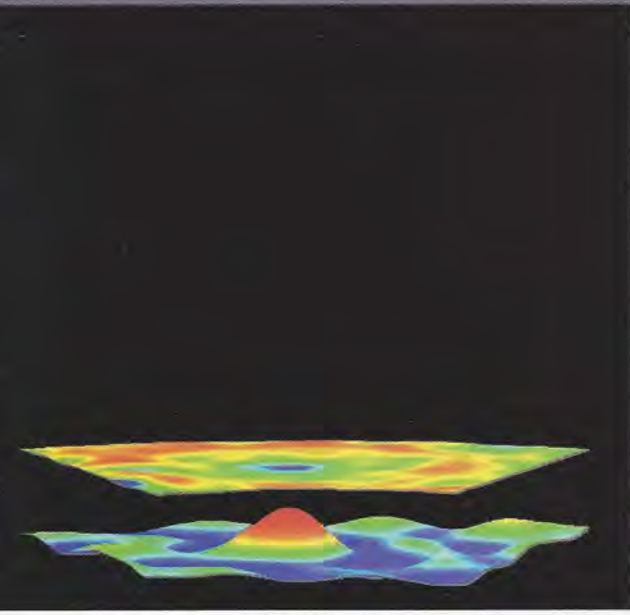
Image: Gregory Terrance

The *Lunar Prospector* spacecraft, placed in orbit about the Moon on January 11, 1998, continues to send a steady stream of data. Meanwhile, in the September 4, 1998 issue of the journal *Science*, mission scientists present the first comprehensive analysis of their observations, giving a new, integrated view of the Moon's surface composition and interior properties. Taken together with earlier results from *Clementine*, *Apollo,* and other American and Soviet missions, the *Prospector* results reinforce some existing ideas, bring others into question, and generally widen the scope for future lunar research.

As an example, there is the long-standing mystery of a lunar core. Does the Moon, like Earth, have a dense, iron-rich central body or not? *Prospector*'s gravity data suggest that the Moon does have a core with a radius of a few hundred kilometers. In the near future, seismic observations by the planned Japanese mission *Lunar A* may verify the presence of a small core, which bears on current ideas about the origin of the Moon and early solar system history.

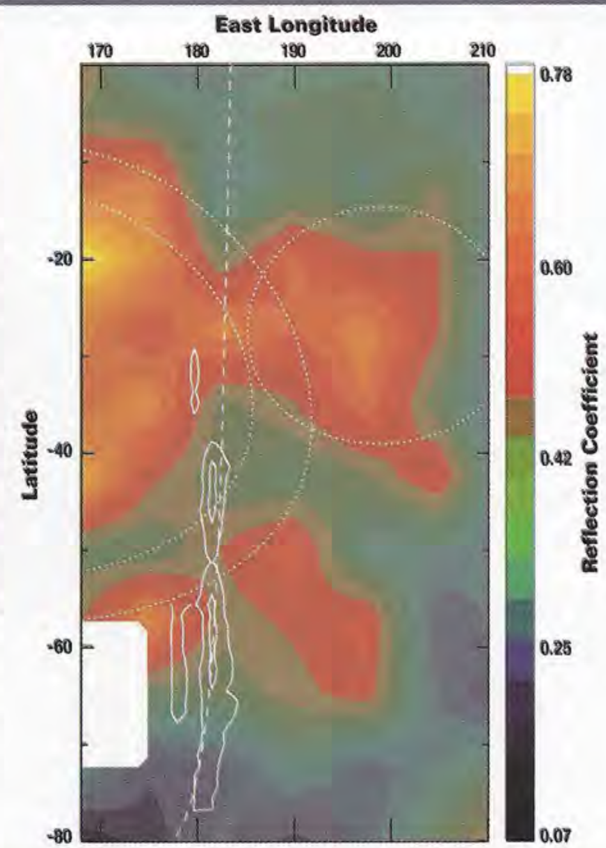
The Experiments

Traveling in a polar orbit at an altitude of 100 kilometers (60 miles), *Prospector* records spectra of gamma rays, neutrons, electrons, and alpha particles, and it measures the Moon's magnetic field. *Prospector*'s gravity measurements, derived from precise observation of Doppler shifts in its radio signal, provide the first detailed, global map of the Moon's gravity anomalies, which are diagnostic for the processes that shaped its impact-ravaged crust. Concentrations of near-surface mass (mascons), first



This model for the mascon at the Mendel-Rydberg basin is based on gravity data from Lunar Prospector. The top layer shows the surface of the Moon, with red indicating topographic highs and blue the surface lows. The blue in the center of the surface is the center of the impact basin. The layer below is the boundary between the Moon's crust and the denser mantle material below. A plug of mantle material, in red, rises about 60 kilometers (about 40 miles), nearing the lunar surface.

Image: NASA/Ames Research Center



The areas of increased surface magnetism detected by Lunar Prospector *are antipodal to (on the opposite side of the Moon from) two giant impact sites. The magnetic-field enhancement may have been due to some combination of enormous shocks and plasma clouds arriving at the antipodes within a few minutes of each catastrophe.*

Image: NASA/Ames Research Center

detected by *Lunar Orbiters* in 1966 and now observed more widely and accurately by *Prospector,* are adding fuel for scientific debates over the evolution of the Moon through a long history of bombardment and of tectonic activity driven by internal heat.

Prospector has two instruments to observe lunar magnetism. A magnetometer measures the field at the spacecraft. An electron reflection spectrometer gives a reading for the lunar surface by observing solar-wind electrons reflected to the spacecraft from regions where the magnetic field is relatively strong. One interesting discovery in this area is the enhanced magnetism antipodal to the giant Imbrium and Serenitatis impact basins, implying enormous shocks and plasma clouds arriving a few minutes after the catastrophic formation of these basins. Another new finding is that in some small areas, local magnetism is strong enough to deflect the solar wind away from the surface and form a miniature magnetosphere. The source of these and other magnetic anomalies remains unknown. A wonderful example of a local anomaly, known since *Apollo 16*, is the Reiner Gamma feature (see page 11). It looks like a whitish splash, and no cause for it, either internal or external, has been convincingly identified to date.

The purpose of *Prospector*'s gamma-ray observations is to provide a global map of many elements forming the lunar surface material. The gamma-ray technique was validated by *Apollo* observations, but the *Apollo* orbits covered only low lunar latitudes. Now, *Prospector* is extending coverage to the entire Moon. Preliminary maps in the September *Science* issue are based on some 360,000 spectra. Further data will refine mapping resolution and discrimination among elements, but already some main trends are evident, allowing scientists to construct models describing how the Moon's crust became differentiated (separated into denser and lighter materials), how its minerals evolved under heat and pressure, and how its materials were redistributed by impacts.

Prospector uses alpha-particle observations in the search for volcanic-gas emissions from the Moon. While the instrument is known to be working properly, most of its data up to September showed only solar-wind events.

Prospector's neutron spectrometer is the instrument that gives the exciting data showing enhanced hydrogen concentrations in near-surface material around the Moon's poles, leading to the possibility of water ice in permanently shaded craters (see the July/August 1998 *Planetary Report*, page 6). Long the subject of theoretical speculation, and possibly detected by *Clementine*'s radar observations, lunar polar ice is of great scientific interest because it may reveal a history of water and other volatiles' having been delivered to the Moon by comets, with implications for the same mechanism of delivery to Earth. In addition, if it is confirmed that water is available in useful quantity and at acceptable cost (questions that can be answered only by surface-roving ventures into the polar dark areas), lunar ice may become a dominant factor in planning for the further exploration and eventual human settlement of the Moon.

The neutron spectrometer can detect other elements, including iron and titanium, both important as markers of lunar evolution and as resources for the future.

Completing the Mission

Raw data from all of *Prospector*'s instruments are steadily accumulating as the mission proceeds. However, there is uncertainty about future work on mission results—the detailed corrections and conversions of the data into useful products, such as calibrated maps for scientific analysis. *Prospector*'s mission team has put out a call to the lunar community for advice on these later data-processing stages, and funding (now nonexistent) is being sought.

Meanwhile, the spacecraft and the ground-control system continue to function perfectly. Soon the orbit will be lowered from 100 kilometers (60 miles) to about 40 kilometers (25 miles) to increase the mapping resolution. Then, about mid-1999, NASA mission funding will end, and the world will again face the question of what to do with a working spacecraft and no one able to listen to it.

James D. Burke is Technical Editor of The Planetary Report.

Water on the Moon?

No Surprise for Planetary Society Leaders

Illustration: R. A. Smith

Decades before *Lunar Prospector*'s 1998 findings made headlines, the possibility of water ice on the Moon was suggested independently by two writers who would later became leaders of the Planetary Society—one an acclaimed science-fiction novelist and the other a young geologist about to take part in NASA's first robotic missions of planetary exploration.

In his 1954 *The Exploration of the Moon,* Arthur C. Clarke, now a Planetary Society Advisor, projected the possibility of water and gas frozen solid in deep lunar crevasses. This prophetic book envisioned a step-by-step process to accomplish what then seemed impossible—launching the first interplanetary spacecraft, refueling in space, landing on the Moon, and establishing a lunar colony.

In the section "Prospecting for Air," Clarke speculated that the temperatures deep within lunar clefts could be as low as –300 degrees Fahrenheit, because any heat from the Sun would be "radiated away into the black sky." An accompanying illustration by R. A. Smith (at right) showed a party of lunar explorers investigating such a crevasse, with one explorer carefully crossing over a fissure hundreds, maybe thousands, of feet deep. Clarke explained that such a task would be extremely dangerous, even though the low gravity on the Moon would lessen the shock of a fall. The discovery of water ice, however, would be well worth the risk.

A few years later, Bruce Murray, now President of the Planetary Society, coauthored "On the Possible Presence of Ice on the Moon" in the *Journal of Geophysical Research* in 1961. This article proposed that water in the form of ice might exist in permanently shadowed regions of the Moon, north of latitude 78 degrees North and south of latitude 78 degrees South. Murray, collaborating with Kenneth Watson and Harrison Brown, argued that water at the poles, sequestered from the Sun's light and warmth, would be more stable because of its low vapor pressure at low temperatures, estimated at roughly –160 degrees Celsius (–250 degrees Fahrenheit).

The paper became a cornerstone for a more detailed analysis by James R. Arnold. Published in the 1979 *Journal of Geophysical Research*, "Ice in the Lunar Polar Regions" drew upon findings from the *Apollo* missions to affirm the "essential correctness of the ideas of Watson, Murray, and Brown."

In the final paragraphs of their 1961 paper, Watson, Murray, and Brown conceded that hard evidence to determine whether or not water ice exists on the Moon would have to wait for the day when "suitable instruments" could be placed in the dark, polar regions. Now, 38 years later, we are many steps closer to this goal.

Early in 1998, *Lunar Prospector*'s neutron spectrometer detected hydrogen at the lunar poles, seeming to confirm the presence of water ice. However, until there is an opportunity to collect and examine samples from these permanently shadowed regions, the tantalizing prediction of water ice on the Moon remains possible, even probable, but not yet proven.

—Jennifer Vaughn, Assistant Editor

A Lunar Polar Orbiter: A Long Time Coming

by James D. Burke

The whitish splash at the left is the mysterious feature Reiner Gamma, the site of a very large magnetic anomaly. The crater on the right is Reiner, with a diameter of 30 kilometers (about 19 miles). The origin of Reiner Gamma and other whitish, swirl-like features on the Moon is unexplained. Lunar Orbiter 4 *captured this image on May 22, 1967.* Image: Courtesy Lunar and Planetary Institute

In 1966, when I returned to the Jet Propulsion Laboratory (JPL) from a tour of duty in Washington, DC, I was placed in charge of studies to define the robotic parts of a post-*Apollo* lunar program. Our colleagues at the NASA Johnson and Marshall centers, believing that the upcoming *Apollo* flights would begin an era of expanding human presence on the Moon, were starting to examine future lunar ventures. We at JPL were given the opportunity to define scientific goals and robotic missions to go along with the advance of human exploration.

Over the next several years, the great lunar contest between the United States and the Soviet Union ran its course. On our side, *Surveyors* and *Lunar Orbiters* yielded the scientific and engineering knowledge needed for *Apollo* planning. On theirs, the *Luna* robots continued the record of historic Soviet "firsts" in space, leading the way to orbiting, landing, and roving on the Moon, while their precursor program for human flight sent *Zond* spacecraft on circumlunar voyages ending with recovery on Earth.

Meanwhile, both sides were readying the enormous rockets and the complicated spacecraft needed for sending astronauts to land on the Moon. These programs were urgent and audacious. The American Saturn V succeeded, but its giant Soviet competitor failed in four flight tests, and *Apollo* won the Moon race.

By 1972, with the voyage of *Apollo 17*, all prospects of a rich and expanding future for humans on the Moon had vanished. We were left with the challenge of designing a robotic mission series that could gain support and continue to unravel the mysteries of lunar science. Our studies at JPL, together with similar efforts in Europe, had yielded a consensus on a logical sequence of missions, beginning with remote sensing from orbit and continuing with long-range roving on the surface. The geophysical and geochemical observing principles for such orbiter missions had been demonstrated during *Apollo* at low lunar latitudes. What we needed now was an extension of the survey by a polar orbiter to cover the entire Moon.

Our attempts to sell that polar orbiter stretched over many years, with an unrelieved record of failure. We did have funding for technology development and mission analyses, but we never were able to marshal enough governmental priority and public support to get a flight-project start.

In preparing to write this article, I have unearthed a sorry record of paper studies and proposals made through the years 1967 to 1991, all directed toward this one mission—known from the beginning as the key to reviving lunar science but ever just beyond our reach. We at NASA tried for an orbiter mission in various versions; a European team tried; there was even an effort to get a minimum mission without government funding.

Nothing succeeded until a small, ingenious, rebellious team of achievers found a way to get the *Clementine* mission with Department of Defense funding, selling it as a test of some sensors for the US Strategic Defense Initiative, known as "Star Wars." *Clementine* planners recruited NASA support in the form of a team of experienced lunar scientists, and the mission, launched in 1994, became not only a sensor test but also a superb scientific venture yielding a cornucopia of new data. At last the Moon was back on the charts, and soon thereafter another science mission, *Lunar Prospector*, was approved as a part of NASA's new Discovery program. *Prospector*, launched early in 1998, is reporting data that point to the existence of hydrogen (possibly in water ice) near the lunar poles.

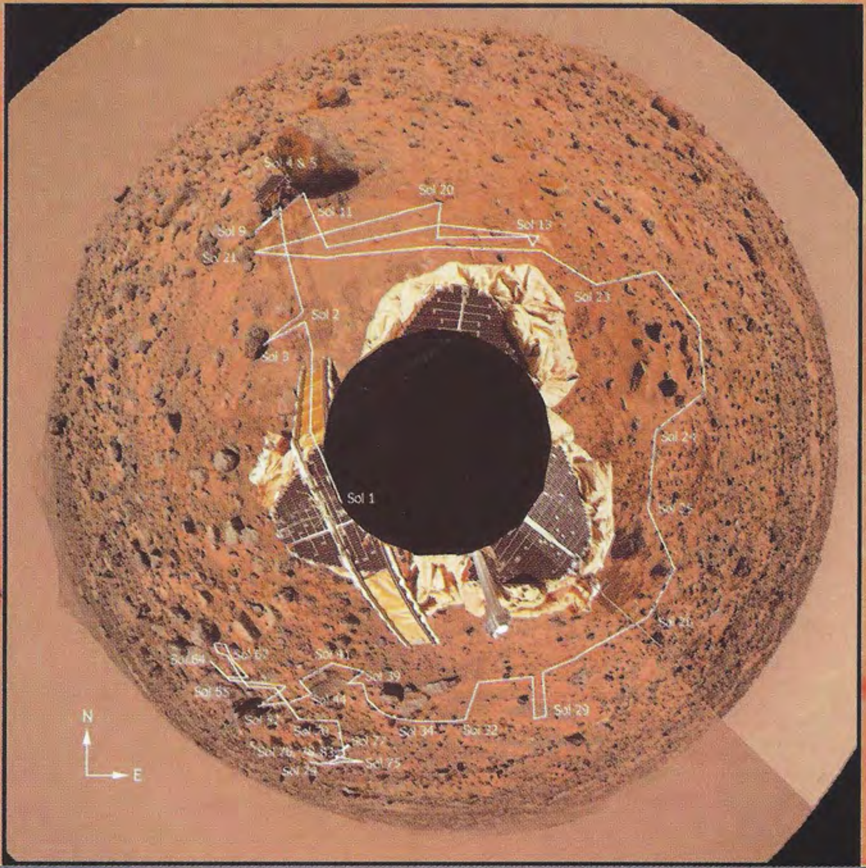
So at last the promise of the lunar polar orbiter is being fulfilled. Is there some lesson here? Perhaps so; persistence in the right is eventually rewarded. But in a deeper context, one must ask about the relation between humanity's reach into the cosmos and humanity's attempt to maintain a livable home on Earth.

Apollo, triumphant in meeting its set political objective, was in the end a failure if regarded as a first human step beyond our home planet. Because its Soviet competitor failed, the world plunged into decades of no achievement at the Moon—decades relieved a bit by the beautiful lunar science pouring in now. But decades still lie ahead before humans again bestride that ancient world. Having lived through these many years of agony and ecstasy, I am mentally prepared to continue along the steep, hard road to the Moon.

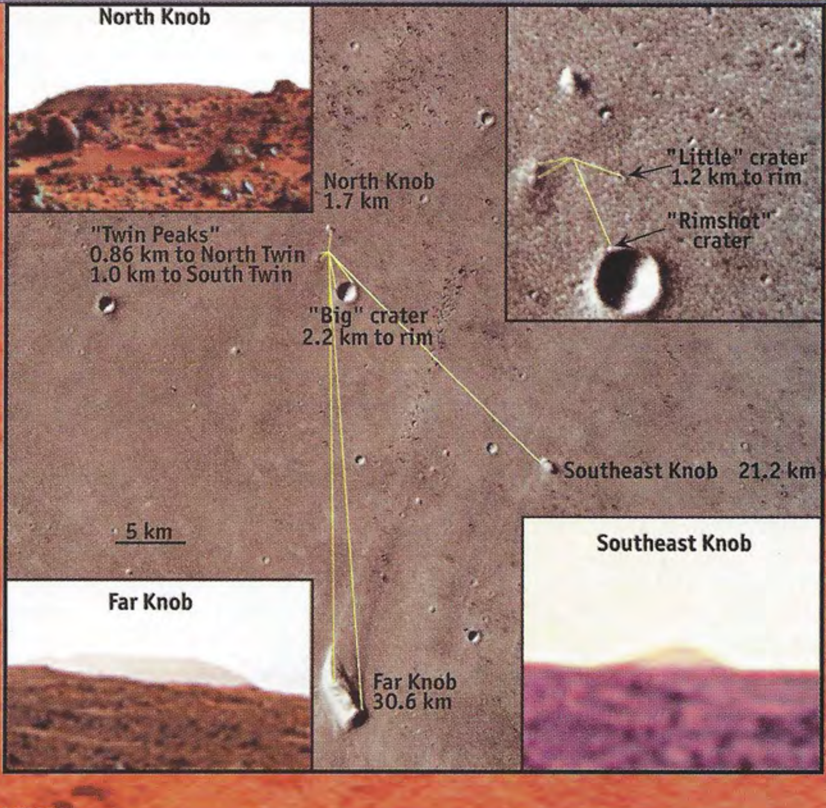
James D. Burke is Technical Editor of The Planetary Report.

Scientific Results

Mars



This somewhat disorienting image shows the path of the Sojourner *rover as it traversed the landing site over 83 sols (Martian days). The circular map was created by projecting data from one of the* Pathfinder *panoramas to the inside of a sphere. The result is called an azimuth-elevation projection.*



Pathfinder *sits at 19.17 degrees North, 33.21 degrees West, as shown at left in the background image (a mosaic of images taken by the* Viking *orbiters more than 20 years ago). The lander site is on the southeast-facing flank of a low ridge, so features to the north are hard for* Pathfinder *to see. The inset at upper right shows a* Viking *view of some of the nearby features, including the famous Twin Peaks. The other insets show features just visible above* Pathfinder*'s horizon.* *Images: JPL/NASA*

of the *Pathfinder* Mission

by M. P. Golombek

Three o'clock in the morning, July 4, 1997: I was going over potential hazards in different parts of the landing zone with the *Mars Pathfinder* mission director, the navigation team, and some of the science and management teams. Navigation data indicated the spacecraft was headed toward the southwest portion of the ellipse-shaped landing zone, where there was a large (and possibly hazardous) streamlined hill. We could not say with any certainty that the hill was more (or less) hazardous than the central and eastern areas of the landing ellipse. We could still reach either of those areas by an emergency trajectory-correction maneuver. However, if there were any error in firing the thrusters, there would be no time to recover.

The five years of preparation—planning, testing, and running operational readiness tests—were over. No matter what we decided, *Mars Pathfinder* was going to intersect Mars in a handful of hours. We decided not to make the trajectory correction.

Mars Pathfinder landed safely at 10 a.m. Pacific Daylight Time (PDT). It deployed a small rover and went on to collect data from 3 science instruments and 10 technology experiments for three months (well beyond the scheduled one month for the lander and one week for the rover). Although *Pathfinder* was designed primarily as an entry, descent, and landing demonstration, this first-completed mission in the low-cost, rapid-development Discovery series eventually returned 2.3 billion bits of new data, including more than 16,500 lander and 550 rover images, 16 chemical analyses of rocks and soil, and 8.5 million individual temperature, pressure, and wind measurements. The rover *Sojourner,* following a clockwise path around the lander (named the Sagan Memorial Station), explored about 200 square meters of the surface of the Red Planet.

Mars Pathfinder, a technical success, also became one of NASA's most popular missions, capturing the imagination of people around the world. On the World Wide Web, sites offering *Pathfinder* updates registered about 566 million "hits" during the first month of the mission, with 47 million on July 8 alone, making the *Pathfinder* landing by far the biggest event in Internet history at that time.

Pathfinder was the first mission to Mars to use a rover carrying a chemical analysis instrument, the alpha proton X-ray spectrometer (APXS). Readings from *Sojourner*'s APXS provided a calibration point or "ground truth" for observations made from orbit. The combination of spectral imaging of the landing area by the lander camera, chemical analyses aboard the rover, and close-up imaging of rock textures by the lander and rover cameras gave us the potential to identify rock types and their mineralogy. With this payload, we chose the Ares Vallis landing site because it offered, in addition to acceptable safety, the prospect of studying a variety of rocks, including materials from heavily cratered terrain that may have been deposited by catastrophic floods. Gathering this kind of information would address first-order scientific questions, such as differentiation of Mars' crust, weathering on the planet's surface, and the nature of the early Martian environment and its subsequent evolution.

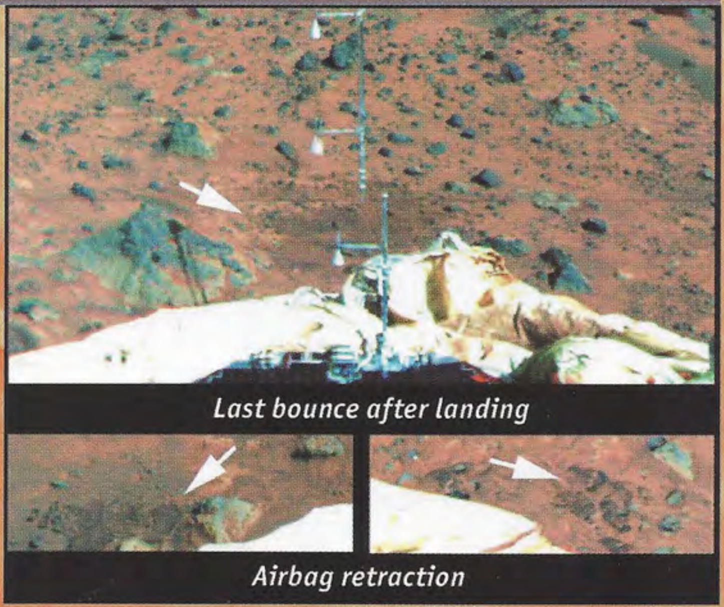
The *Pathfinder* results, taken together, support the view that early Mars may have been Earth-like. Some crustal materials on Mars may be similar in silica content to continental crust on Earth. We found rounded pebbles, cobbles, and possible conglomerates (rocks made of pebbles cemented together) as well as abundant sand- and dust-sized particles, all of which, given the processes that form them, indicate that the early Martian environment may have been warmer and wetter and that liquid water was present. Since then, over the past 2 to 3 billion years, Mars appears to have been very unlike Earth, as low erosion rates have produced only minor changes to the surface at the *Pathfinder* landing site.

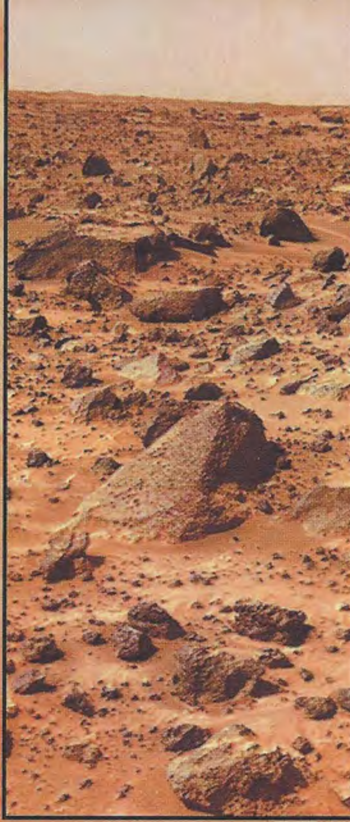
Where Exactly Did We Land?

During descent through the Martian atmosphere, *Pathfinder* deployed its parachute system, jettisoned the heat shield, "found" the ground below by radar, inflated its protective air bags, and fired rockets to slow itself as much as possible before impact. The landing occurred at 2:58 a.m. true local solar time (9:56:55 a.m. PDT).

The heat shield appears to have fallen 2 kilometers (1.2 miles) downrange, in a west-southwest direction, with the backshell about 1 kilometer (0.6 mile) uprange. Both appear as bright pixels in the lander scene. Due to horizontal winds, the lander bounced about 1 kilometer northwest of where the rockets fired. The lander bounced at least 15 times, as high as 12 meters, onto one of the rockiest locations on Mars without air bag rupture,

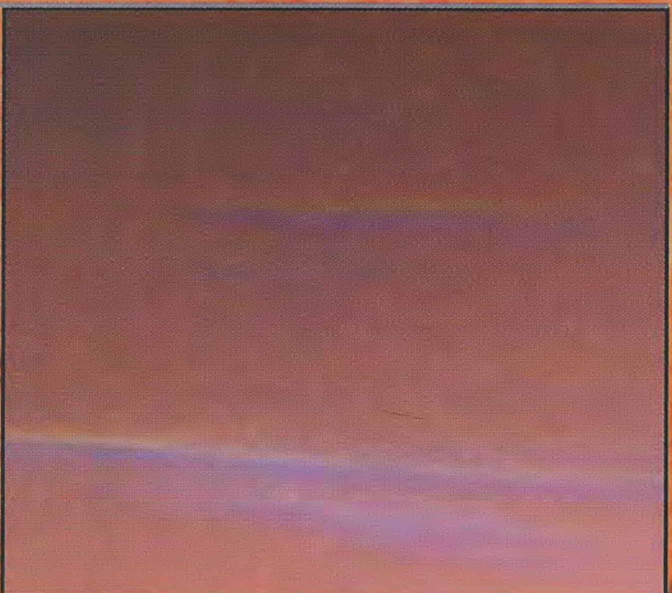
Mars Pathfinder was primarily a technology-demonstration mission, and one of the things it tested was an air-bag landing system. Completely surrounded by inflated bags, the lander hit Mars and bounced at least 15 times before coming to rest. When Pathfinder was safely down, the air bags deflated and retracted. In this enhanced-color image we can see how the last bounce disturbed the soil and revealed a shallow subsurface that is darker than the surface layer.
Image: Johns Hopkins University





On a planet rich in liquid water, such as Earth, rounded pebbles and slightly larger cobbles are common rock forms. Their presence on Mars, as seen in this image, indicates that in a warmer past, water flowed on the planet and rounded the pebbles and cobbles. In the upper left is a relatively large cobble within the rock called Lamb, suggesting that Lamb is a conglomerate of smaller rocks cemented together over aeons.
Image: US Geological Survey

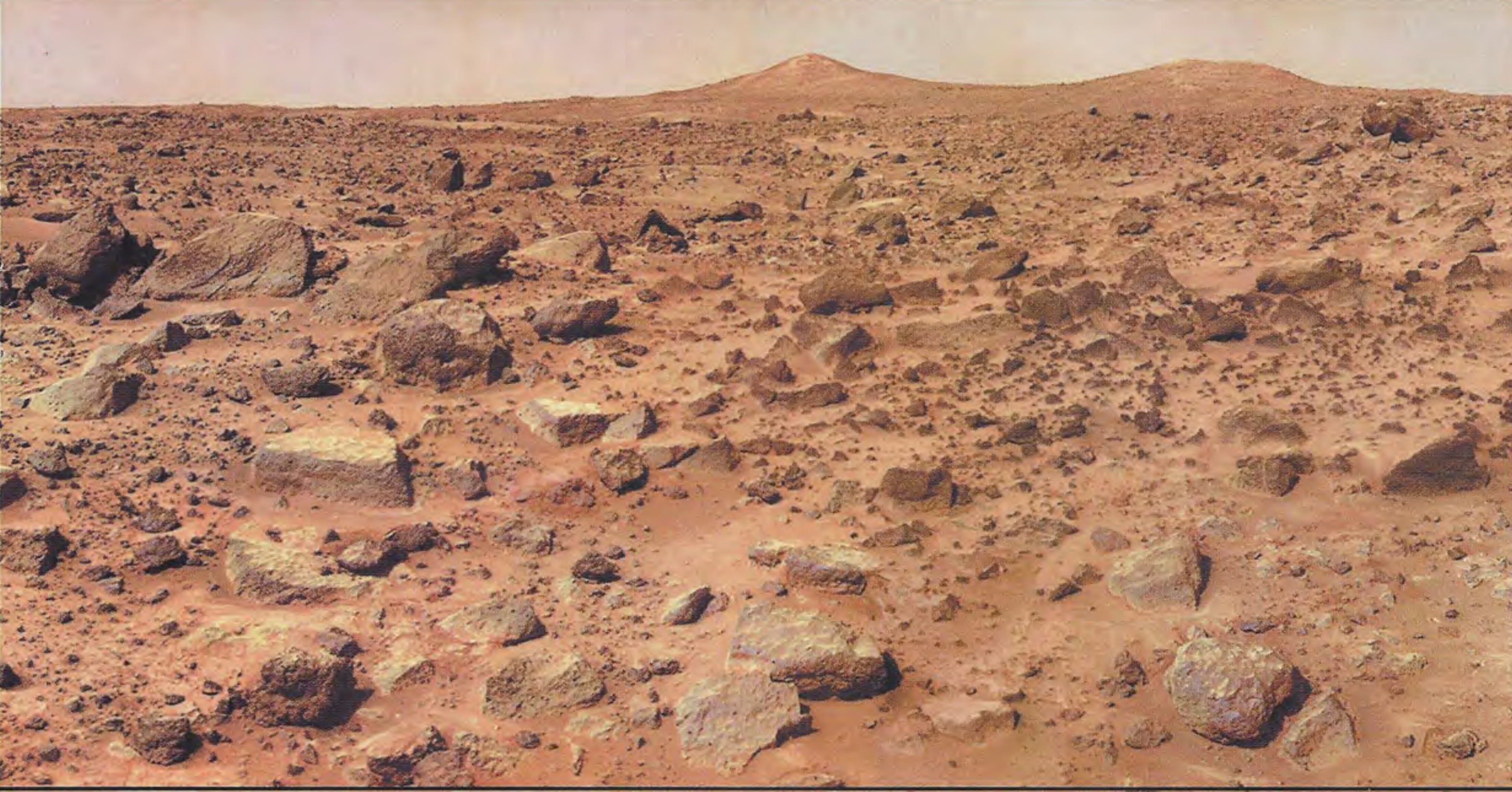
In the Martian dawn, wispy blue clouds of water ice streak the brightening sky. Mars' thin atmosphere is primarily carbon dioxide, but it does hold enough moisture to occasionally form water clouds. These tenuous clouds are probably about 10 to 15 kilometers (6 to 9 miles) above the ground.
Image: JPL/NASA



thereby demonstrating the robustness of this landing system.

Using images taken by a *Viking* orbiter as a reference, we identified five prominent horizon features and two small craters in the lander's field of vision and so determined its position as being within 100 meters of features shown on US Geological Survey maps at coordinates 19.13 degrees North, 33.22 degrees West. Because the *Pathfinder* landing site has also been identified by two-way ranging and Doppler tracking, it is the best known location on Mars (neither of the *Viking* landers is located with the same degree of certainty). Knowing *Pathfinder*'s location provides a tie point for the location of surface features on Mars in inertial space, tightening the accuracy of our maps of the Martian surface.

From the two-way ranging and Doppler-tracking results, we know the precise angle of Mars' rotation axis, which, combined with earlier results from the *Viking* landers, improves by a factor of three our fix on Mars' precession constant (describing the regular motion of the axis). Using the precession constant, we can calculate the moment of inertia, which constrains the size of the planetary core.



Twin Peaks *on Earth was a television series. Its namesake on Mars is a pair of hills that may hold clues to the mystery of Mars' past. During the* **Pathfinder** *mission, they became familiar features on the horizon. And since they were visible in earlier* **Viking** *orbiter images of the region, they were convenient landmarks for determining the lander's location. Their streamlined shape indicates that they were carved by the enormous catastrophic floods that created the landing site.* *Image: JPL/NASA*

The data from *Pathfinder* tell us that Mars' core has a radius greater than about 1,300 kilometers but no larger than about 2,000 kilometers (greater than 800 miles but no more than 1,200 miles).

Many characteristics of the landing site are consistent with its being a plain composed of materials deposited by catastrophic floods that we believe took place in the Ares and Tiu regions. The rocky surface, composed of poorly rounded pebbles, cobbles, and boulders, generally resembles plains deposited by catastrophic floods on Earth, as seen on the Ephrata Fan in the Channeled Scabland of Washington state. In lander images, the Twin Peaks appear to be streamlined hills, confirming our expectation from *Viking* orbiter images and suggesting that the lander is on the flank of a broad, gentle ridge or on a debris tail deposited in the wake of Twin Peaks.

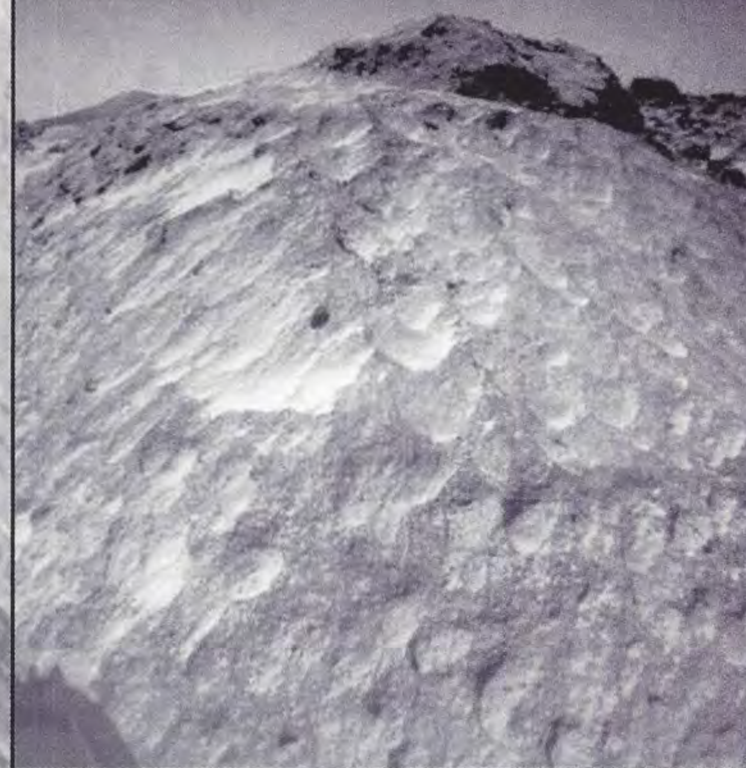
Close-up on Martian Rocks

In the area known as the Rock Garden we see what may be imbricated or inclined blocks, generally tilted (like a stack of books) in the direction of flooding. Troughs visible throughout the scene may be primary features, produced by the flood, or they may have been carved by late-stage drainage of water, which would have carried off the fines (small particles), leaving behind a blocky, armored surface (analogous to channels and surfaces on the Ephrata Fan). Large rocks appear tabular and slightly rounded, and many are perched, which is consistent with deposition by a flood. The site appears little altered since it formed a few billion years ago, except by wind action that has eroded away the top 5 to 7 centimeters (2 to 3 inches) of the soil, produced dust tails behind rocks, collected sand into dunes, and grooved and fluted rocks.

Soil types at the site look like poorly crystalline or nanophase iron oxides. The APXS readings taken by *Sojourner* indicate the soil around *Pathfinder* is generally similar in elemental composition to the soils measured at the *Viking* lander sites. Because the *Pathfinder* and *Viking* landers are widely spaced, the similarities suggest that soil compositions are influenced globally by airborne dust. And since the compositions are similar, the differences we see in soil color may be due to either slight differences in iron mineralogy or differences in particle size and shape, meaning that the soils are likely complex mixtures of a variety of weathering products.

In general, the rocks we've examined are dark gray. The rock chemistry measured by the APXS is similar to that of basalts, basaltic andesites, and andesites on Earth.

Considering other evidence, we observe generally linear relationships between the red/blue ratio of the rocks, their silica or sulfur content, and the average soil composition, which together suggest that these are dark, high-silica rocks coated with sulfur-rich, bright, reddish dust. Given the linear relationships, we can calculate rock composition without the dust: results indicate rocks that are andesitic in composition. It's interesting to note that their composition is distinct from that of meteorites that have come to Earth from Mars. The meteorites are mafic (rich in magnesium and iron) and relatively silica-poor.



Above: Moe, another denizen of the Rock Garden, is a boulder about a meter across with a smoother surface than some of its neighbors. Looking closely, you can also see pits and a texture that suggests Moe has been sandblasted into this shape by strong Martian winds.

Right: One of the "luxuries" of the *Pathfinder* mission was the ability to send the *Sojourner* rover over to get a close-up look at interesting rocks. This is Shark, one of the denizens of the so-called Rock Garden. In this area, scientists found another type of evidence that water may once have flowed across Mars. The rocks are generally tilted in the same direction, and some are perched on top of others, as would be expected if they were deposited during a flood. Images: JPL/NASA

The *Mars Pathfinder* team delighted in naming rocks at the landing site after cartoon characters. This one celebrates Stimpy. The detailed texture on this rock suggests another source of erosion on Mars—the wind. The pits and flutes on Stimpy's face are products of small, sand-sized grains that hop along with the wind, nicking rocks in their way and leaving these characteristic marks. Image: JPL/NASA

The chemistry and normative mineralogy of the sulfur-free rock are similar to those of common terrestrial rocks called anorogenic andesites (*anorogenic* in this context means not associated with subduction zones). Examples of such rocks on Earth include icelandites, which formed by fractional crystallization of material derived from the mantle.

Lander images and rover close-ups reveal a variety of morphologies, textures, and fabrics—pitted, smooth, bumpy, layered, and lineated—suggesting a variety of rock types. Some of the rocks may be conglomerates, composed of rounded pebbles with shiny, hemispheric pockets or indentations where pebbles that were originally embedded in a fine matrix have fallen out. Rocks such as these could be the source for the loose pebbles and cobbles on the ground. If the rocks are conglomerates, they would have required running water over long periods of time to smooth and round their pebbles and cobbles. In the formation of conglomerate rocks, the rounded materials would have been deposited in a fine-grained (sand and clay) matrix and lithified (turned to rock). A tremendous flood then swept up these conglomerate rocks and dropped them in an area that would be visited one day by a small but versatile robotic explorer.

Dust Everywhere

The magnetic-properties experiment shows that airborne magnetic dust has been deposited progressively with time on most of the magnetic targets on the lander. The dust is light yellowish-brown (the same color as seen in the bright soil and in the atmosphere), and it has a magnetization and chemistry consistent with composite, clay-sized silicate particles with a small amount of a very magnetic mineral, believed to be maghemite. The preferred explanation for the magnetic material is that an active hydrologic cycle at some time in the past dissolved iron from the Martian crust; a process of freeze-drying then caused the iron to precipitate (drop out) as maghemite onto the silicate Martian dust. Dust devils, detected repeatedly around midday, appear to be an effective mechanism for raising the fine-grained dust into the atmosphere. Analyses of images have captured dust devils tens of meters wide and hundreds of meters high.

Observations of *Sojourner*'s wheel tracks and results from soil-mechanics experiments suggest a variety of materials with different physical properties. Rover tracks in bright drift material and elsewhere preserve individual cleat marks that are shiny, indicating compressible deposits of fine-grained dust. This material

Above: **Sojourner**'s *discovery of rocks that look like conglomerates is among the strongest pieces of evidence that water once flowed on Mars. These types of rocks form when water deposits pebbles and cobbles in fine sand or clay; over aeons, the conglomerate hardens into a more or less solid rock. This example, named Ender, shows a subtle horizontal texture. In the top right is the* **Pathfinder** *lander, surrounded by its air bags.* *Image: JPL/NASA*

also forms the wind tails and other fine eolian (wind-produced) features and so is likely the same fine dust we see suspended in the atmosphere. Cloddy deposits appear to be composed of poorly sorted dust, sand-sized particles, lumps of soil, and small rock granules and pebbles. The interaction of these materials with the rover wheels indicates they are like typical soils on Earth with bulk densities near 1.5 grams per cubic centimeter. Thick coatings of dust that intermittently accumulated on the rover wheels suggest that the dust becomes electrostatically charged when compressed.

During the mission, the sky was a light yellowish-brown color. Images taken early in the morning revealed white to light-blue clouds that appear to be composed of water ice. The size of particles in the "air" and trace measurements of water vapor were all consistent with results from *Viking*.

Winds were light (less than 10 meters per second, or roughly 20 miles per hour) and variable, peaking at night and during daytime. In other meteorology measurements, we saw abrupt temperature fluctuations each morning at heights between 0.25 and 1 meter above the ground. These observations suggest that cold morning air was warmed by the surface and convected upward in small eddies. On Sol 20 (20th Martian day of the mission), *Pathfinder* recorded its lowest barometric reading, which signaled that the winter expansion of the south polar cap had reached its maximum.

Pathfinder landed safely by bouncing more than 15 times on one of the rockiest locations of Mars without suffering any air bag tears or ruptures, thereby successfully demonstrating an extremely robust and inexpensive landing system that was developed and built in a relatively short period. Even in rocky areas of Mars, small rovers are excellent for placing instruments up against rocks and for exploring the local area. The mission has returned an enormous amount of new information, which will continue to be analyzed for years to come. Analysis to date suggests early Mars may have been warmer and wetter than at present. *Pathfinder* demonstrated that the public is very interested in and can be fascinated by the exploration of Mars. Many of the subsystems developed by this mission will be used by future missions to Mars, carrying on the tradition begun by *Pathfinder*.

M. P. Golombek is a Research Scientist at the Jet Propulsion Laboratory and Project Scientist for the Mars Pathfinder *mission.*

News and Reviews

by Clark R. Chapman

The question of life in the universe has dominated scientific, philosophical, and theological thought since the dawn of civilization. We live at a time of exceptional progress in understanding life and the environments in which it may form and evolve. Consider the telescopic discovery of extra-solar planets, identification of potentially habitable abodes on other solar system bodies, and rapidly changing perspectives about life on Earth. While our planet remains the only known abode of life, we may find life elsewhere any time.

A new book, *The Search for Life on Other Planets* by Bruce Jakosky (Cambridge University Press, 1998), thoroughly covers topics ranging from the origin of life on Earth to intelligent life in other stellar systems. The treatment of Mars, Jakosky's specialty, is excellent, including evaluation of the *Viking* biology experiments and the putative fossil life in Martian meteorite ALH84001. Developed from notes for a college course, this paperback volume reads less like a popular tradebook than a textbook (though it lacks problem sets and equations, except for some chemical formulae). The author consciously avoids scientific jargon, making the book easily accessible to *Planetary Report* readers.

"Scientist-speak"

Unfortunately, this lightly edited book retains the "scientist-speak" that researchers use unconsciously. One of the most common words is "suggest," used in an uncommon passive sense: that there is inconclusive evidence about something. Hence, about Mars, we read the convoluted sentence: "Although the oldest surfaces do not show features suggesting that they are volcanic, some people expect that volcanism was very active then . . . ." This means that there are ancient places on Mars that may have been affected by volcanism, but pictures show no volcanoes, lava flows, or other volcanic features. Of course, we can never really *know* that something is a volcano just by looking at spacecraft images of it; the long debate about whether lunar craters were of impact or volcanic origin wasn't resolved until Moon rocks returned by *Apollo* were examined in the laboratory. So Jakosky uses "suggesting" to be clear that *if* any of these nonexistent features *were* to be seen, we still might not be sure that they were really volcanic.

Forms of "suggest" appear nearly as often as the word "is." And "is" is most often used in phrases that are synonyms for "suggest," such as "is thought to have been," "is likely," "there is every reason to believe that," "is quite possible and even plausible," and even "is suggested by." Other qualifications abound in this book: "may be indicative of," "the possibility exists that," "could [or may, or might, or appear to] have been," et cetera.

Evidence and Inference

The use of "suggest" reflects an issue more fundamental than undisciplined writing style. As others have said, extraterrestrial life is a topic without a subject, except in the conjectural sense. We know of none, yet. All we have is "suggestive" evidence, pro and con. Moreover, the relevant sciences depart from the classic methodology taught in schools—that a scientist formulates a hypothesis in his or her head, dons a white coat, runs an experiment, and evaluates the results, which either prove or disprove the hypothesis.

Astronomy and planetary science are *observational* sciences. Rather than experiment, we *look* at what is out there, using telescopes or remote-sensing instruments on spacecraft. (Laboratory studies of returned samples and relatively crude experiments conducted on Mars by *Viking* and *Pathfinder* landers are exceptions.) Astronomical and planetary observations must be interpreted passively, and our inferences are often wrong.

Geology, an historical science, figures prominently in Jakosky's tale of the origin and evolution of terrestrial life. Absent time-travel, geologists must infer ancient events and processes from evidence (such as fossils) in the geologic record. Whereas terrestrial rocks *can* be examined in the laboratory, measurements pertain to the present nature of the rocks. We learn about the past through a chain of logic involving uncertain inferences.

Even experiments can be misleading or inconclusive. Jakosky describes how all three of *Viking*'s biology experiments yielded, at least initially, positive indications for life on Mars; it took another *Viking* instrument to demonstrate the virtual absence of organics in Martian soils, which led experimenters to realize how unanticipated chemical processes could imitate the apparent proofs for life on Mars.

Therefore, our knowledge about the evolution of life, potentially habitable extraterrestrial environments, or even the present existence of life or fossilized life on Mars is all inherently uncertain. Little of that uncertainty can be quantified by formal statistics. We must subjectively judge the "preponderance of evidence." The wise researcher—and Jakosky, director of one of the new NASA Astrobiology Institutes, is certainly one—carefully qualifies the certainty of each piece of the large puzzle that is extraterrestrial life.

This is a good book, and I recommend it. My only quibbles, besides the surfeit of qualifications, are a few technical errors (which don't affect the main points), the omission of chapter numbers in the text, and the ornamental but useless index (among the missing entries under "A" are amino acids, Arecibo, asteroids, ATP, and *Australopithecus*).

Clark R. Chapman is curator of the exhibit "IMPACT" at the University of Colorado Museum through October 1999.

World Watch

by Louis D. Friedman

Paris—A year ago it appeared that Europe had no interest and would have no involvement in Mars exploration. Now, in addition to France's joining the United States as a partner in the Mars Sample Return mission, the European Space Agency (ESA) has received approval to proceed with development of Mars Express for 2003. Its governing council gave ESA the go-ahead contingent on financial adjustments to be worked out in the space science program. Officials were confident that those adjustments could be made.

Mars Express is an orbiter that will re-fly two instruments from the ill-fated *Mars '96*: a multispectral imaging system from Germany and an infrared remote-sensing instrument from France. The US will contribute a radar designed to search Mars for subsurface water.

Mars Express might also include a lander: Beagle 2, proposed by scientists from the Open University in Great Britain. However, no ESA funds are available for the lander, and no government funds from England or any other country have been offered. The Beagle 2 team is seeking private contributions to fund the £30 million (roughly $50 million) lander. They have until November 1999 to come up with the funding plan.

Mars Express is an ESA mission. Meanwhile, the Mars Sample Return is now a US-France partnership. The French are committing an Ariane 5 for the launch in 2005, and they have offered to build the orbiter that will carry the Earth-return vehicle. (They have also made Ariane launches available for secondary payloads [piggybacks] on "micro-missions" starting in the year 2003. These elements are being incorporated into the Mars Architecture under development at the Jet Propulsion Laboratory and NASA.)

The Italian Space Agency is studying the development of a drill for Mars subsurface sampling. They are also committing resources to extend the life of the Mars Express orbiter so that it can be used as a communications relay for the Mars Sample Return missions in 2005 and afterward.

Washington, DC—While the US Congress struggled to get the 1999 appropriations passed, NASA officials and the administration were already negotiating budget levels and programs for the Fiscal Year 2000 budget. The administration's proposal for NASA is part of a general presentation to Congress made each year in early February. Congress considers the budget through a lengthy process involving the Budget Authorization and Appropriations committees in the House of Representatives and Senate. In the past several years, the Planetary Society has been heavily involved in this process, with testimony and background briefings and with direct action from members of the Society writing in favor of planetary exploration missions. Last year, as a result of Planetary Society action, Congress added money for Mars exploration to the administration budget request.

Budget pressures will increase this year because of the International Space Station, which needs additional money to cover failures of the Russian government in funding its portion of the project. Congressional approval for this additional funding may be difficult, but the popular flight of John Glenn aboard the shuttle *Discovery* and the successful assembly of *Zarya* and *Unity*, the first two elements of the station, may have a positive effect.

Washington, DC—In the next few years several deep-space missions will require nuclear power sources like the radioisotope thermal-electric generator used on *Cassini*. The amount of nuclear power, and hence the amount of plutonium-238, required for these missions is much smaller than for *Cassini*. Nonetheless, the US Department of Energy is considering whether to resume domestic production of plutonium-238 (different from plutonium-239, which is used in nuclear weapons).

Research is under way for more efficient radioisotope power systems for the next generation of spacecraft. Higher efficiency would result in still lower amounts of plutonium being required. Two missions that will need the nuclear power source are the Pluto/Kuiper Belt Express and the Europa orbiter, both of which are part of the outer-planets program approved in the 1999 budget. The Europa orbiter is slated for launch in November 2003 and the Pluto Express in December 2004.

The Mars Lander missions of 2001 and 2003 and the Mars Sample Return will also require plutonium radioisotopes. In these cases, the plutonium will be in heater units (RHUs), more for temperature control than for power. The amount of plutonium in RHUs is very small.

The Department of Energy has announced that it will develop an environmental impact statement for the outer-planet missions and has invited comments from interested groups and individuals.

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

Questions and Answers

In the September/October 1998 issue of **The Planetary Report,** *Paul Geissler stated, "Even the cleanest ice on Europa has a yellow tinge. It suffers from [Io's] second-hand sulfur."*

The thermodynamically stable form of sulfur is yellow only at the temperatures common on Earth's surface. Warm that sulfur, and it becomes more orange. Cool it, and its color fades. Could the color of Io be an indicator of its surface temperature?
—Frank Weigart, Wilmington, Delaware

This interesting question was debated by planetary scientists more than a decade ago in discussions almost as colorful as Io itself. Indeed, ordinary orthorhombic sulfur brightens as it cools and is nearly colorless at the average surface temperatures of Io and Europa.

An even bigger problem for those working on the sulfur interpretation was the lack of any observable changes after Io emerged from eclipse, contrary to the expectation that its surface should have brightened as it cooled while in Jupiter's shadow. Adding to the controversy was the fact that *Voyager*'s (and *Galileo*'s) violet filters were sensitive to wavelengths slightly shorter than the blue hues used to render color images from the spacecraft.

The solution to this puzzle came from laboratory detective work on sulfur under the harsh conditions that exist on Jupiter's moons. Researchers found that several factors act to darken sulfur and restore its yellow hue. With little protection from the tenuous atmosphere, Io's surface is exposed to solar ultraviolet radiation, galactic X-rays, energetic charged particles, and a near-vacuum. In the laboratory, ultraviolet and X-ray radiation quickly yellows sulfur specimens even at frigid temperatures, probably by breaking up rings of sulfur atoms and forming long chain-like molecules (diradicals). Also, when placed into a vacuum, sulfur sublimates (evaporates) until a powdery coating forms on its surface. Neither the reflectivity of this coating nor the color of irradiated sulfur varies much with temperature, explaining the absence of post-eclipse brightening on Io.

Yet another form of sulfur, made up of short chains of only 3 or 4 atoms, may account for the riotous reds seen in many deposits from Io's active plumes. Apparently, sulfur from Io not only pollutes its neighbor Europa but also contributes to the color of nearby Amalthea.
—PAUL GEISSLER, *University of Arizona*

This view of Io is the highest-resolution color image yet returned from Galileo. *Jupiter's cloud tops appear as the blue background in this false-color composite. Scientists were surprised by the greenish patches and subtle violet hues at the cores and margins of bright, sulfur-dioxide-rich regions like the one at lower right. The dark spots, many flagged by red pyroclastic deposits, mark the sites of current volcanic eruptions. Most of Io's riotous color can be explained by sulfur compounds, but the dark materials that comprise the volcanic flows and calderas are probably silicates.* Image: Paul Geissler, University of Arizona

The explanation always given for the extreme tilt of Uranus' axis is that it may have been the result of a large impact. Wouldn't the gyroscopic effect of the spinning planet rule out a tipping of the axis?

And how could an impact explain the tilted plane of Uranus' moons, which align with the planet's tipped equator?
—George Farago, Wayne, New Jersey

As the solar system formed, most of its angular momentum was in the same direction as the angular momentum of the original mass from which the Sun formed. So planets should orbit in planes that are roughly at the Sun's equator, and they should revolve around the Sun in the same direction as the Sun's rotation. Only tiny Pluto, with an orbital tilt of 17 degrees, departs from the plane of Earth's orbit (the ecliptic) by more than 7 degrees, and all the planets orbit in the same direction as the rotation of the Sun.

However, the momentum associated with a planet's rotation is almost negligible in comparison to its orbital angular momentum. Only two of the solar system's nine major planets (Mercury and Jupiter) have equators that lie within 20 degrees of their orbital planes, and Mercury's rotation probably evolved to that orientation as a result of tidal forces from the nearby Sun. Moreover, three of the planets (Venus, Uranus, and Pluto) rotate backwards.

Uranus is the largest of the three planets with reverse spins. Because it has by far the most rotational angular momentum ("gyroscopic effect"), its tilt is the most difficult to explain. The tilt could have come naturally as a result of motions in the material out of which Uranus formed (that is, motions causing a large local difference from the average motion of the early solar nebula). However, most scientists prefer to attribute the tilt of Uranus to an early impact of an Earth-sized chunk of material (a planetesimal) near one of Uranus' poles.

In this hypothesis, the planetesimal became a part of the "new" Uranus. Rather than turning the spin axis (north pole) of the planet, this planetesimal would have imparted enough energy to Uranus to cause it to spin about an entirely different pole. The effect would have been somewhat like a relatively slow-moving Moon-sized object striking Earth in Siberia with such force that the Earth began spinning around an axis near Quito, Ecuador!

If Uranus had moons before the supposed impact event, they would likely have been lost during the aftermath of that impact. Uranus' present-day moons probably began forming during or after the impact event, which accounts for their orbits being near the planet's "new" equator.

—ELLIS D. MINER,
Jet Propulsion Laboratory

Factinos

The Hubble Space Telecope (HST) has given us a new view of Uranus, complete with rings, moons, and a batch of bright clouds (see image at right). This false-color portrait was created by Erich Karkoschka from the University of Arizona, using data captured on August 8, 1998 with HST's near-infrared camera and multi-object spectrometer.

Hubble recently found about 20 clouds on the mysterious gas giant —almost as many as have been seen there in the history of observation. According to team member Heidi Hammel from the Massachusetts Institute of Technology, the clouds race around the planet at more than 500 kilometers (300 miles) per hour.

Levels of altitude in this image are defined by color. Another team member, Mark Marley of New Mexico State University, explains that green and blue depict areas where the atmosphere is clear and sunlight can penetrate deeply. Sunshine reflected off higher clouds is shown in yellow and gray. Orange and red indicate very high clouds, like cirrus clouds on Earth.

—from the Space Telescope Science Institute

Uranus shows off its four major rings, several of its moons, and some bright clouds in this recent Hubble Space Telescope view. Data taken on August 8, 1998 were used to generate this false-color image.

Image: Erich Karkoschka, University of Arizona and NASA

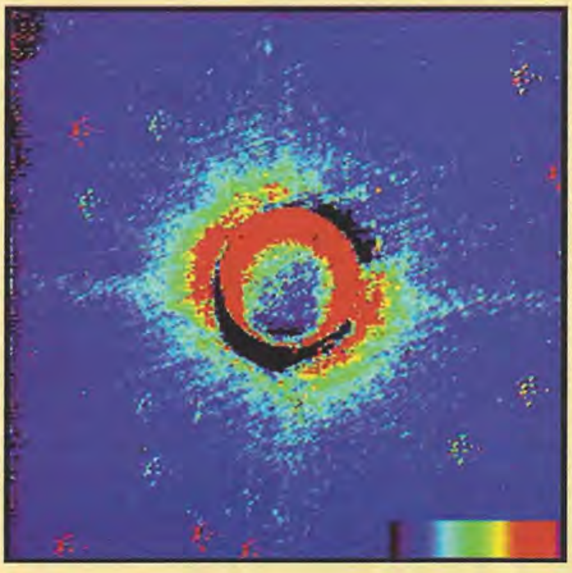
❖

Planetary scientists have discovered the first circumstellar disk ever seen around a star similar to our Sun and known to be orbited by a planet (see image at right). The disk surrounds the star 55 Cancri, which is 40 light-years away in the constellation Cancer and barely visible to the naked eye. In many ways the disk resembles the Kuiper belt, a ring of cometary nuclei and debris left over from the formation of our solar system.

David Trilling of the University of Arizona (UA) Lunar and Planetary Laboratory made the discovery with UA Planetary Sciences Professor Robert Brown. The researchers used NASA's Infrared Telescope Facility on Mauna Kea, Hawaii with "Co Co," the Cold Coronagraph, an instrument Brown developed specifically for this telescope. A coronagraph masks light from a star so that observers can image the surrounding area at high sensitivity.

"The disk we have found is similar in extent to our solar system's Kuiper belt and has a spectral signature similar to some Kuiper belt objects, suggesting similar compositions," Trilling said. Trilling and Brown reported on their discovery in the October 22, 1998 issue of *Nature*.

—from the University of Arizona



This infrared image shows the circumstellar disk around 55 Cancri, a star known to have a planet of its own. The red circle in the center of this picture is the mask of the coronagraph used to block the star's light. This image was captured in February 1998.

Image: David E. Trilling and Robert H. Brown, University of Arizona

Society News

We've Retired the Mortgage!

At our holiday party on December 21, 1998, we officially retired the mortgage to the Planetary Society's headquarters building in Pasadena. Thanks to generous donations from many members, we were able to ceremoniously "burn" the mortgage on the 1903 Greene and Greene "Craftsman" that has been our home for more than a decade.

Star Trek Voyager cast member Robert Picardo took part in the event, as did a LEGO rover, one in the next generation of toy rovers in the Planetary Society's *Red Rover, Red Rover* project. Equipped with a burning candle, the rover was remotely maneuvered toward a pot with rolled-up copies of the mortgage documents.

The Planetary Society first moved to the building at 65 North Catalina Avenue in 1985. Four years later, 2,700 members helped us put a down payment on the $850,000 home. "It's extremely rewarding," said Society President Bruce Murray of the mortgage retirement. "It's a milestone." Having no mortgage payment will enable us to put more funds toward programs and projects.

—Lu Coffing, Financial Manager

More News

Mars Underground News
Viking orbiter and *Mars Global Surveyor* scientist Mike Carr theorizes on the history of water on Mars.

Bioastronomy News
Final comments in the Case for Life on Mars debate. Is there evidence for past life in ALH84001?

The NEO News
Tsunami predictions for ocean impacts. An object inside Earth's orbit.

For more information on the Planetary Society's special-interest newsletters, phone (626) 793-5100.

Name Craters on Eros

Once the Near-Earth Asteroid Rendezvous (NEAR) spacecraft reaches its target asteroid—433 Eros—in February 2000, the mission team will be faced with the daunting challenge of naming more than 100 craters that may be found on the rocky object. The NEAR team has asked Planetary Society members to help suggest names, which will be submitted to the International Astronomical Union (IAU) for official consideration.

The selection process follows strict rules to ensure that the names chosen are appropriate and worthy. Naming regulations can be found at the IAU site on the World Wide Web: **http://wwwflag.wr.usgs.gov/USGSFlag/Space/nomen/nomen.html**. Names of geologic features on a planetary body generally follow a theme. For example, Gaspra, the first asteroid imaged by *Galileo*, was named for a resort in the Crimea. Gaspra's craters are named after spas of the world. The astronomer Galileo named asteroid Ida for a nymph who lived on the shores of Crete. Its craters are named after caverns and grottos of the world.

Eros suggests the theme of love, and this asteroid's craters may be named after famous lovers, legendary romantic locales, aspects of love, and so on. Each suggested name must be accompanied by a short explanation (50 words maximum). Please use a separate sheet of paper for each suggestion. Send your entries to: Names on Eros, The Planetary Society, 65 N. Catalina Avenue, Pasadena, CA 91106, USA.

—Charlene M. Anderson, Associate Director

Send Us Your E-mail Address

In our efforts to develop better contact with our membership, we've been upgrading and reorganizing our Web pages (Sun Microsystems donated a powerful server, which was installed late last summer). Beginning in 1999, we'll be working toward developing an e-mail list server to provide members with regular headlines, project updates, special appeals, and political action items.

Visit the Guest Book area on the Planetary Society's home page and leave us your e-mail address so we can keep you and other active members informed of events more quickly and efficiently.

—Cynthia Kumagawa, Manager of Electronic Publications

Society Projects in the News of 1998

Planetary Society programs and projects received media coverage in publications around the world during 1998. The Mars Microphone, a semi-finalist in the annual Discovery Channel awards, was profiled in the August issue of *Popular Mechanics:* "The Society not only sold the idea to NASA," the article says, "but also financed the project and even found a place for it on a Russian experimental module scheduled to fly aboard the Mars Surveyor [*Mars Polar Lander*] in January 1999."

The Planetary Society's expedition to Belize at the beginning of 1998 was the lead story in the April 19 issue of the *Washington Post* magazine: "In the town of Corozol, not far from the Mexican border in the north of Belize, I caught up with an expedition of scientists and volunteers for the Planetary Society. They were searching for crater ejecta and hoping to find new sites to study the K/T boundary." The reporter stayed with volunteers and staff who assisted scientists in the third expedition to Mexico. "Voyages of discovery aren't completely over," the article said. "You may simply need to look at old places with a new vision."

—Susan Lendroth, Manager of Communications and Events

Check out the Planetary Society home page on the World Wide Web http://planetary.org

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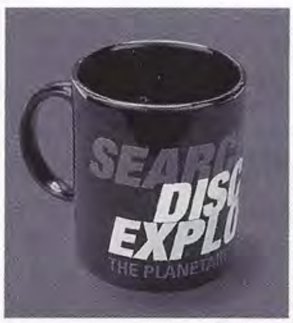

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The monthly cycles of the Moon, goddess of the night sky, have always served as a celestial calendar for viewers on Earth. For thousands of years, humans have gazed in wonder as our world's small companion waxes and wanes in the sky. In *Gibbous Moon*, Paterson Ewen portrays the bulging lunar phase between a half and full Moon.

Paterson Ewen's work is in the collections of most of the major public art institutions in Canada and has been exhibited widely in North America and Europe. He was chosen to represent Canada at the 1982 Venice Biennale art show, and he has been honored with the Toronto Arts Award and the Chalmers Award for Visual Arts. Born in 1925, Ewen lives and works in London, Ontario.

Painting courtesy of the National Gallery of Canada, Ottowa

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