The PLANETARY REPORT

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Martian Sunset

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Table of Contents

Features

Departments

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On the Cover:

The Sun sets on another exciting and productive day on Mars for the *Pathfinder* lander and the *Sojourner* rover. *Pathfinder*'s camera collected this picture on Sol 24, the 24th Martian day of the mission. The blue and red of the sky are about the same as they would appear to the human eye, but the Sun itself is overexposed—it would appear nearly white or slightly blue. As the spacecraft landed on July 4, 1997, thousands celebrated at Planetfest '97, a festival of exploration sponsored by the Planetary Society. There Tony Spear, *Pathfinder* project manager, announced that the lander had been named the Carl Sagan Memorial Station and that it had carried the names of 100,000 Society members to the Martian surface.

Image: JPL/NASA

From The Editor

I have never liked any written piece that opens with a cute anecdote about the author's children. But this time I can think of no better way to illustrate what Planetfest '97 was and how it affected people, so:

My two-year-old daughter walked into the main hall at Planetfest just as the thousands of guests got word that *Pathfinder* had landed. The resulting roar of delight rocked the Pasadena Center and terrified my daughter. She's far too young to appreciate the technical and political achievement, and she immediately started chanting, "I want to go home. I want to go home NOW!"

But her mother was on staff and her father was a volunteer. She stayed. She started to enjoy herself. She joined in the excitement and enthusiasm of the people who had gathered together to witness a spacecraft landing on another planet. A feeling of camaraderie and shared success settled over the thousands filling the convention center. Such moments happen so rarely it's hard to let go when the event is over. That's what happened with my daughter. "I don't want to go home. I want to stay here with my friends!" That was the chant by the end of Planetfest.

Planetfests exemplify what this Society does best: sharing the wonder of exploring the planets with everyone. My daughter will be at the next one; I hope you will be too.
—*Charlene M. Anderson*

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Members' Dialogue

Names on Mars After All

I was glad to read in the September/October 1997 *Planetary Report* that my name made it to Mars, after all. I followed the landing and subsequent findings of the Sagan Memorial Station and *Sojourner*. But never did I hear that the list of Planetary Society members was also safely on the Red Planet. It's exactly this kind of personal honor, to be involved in space exploration, that has earned the Society a member for life.

Thanks for putting me on Mars.
—CURT PETROVICH,
Winnipeg, Manitoba, Canada

Ice Insights

I was quite dismayed by "The Color of Europa" (see the September/October 1997 issue of *The Planetary Report*) because Paul Geissler discusses the Ross Ice Shelf and then describes it as sea ice. I worked for three austral summers on the Ross Ice Shelf and it is comprised of glacial ice, not sea ice. The Ross Ice Shelf is formed from the convergence of glaciers near sea level, as are all shelf ice structures. Seasonal sea ice does form adjacent to the Ross Ice Shelf in McMurdo Sound but is not considered to be part of the ice shelf.

Its seems that many researchers are suddenly jumping on the "sea ice bandwagon" since the *Galileo* images of Europa have become available. However, I would advise caution in gross generalizations regarding ice processes. Some of us have been studying the formation and physical properties of sea ice, glacial ice, and snow for our entire careers and are continually challenged with the complexity of studying and interpreting surface ice processes on Earth, let alone on a distant moon of Jupiter.
—RENEE M. LANG,
Gig Harbor, Washington

You're quite right, a better choice of terms would have been "floating ice." In addition to having a different origin, shelf ice is much thicker than the seasonal pack ice, making it perhaps a better analog to Europa. Both types of ice are seen in the Antarctic image accompanying the article. The Ross Ice Shelf, like the pack ice, appears blue in the false-color Galileo *image because the ice particles in the top tens of centimeters of the surface are larger, on average, than those of the continental snow visible on the horizon. The coarse surface grains result from the relatively warm temperature of the floating ice, because it is in contact with liquid water.*

At a recent Flagstaff, Arizona meeting of planetary scientists and specialists in remote sensing of terrestrial ice, we were impressed by the diversity of morphologies produced by various surface ice processes on Earth and by the fact that many of these remain poorly understood. Because of the differences between Earth and Europa and our incomplete knowledge of both of these worlds, there may be important insights about Europa to be gained from studies of surface ice processes on this planet, and vice versa.
—Paul Geissler

Humans on Mars

I'd like to add to the recent exchange between Norman Horowitz and Rosanna Shapiro based on "The Future of the Planetary Society" by Louis Friedman in the May/June 1997 issue. Horowitz states that all future exploration of the planets can be done by robots. No supporting evidence is ever given for this statement. Many measurements can, of course, be done by instruments, and many must be. But most geologists, including me, would argue that field geology, requiring the complex interplay of many observational factors, cannot be done with foreseeable robotic means. We can start with robots, but we have not adequately explored what will be missed by using only robots.

Pathfinder, a wonderful mission within its constraints, actually demonstrated clearly some of what is missed when humans are not present. Several questions anguished over for days could have been answered in a few seconds by a field geologist—such as whether a particular sample had soil on it, or was a volcanic rock or a breccia. It is not merely a case of better, faster-responding rovers and optics (unless we get close to an android). I am almost offended by statements that robots are not only "smaller, cheaper, faster" but also better. If only it were that simple!

Unfortunately, the exchange between Horowitz and Shapiro was headlined, in a polarized way, as "Humans Versus Robots" and "Men or Machines." This sets up a conflict, when future exploration of the planets will surely be performed by combinations of robots and humans, each doing what they do best.
—GRAHAM RYDER,
Houston, Texas

Addenda

In the July/August 1997 Members' Dialogue, Joel Greenman's name was printed, incorrectly, as Joel Greenberg.

The photo of Carl Sagan with former students on page 7 of the May/June 1997 issue was taken by Philip Handler.

Please send your letters to
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PLANETFEST 97

Mars Pathfinder Landing Inspires Thousands Celebrating the Adventure of Exploration

by Jennifer Vaughn

On the morning of July 4, 1997, an eager crowd gathered outside the Pasadena Center, hours before *Mars Pathfinder* bounced down on the Martian surface and well ahead of the 10 a.m. opening for Planetfest '97. Planetary Society Executive Director Louis D. Friedman decided to begin the weekend celebration early. With more than 7,000 people visiting the center each day, the three-day celebration marked a new highpoint in our fantastic journey beyond planet Earth.

Cheers erupted from the standing-room-only crowd in the 1,800-seat Main Hall on the afternoon of July 4, as the first *Mars Pathfinder* image filled the 25-foot video screen. For the first time in 21 years, we all stood on Mars together and took a look around.

Jet Propulsion Laboratory (JPL) scientists came down from Mission Control and joined the crowd to offer first-hand insights into *Mars Pathfinder*'s flawless landing and the camera's outstanding images. Planetfest '97 brought together leaders in space science, demonstrations of the newest technological innovations, and exhibits of future space missions. Planetfest '97 was a spectacular success.

Live from Mars and JPL

As images were released over the weekend, crowds continued to gather in the Main Hall, where lectures, panels, and tributes involved the biggest names in space today. In a moving tribute, Carl Sagan's wife and collaborator Ann Druyan accepted honor for her late husband from NASA Administrator Dan Goldin, who announced that the *Mars Pathfinder* lander had been renamed the Carl Sagan Memorial Station. Druyan's speech was an emotion-filled prelude to a special announcement by *Mars Pathfinder* Project Manager Tony Spear that a microchip containing the names of 100,000 Planetary Society members—a duplicate of the October 1993 list of names on "Visions of Mars" that was lost with *Mars '96*—had been placed on the Sagan Memorial Station now sitting on the surface of Mars.

Hands-On Exhibits, First-Hand Accounts

Outside the Main Hall, the conference center was filled with exhibits that offered space and mission information, memorabilia, book signings, and raffles. One exhibit

Top: In the Main Hall, the 25-foot screen displays Mars Pathfinder's *new home on Mars as Flight System Chief Engineer Rob Manning describes to an attentive audience the spacecraft's successful descent and landing.*

Middle: In a special dedication ceremony to the Society, astronaut Story Musgrave presented a banner emblazoned with the Planetary Society logo. The banner was aboard his last flight on the space shuttle. From left to right, Society President Bruce Murray and Story Musgrave are joined by the Society's Executive Director, Louis Friedman, and Society Board member Ann Druyan.

Bottom: A Red Rover, Red Rover Marscape draws an enthusiastic crowd to cheer on LEGO microrovers as they conquer terrain obstacles.

Photos: Lee Thomas

demonstrated the workings of a system designed to create propellant from Mars' carbon dioxide-rich atmosphere—fuel that future spacecraft may use for return trips to Earth. A steady stream of attendees ogled a piece of the famed Mars meteorite ALH84001, containing possible evidence of Martian microbial life. Still other exhibits focused on current and future missions, including *Galileo, Cassini, Stardust, Pluto Express*, the Near-Earth Asteroid Rendezvous (NEAR), *Mars Global Surveyor*, and, of course, *Mars Pathfinder*.

Distinguished scientists and engineers gave talks and joined in panel discussions during three days of Discovery Symposia presentations. July 4 featured a full schedule of workshops conducted in Spanish. Astronaut Story Musgrave, who participated throughout the weekend, shared details from his six adventures aboard the space shuttle. A capacity crowd flocked to hear astronomer Thomas Bopp's account of his discovery of the most widely observed comet in human history. And in an engaging panel presentation, notable women scientists and engineers, including Mars Exploration Program Manager Donna Shirley, discussed current obstacles and opportunities for women in planetary exploration.

Press interest surged over the course of the weekend as reporters and TV crews—including two crews from CNN—documented the excitement at the conference center, interviewing attendees, lecturers, and exhibitors. NASA-TV, which was simulcast throughout the center, kept attendees informed of what was happening a few miles away at JPL.

Future Mission Members

Self-contained in an outdoor patio, A Child's Universe showed young Planetfest '97 attendees that space science is fun and fascinating. Grouped with their peers and supervised by Planetary Society staff and volunteers, children of all ages participated in numerous science-oriented educational play activities. Even in the mid-afternoon Pasadena heat, children romped through A Child's Universe, delighting in projects and games.

More than 300 children built and launched water rockets—an estimated 1,500 launches took place at the nearby Kidspace Museum. Children and adults gathered around a simulated Martian terrain to watch six Red Rover, Red Rover microrovers maneuver through obstacles of rocks and uneven soil. These rovers were controlled by Planetfest '97 attendees at the Mars Base Control Room adjacent to the terrain. Meanwhile, there was a second simulated Mars terrain where participants used

(continued on page 6)

A child's natural fascination with space is captured by this official NASA spacesuit—one of the many awe-inspiring exhibits featured at Planetfest '97. *Photo: Lee Thomas*

A Martian Walkabout

by Charlene M. Anderson

On July 4, 1997, an emissary from Earth came to the Red Planet for the first time in over 20 years—*Mars Pathfinder*, a harbinger of the "faster, cheaper, better" missions now underway in NASA. *Mars Pathfinder* demonstrated the effectiveness of a novel system of airbags to cushion landing spacecraft, small and clever instrument packages, and the show-stealing microrover *Sojourner* (named by Valerie Amboise in a Jet Propulsion Laboratory/ Planetary Society student contest).

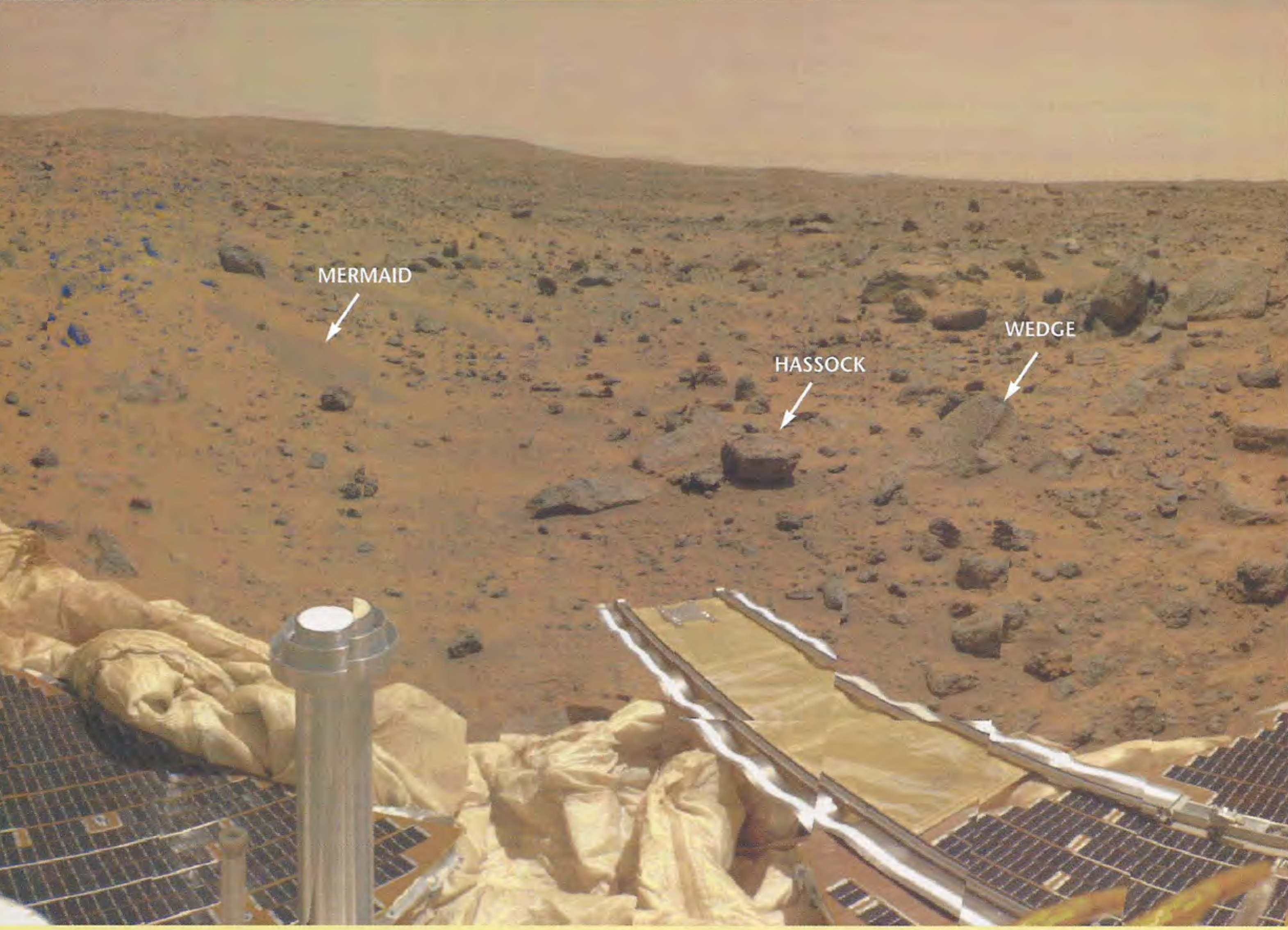
Mars Pathfinder is, of course, very close to Planetary Society hearts. The spacecraft carried the names of all Society members (as of October 1993), inscribed on a microchip, to Mars. The landing craft itself is now named the Carl Sagan Memorial Station after our first president and co-founder. And at Planetfest '97, the Society's everybody-welcome celebration of the *Mars Pathfinder* landing, more than 7,000 people per day shared first-hand in the excitement of exploring Mars.

Mars Pathfinder is providing plenty of excitement to go around. Scientists and engineers alike are elated by its success. Initially designed as an engineering test mission, *Mars Pathfinder* is returning a trove of scientific data. Full analysis of the data will take time, but the story that *Mars Pathfinder* will tell about Mars has begun.

Scientists chose the landing site in Ares Vallis because it is a plain where they expected to find samples from different parts of Mars within easy reach, deposited by ancient, catastrophic floods. Their strategy seems to have worked, for the spacecraft has identified several different types of rocky characters for study.

With the 360 degree panorama on the top of the next four pages, we begin *Mars Pathfinder* coverage that will continue over several issues. We'll start by walking a complete circuit around the Sagan Station. As you look at the panorama, keep in mind that if this image were projected on a circular screen, the left margin of page 6 would meet the right margin of page 9. Enjoy your walk on Mars!

Charlene M. Anderson is Director of Publications for the Planetary Society.



PART 1: We begin our tour at Mermaid, an area of dark soil whose shape suggested the piscine temptress of sailors' lore to *Mars Pathfinder* scientists. There seem to be several types of soils at the landing site. The color gradations may represent different compositions or particle sizes. *Sojourner* undertook some soil mechanics tests at Mermaid, scraping out trenches with its tires.

The billowy material underneath the lander's solar-cell-covered petal is part of the airbag system that cushioned the spacecraft's landing. The cylindrical, upright object is the low-gain antenna for communicating with Earth. To the right of that is the front rover ramp, down which *Sojourner* did not come—the terrain near the back ramp was judged safer for the novice rover to navigate. Just above the end of the front ramp is the boulder called Hassock, which seems to be made of columnar basalt. To the right of Hassock is Wedge, whose name, too, reflects its shape. The rover spent a couple of days stuck on top of Wedge but eventually freed itself to continue exploring.

(continued from page 5)

computers to drive on-site rovers as well as remote rovers as far away as Illinois, Georgia, and Florida.

World Wide Interconnectivity

Planetfest '97 reached far beyond the walls of the Pasadena Center. Computer users logged onto the Internet to monitor *Mars Pathfinder*'s landing and witness lectures that were transmitted around the world via the World Wide Web. The 17 *Mars Pathfinder* Web sites endured approximately 30 million hits on the day the capsule bounced down on Mars (NASA Web site hits peaked on July 8 at 45 million). The Planetary Society's Web page funneled updates and information to tens of thousands of visitors throughout the weekend, with more than 600,000 hits by the end of the holiday weekend.

More than 100 computer stations set up throughout the conference center offered celebrants a remote look at what was taking place at different sites around Planetfest '97. Sun Microsystems brought more than 70 powerful workstations, supplemented by computer technology from Gateway 2000, Earthlink Network, and the Los Angeles Unified School District. NASA Integrated Systems Network and Cisco Systems provided Internet connections and Graham Technology Solutions provided live video and audio technology that made Planetfest '97 a truly sensational event.

Archiving for the Future

Sun Microsystems is working with the University of North Carolina and the Planetary Society to archive much of the video from Planetfest '97. World Wide Web users will be able to download video clips from the Sun site and the Society's Web page. We will soon be putting many other challenging computer technologies to work, spreading the word about this new age in space exploration.

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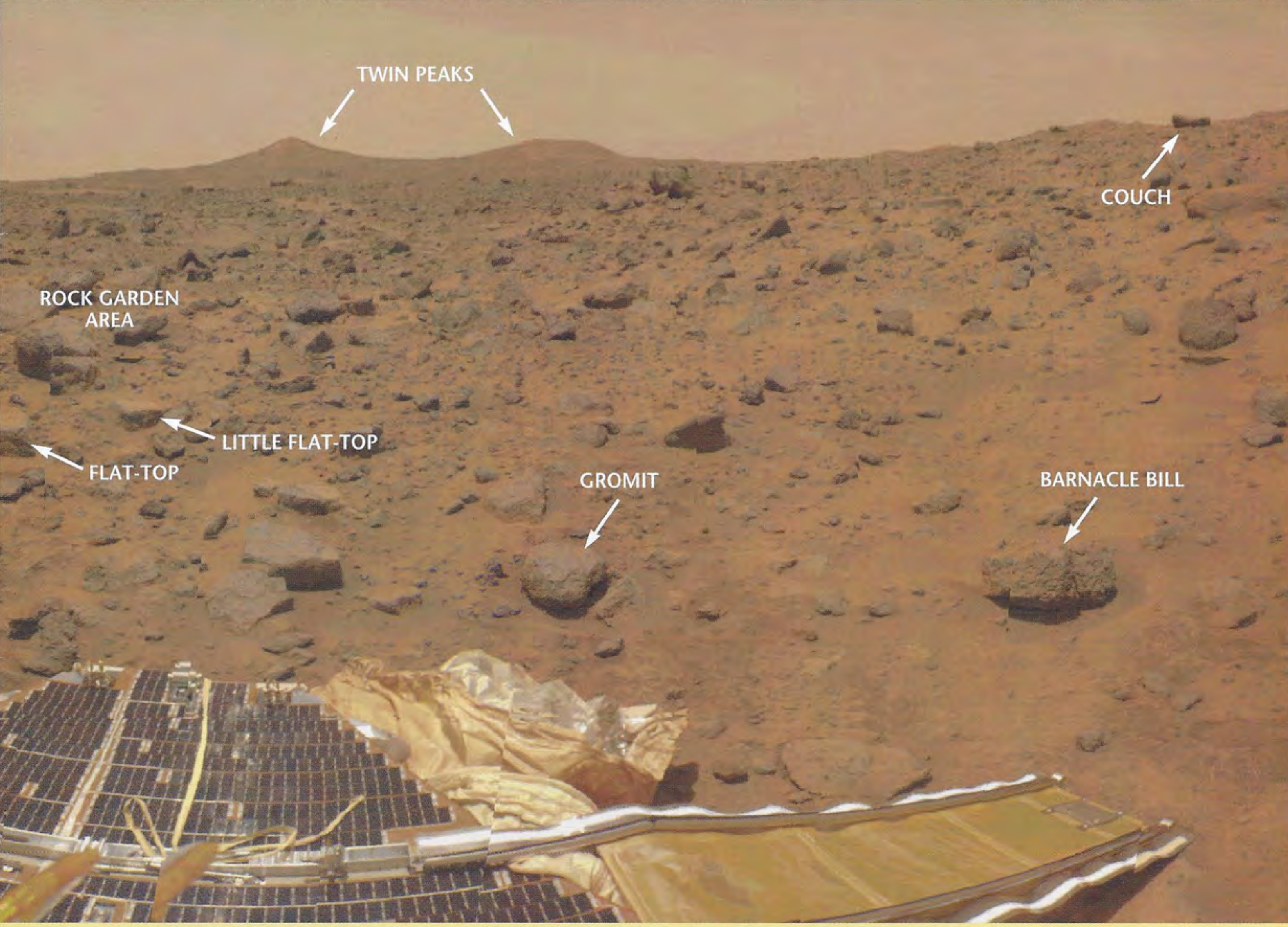
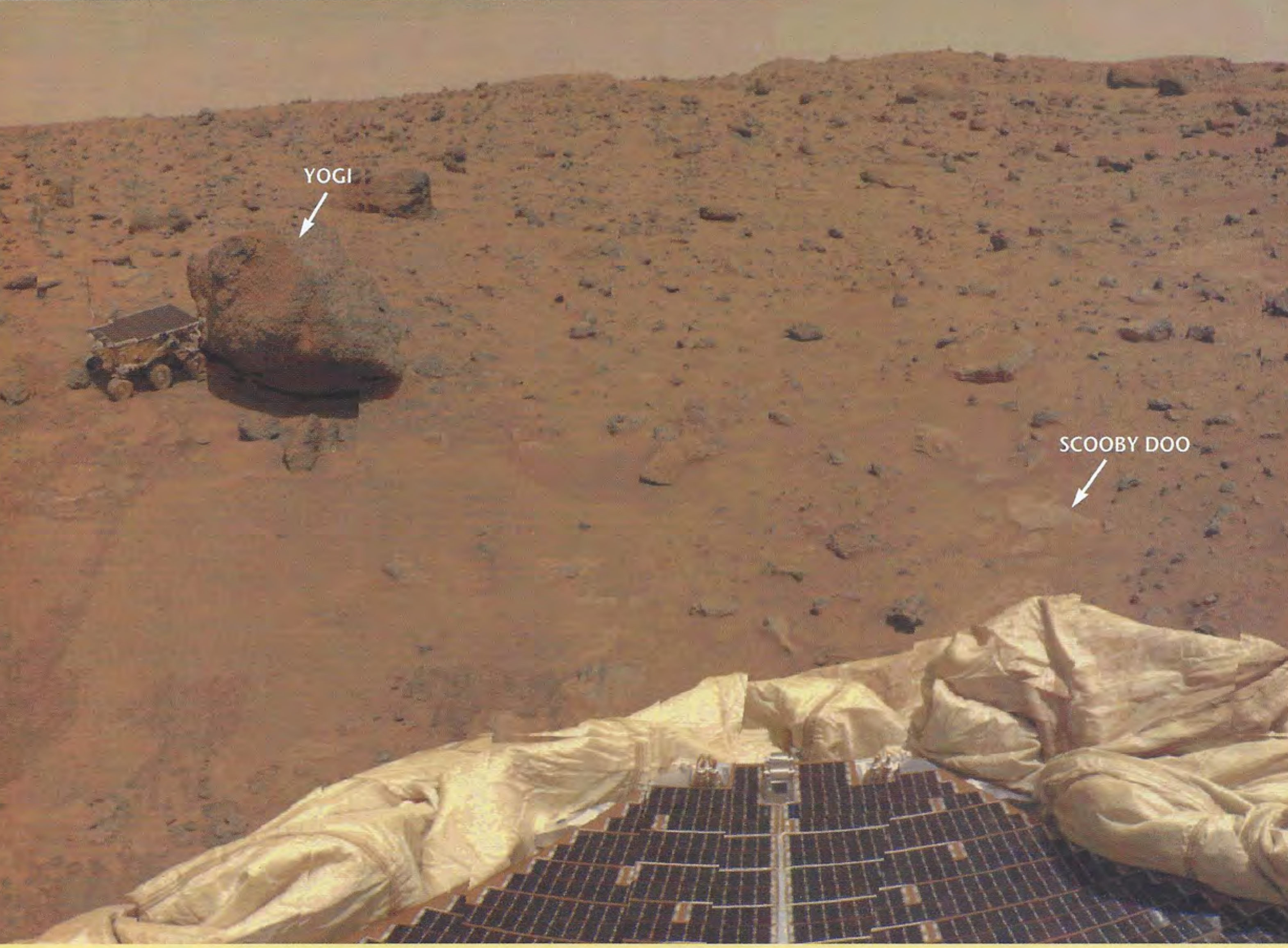


PART 2: Now we enter the Rock Garden, populated with a variety of intriguing features in the left of this page's image. Some of its denizens are Flat-Top and, just to its right, Little Flat-Top. On the horizon above the Rock Garden rise Twin Peaks; North Peak is 800 meters from the landing site, while South Peak is 1,200 meters away. Just above the collapsed airbag is Gromit. Right of the airbag is the ramp *Sojourner* used to reach the Martian surface. The large boulder above the ramp is the famous Barnacle Bill. The Alpha Proton X-ray Spectrometer (APXS) on *Sojourner* took measurements indicating that this rock contains more silica than scientists expected to find in rocks on Mars. It resembles andesite, a type of volcanically processed rock common in the Andes. On the horizon just to the right of Barnacle Bill is a dark rock named Couch.

Left: Mars Pathfinder *Project Manager Tony Spear found time to break away from Mission Control to share in the celebration at Planetfest '97. Above: NASA Administrator Dan Goldin (middle) poses proudly with Everett Gibson (left) and David McKay, leaders of the research team investigating the Martian meteorite containing possible evidence of microbial life. Right: The presenters of the Women in Science panel were, from left to right, Adriana Ocampo, Donna Shirley, Eleanor Helin, Sandra C. Miarecki, Ellen Stofan, and Kari Magee.*
Photos: Lee Thomas



PART 3: Here we catch up with 63 centimeters (24.5 inches) long *Sojourner*, taking measurements of the large boulder Yogi. Yogi is basaltic, the most common rock type on Earth (where it forms most of the ocean basins) and expected to be common on Mars. According to APXS data, it contains less silica than Barnacle Bill. Below Yogi, it's easy to see the rover's tracks, including a circle it executed while turning to investigate Barnacle Bill.

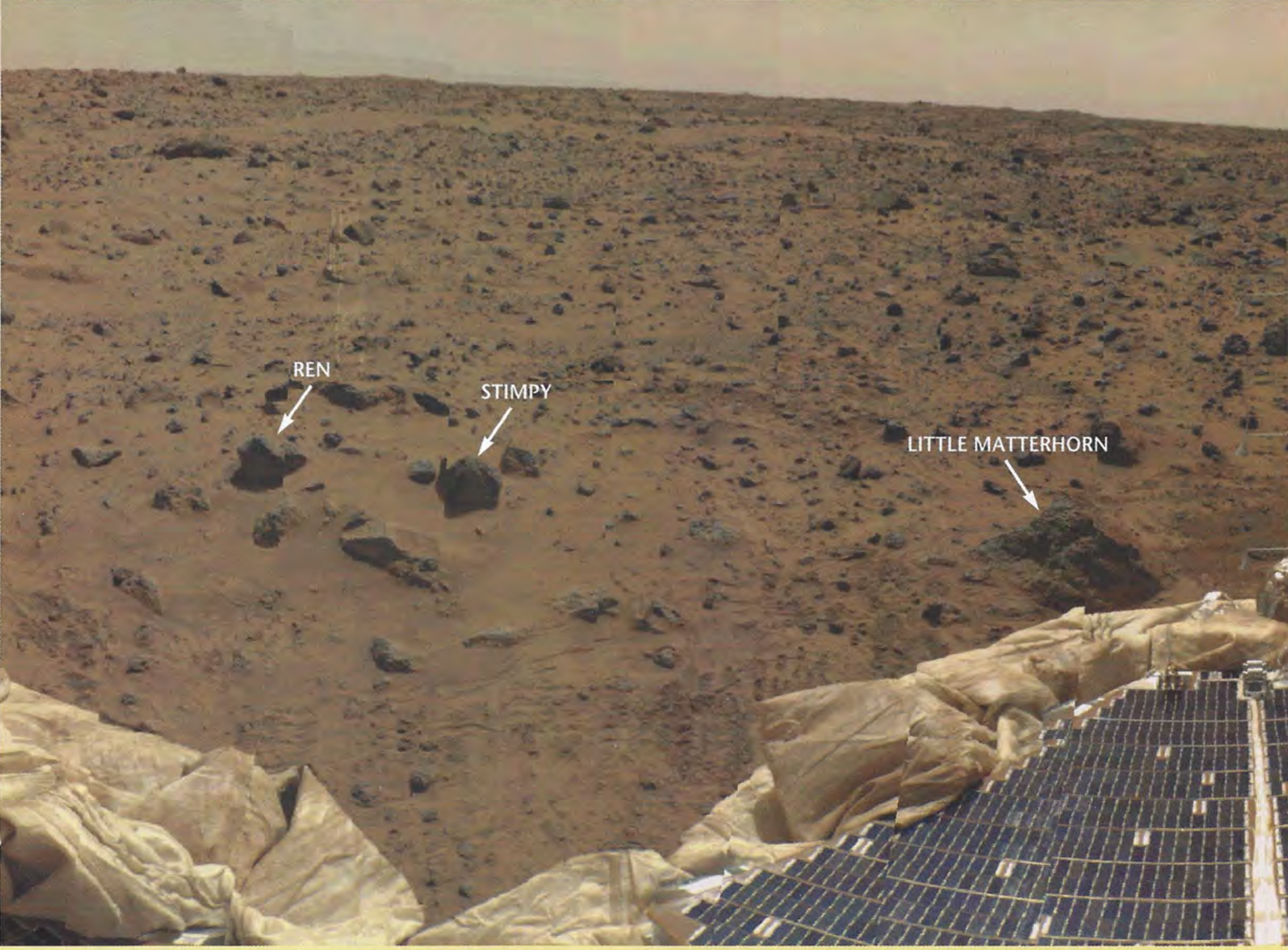
In the early days of the mission, *Sojourner* took seven soil measurements in the flat area above the air bag. The soil's composition is very similar to that of the *Viking* landing sites measured 21 years ago. The white patch just above the airbag is Scooby Doo. Named for a television cartoon contemporary with *Viking,* Scooby Doo is probably not a rock but a hardened patch of soil, perhaps similar to caliche or hardpan on Earth.

The slight rise on the horizon is a feature called Little Crater, which is visible on *Viking* orbiter images of the landing site.

Inspired depictions of space and exploration lined the walls of the concourse connecting the exhibition halls at Planetfest '97. The juried art show, "Exploring the Art of Space," featured 99 paintings by 48 artists whose work ranged from "scientific realism" to "visionary."

At the show's opening reception, Rick Sternbach, senior illustrator and technical consultant for Star Trek, *presented the awards.* Lonely Orbit *(near right) by Molly Barr won the prize for first place. The second place award went to Roger Ferragallo's* Nova Genesis *(far right), and Don Davis took third place for* Imaginary Earthlike World *(bottom).*

"Exploring the Art of Space" received nationwide attention thanks to an article published in the July 29, 1997 New York Times. *In "New Visions of the Cosmos Now That It's Close at Hand," M. G. Lord wrote that "artists have long been fascinated by heavenly objects, but new technology has given a breathtaking reality to their visions."*



PART 4: We are now completing our circuit of the Sagan Station. The two boulders to the left of center are Ren and Stimpy, honoring some not-so-classic cartoon characters. Above the air bag on the right is the Little Matterhorn, named for its resemblance to the peak found in the Swiss Alps and in the cartoon-world of Disneyland.

Sojourner **undertook its largest traverse (at least by press time) in this region, covering four meters in one day. The rover's batteries have lasted past the end of the nominal mission, so more adventures lie ahead. As it traverses this alien landscape, scientists back on Earth are calibrating the rover's instruments and trying to create from its data a coherent history of this jumbled region of Mars. Look for an update on more findings from *Mars Pathfinder* in future issues of *The Planetary Report.*** Images: JPL/NASA

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The Adventure Continues

With so many exciting missions coming up as we approach the new millennium, we're gearing up for our next celebration. We're especially excited about a *Mars Surveyor* lander, which will touch down on December 3, 1999 near the Red Planet's south polar cap to begin one of the most intriguing missions ever undertaken. The lander will carry the Mars Microphone, supported by the Planetary Society.

Plus, the *Galileo* Europa Mission will be ending in early December 1999, and we'll have the discoveries of that mission to salute. We have not yet selected the dates for the next Planetfest, but we hope to start making plans soon. Keep your eye on *The Planetary Report* for the latest information.

Jennifer Vaughn, Editorial Assistant for The Planetary Report, *was among the tireless Society staffers who made Planetfest '97 run smoothly.*

We Could Never Have Done It Without . . .

The Society congratulates NASA/JPL, the private companies, and the individual scientists whose vision, expertise, and commitment made *Mars Pathfinder*'s success happen.

We also extend special gratitude for the generous support from the companies and organizations who helped make Planetfest '97 a success, including Sun Microsystems Computer Corp., NASA Integrated Systems Network, LEGO Dacta, Gateway 2000, Earthlink Network, Home Depot, Final Frontier, Lockheed Martin, Sky Publishing Corp., Wind River Systems, Los Angeles Unified School District—Los Angeles Systemic Initiative, Interplay Productions, Vroman's Bookstores, Guardian Services, Price Costco, Ball Plastic, Cisco Systems, Colorland, Digital Link, Instructional Fair, Plaza Pasadena, Smart & Final, InFocus Photofinishing & Image Centers, Enterprise Entertainment, Warner Bros. Studios, Paper Graphics Ink, Northwest Asset Management, Target Pasadena, URLabs, Kidspace Museum, Wells Fargo Bank—Pasadena, and NASA Education Office.

Mars Life? One Year Later

BY BRUCE JAKOSKY

Unless you lead a very sheltered life, you are aware of the discussions during the past year regarding possible evidence for life on Mars. In August 1996, a team of scientists headed by David McKay of NASA's Johnson Space Center published the initial report on this evidence in the journal *Science* and presented the results to the public in a widely reported press conference. Since then, other teams of investigators have conducted their own analyses, some reaching conclusions that differ from the initial reports. Results from others support or at least are consistent with the NASA team's proposed evidence.

A year later, are we any closer to knowing whether the features within the meteorite are remnants of Martian life? Or whether life ever existed on Mars?

Proposed Signs of Life in ALH84001

The original evidence was found using geochemical analyses and scanning electron microscope imaging of portions of the meteorite ALH84001. This meteorite, collected in Antarctica, is one of 12 thought to be from Mars. Because of the meteorite's age (having formed at a time when the planet probably had a warmer, wetter climate) and because of the veins of carbonate minerals that run through it (which probably precipitated out of liquid water flowing through the rock), McKay's team immediately recognized that ALH84001 might contain traces of Martian biology. They made five observations that they felt indicated Martian biota.

First, they found polycyclic aromatic hydrocarbons (PAHs, pronounced "pahs") associated with the carbonate deposits. The PAHs are organic molecules, consisting primarily of carbon rings, which may be decay byproducts of living things or may be produced by non-biological processes such as high-temperature combustion of organic molecules.

Second, the McKay team identified a compositionally layered structure within the carbonates that is similar to layered structures in terrestrial carbonates whose formation is aided by bacteria.

Third, they found magnetite grains that have not previously been seen in meteorites and that are of a size and shape similar to terrestrial mineral grains produced by certain types of bacteria. They also found grains of an iron sulfide mineral that they tentatively identified as greigite, which on Earth is only produced by bacteria.

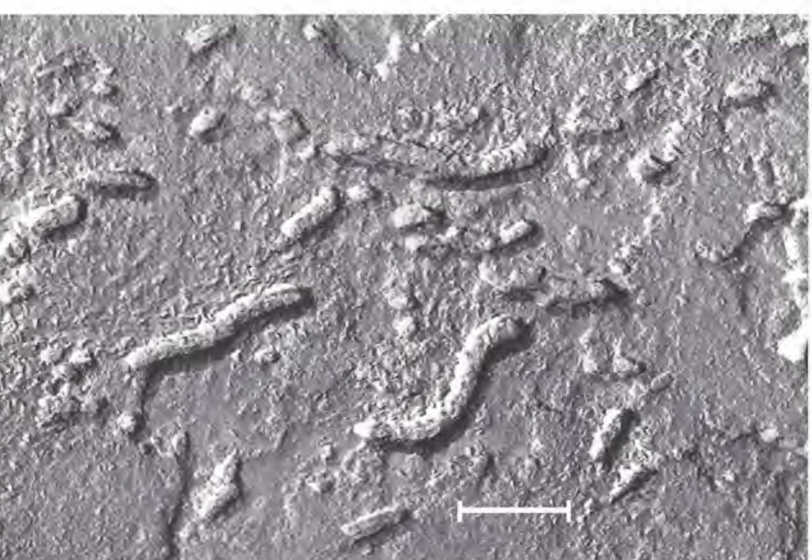
Fourth, they found grains of iron-sulfide minerals, magnetite, and carbonate adjacent to one another; these materials would not all be stable under any one set of physical conditions, which suggests formation by a non-equilibrium process (by bacteria).

Fifth, they found structures about 100 nanometers in size (nanometer = one billionth of a meter) that bear a striking resemblance to terrestrial fossil bacteria. While these structures are much smaller than bacteria, they are similar in size to "nannobacteria," which are structures found within some terrestrial minerals that may be living organisms.

McKay and colleagues recognized that each of these observations, taken individually, could result from inorganic, geochemical processes. However, they felt that the combination of all of them was better explained by biological processes.

Clearly, big issues were (and still are) at stake here—nothing less than the possible discovery of extraterrestrial life! In the year since the initial announcement, there have been perhaps a dozen investigations reported in the scientific journals or presented at conferences on meteorites, planetary geochemistry, and the origin of life. Innumerable discussions have taken place among scientists standing around the water cooler, trying to understand both the original and the new results. While the new results have a lot to say about the conditions surrounding the formation of the meteorite, ultimately they do not allow us to decide yet whether the rock contains evidence of life.

Determining whether the features that we see are of biological origin is difficult—how do you identify something as uniquely biological? Most of the analyses have focused instead on the properties of the carbonates and of the deposits.



These worm-like structures in ALH84001 appear similar to some of the earliest forms of life on Earth, but they are so small that some researchers claim they are too tiny to contain the processes necessary for life. However, there are similarly sized entities on Earth, called nannobacteria, that other researchers claim are living things. The white line indicates a measure of 500 nanometers (a nanometer = one billionth of a meter). Image: David McKay, Johnson Space Center

Carbonate Formation: How Hot?

Half a dozen studies have tried to use various techniques to determine the temperature at which the carbonate minerals were deposited. Carbonates can be deposited from a fluid mixture of carbon dioxide and water at temperatures above 600 degrees Celsius (1,100 degrees Fahrenheit) or from water at temperatures around 50 to 150 degrees Celsius (110 to 300 degrees Fahrenheit)—or, really, at almost any temperature in between. The bacteria-like structures in ALH84001 were encrusted into the carbonates as they formed, so a very high formation temperature would preclude their having been alive—life cannot function at such high temperatures, as the organic molecules are unstable and break apart very quickly.

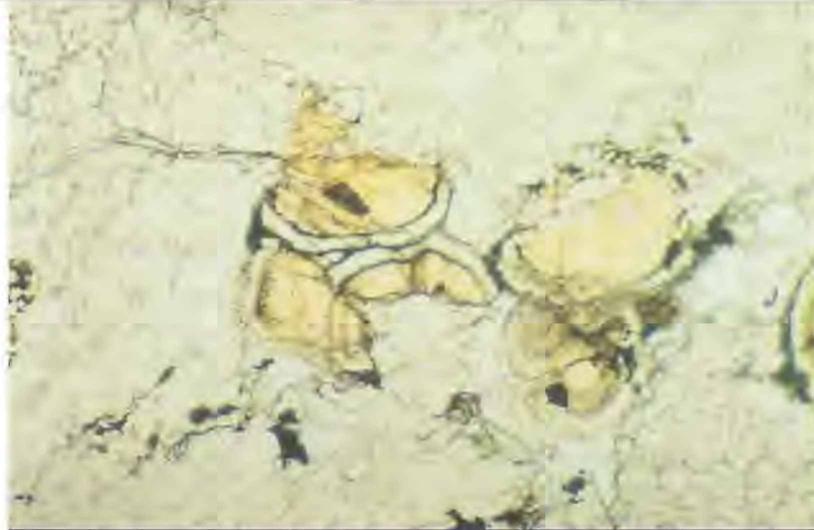
The original suggestion of a low-temperature formation came from oxygen-isotope measurements. When carbonate minerals form from dissolved atoms, the minerals prefer the lighter isotopes of oxygen (the isotopes differ only by having one or two extra neutrons in their nucleus, making them just a little bit heavier). The degree of preference depends on temperature, so comparison of isotope ratios, between the carbonate grains and the carbon dioxide from which the grains formed, can be used to determine the temperature. Whether the original ratio was set by interaction with the minerals (as suggested by Chris Romanek and colleagues, including many of the members of McKay's group) or by exchange with the atmosphere (as proposed by Kevin Hutchins and me), the isotope ratios indicate a low temperature of formation—certainly less than 300 degrees Celsius (600 degrees Fahrenheit).

On the other side, an indication of a high-temperature formation came from observations of the structure of magnetite grains held within the carbonates. John Bradley and colleagues found mineral grains that they described as looking like small "whiskers." These are thought to form only at high temperatures, around 650 degrees Celsius (1,200 degrees Fahrenheit). In addition, some were not perfect crystals, as would occur in biologically produced grains, but had a particular type of defect that is termed a "screw" dislocation. In a screw dislocation, atoms in one row of the crystal are offset from where they should be. Such a defect can occur in crystals grown from vapor but not from those grown biologically. These researchers conclude that the crystals in ALH84001 could not have been produced by bacteria.

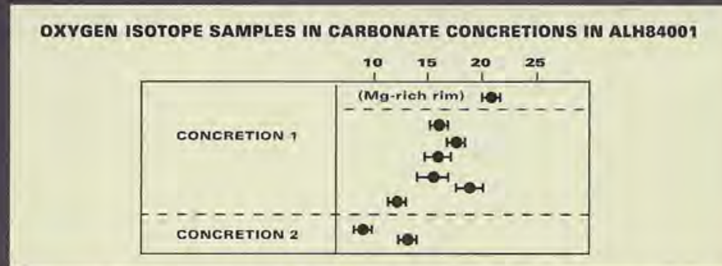
A History Written in Atoms

Joseph Kirschvink and his colleagues from the California Institute of Technology examined the magnetic field retained by individual magnetite grains trapped within the carbonate deposits. When it forms, magnetite will retain an "imprint" of whatever magnetic field is present at the time; it will keep this imprint unless it is heated up to high temperatures. Magnetite will completely lose the field at about 600 degrees Celsius (1,100 degrees Fahrenheit). Measuring the amount of magnetic field retained, the researchers estimate that the grains have not been heated above 325 degrees Celsius (617 degrees Fahrenheit) and probably not above about 110 degrees Celsius (230 degrees Fahrenheit). Had the carbonates formed at extremely high temperatures, the imprinted magnetic field would have been lost.

Meanwhile, John Valley (University of Wisconsin) and colleagues and Laurie Leshin (University of California at Los Angeles) and colleagues obtained detailed measurements of oxygen isotopes within the carbonates. They found variation



This thin section, just 0.03 millimeters (0.001 inch) thick, shows the carbonate globules from ALH84001 in actual color. At their centers, the globules are orange-brown and rich in iron. They grade out to clear, magnesium-rich carbonate with dark rinds. This view is 0.55 millimeters (0.02 inch) across. Photo: Allan Treiman, Lunar and Planetary Institute



Sampling by ion microprobe shows that concretion 1 has a higher abundance of oxygen-18 in its magnesium-rich rim than within its interior. Concretion 2 has lower oxygen-18 abundance than most of concretion 1. The range in measured values is larger than the uncertainty in each measurement, so the variations within a single concretion and between concretions are real. The values shown here are the difference in parts per thousand between the oxygen-18/oxygen-16 ratio and a standard ratio.

Chart based on results reported by John Valley and colleagues in Science, 14 March 1997, p.1633

in the ratio of oxygen-18 to oxygen-16, ranging from Mars' planetwide value to values extremely enriched in the heavier isotope. Valley suggested that this variation meant a low formation temperature (in chemical equilibrium with surrounding minerals) while Leshin held that it meant a high formation temperature (not in equilibrium but isolated from surrounding minerals)! Clearly, the correct interpretation depends on the history of the individual atoms in the grains, and this is not known.

To complicate our understanding even further, Tim Jull (University of Arizona) and colleagues have suggested, after looking at measurements of the isotope carbon-14, that there might be terrestrial carbon and oxygen within the grains! Carbon-14 is radioactive and decays quickly, so there should be much smaller amounts in the carbonates than are observed. The only explanation is that terrestrial carbon is entering the meteorite (carbon-14 is continually replenished in the Earth's atmosphere). If terrestrial carbon is entering the grains, it is likely that terrestrial oxygen is doing the same.

Why are there so many different interpretations? The various investigators are looking at the same rock, and it can have had only one history, right? Possibly not. Simon Clemett of Stanford, one of the members of McKay's team, argues that the meteorite contains at least five different forms of carbonate minerals (for example, filling small holes versus filling small fissures and cracks). Carbonates might have been

Two necessary factors for life are liquid water and energy. On Mars we see evidence that both existed on the surface in the distant past. In this Viking *orbiter image, we see a very distinct channel, named Dao Vallis, that begins near the slopes of an extinct volcano, Hadriaca Patera (top center). This channel may have been formed when subsurface volcanic activity melted ground ice and released water to flood across the landscape.* Image: Jack Farmer, NASA/Ames Research Center; JPL

deposited into the different locations at different times or in association with different events. Some may have been deposited at higher temperatures and some at lower temperatures.

If nothing else, the intense investigation reveals that ALH84001 has had a complex geological history!

PAHs and Martian Chemistry

The issue of terrestrial contamination is basic to any conclusions we draw from ALH84001. For example, the organic PAH molecules would be significant in themselves if they proved to be Martian. Even if they were not decay byproducts of a Martian biota, the presence of organics on ancient Mars would add support to the case for an origin of life there.

PAHs, though, are nearly ubiquitous throughout the solar system. They have been found in meteorites (formed from other organic molecules in interstellar and interplanetary space), and they are found on Earth (for example, as byproducts from the burning of gasoline). PAHs are found in the ice in Antarctica.

Luanne Becker (University of California at San Diego) and colleagues found that PAHs in seasonal meltwater in Antarctica would attach to carbonate grains preferentially and would, if they could diffuse into the meteorite, become concentrated in the grain interiors. However, Clemett pointed out that there were problems with the experiments that led to these findings. In particular, the experimental conditions did not allow sufficient time for the PAHs to attach to the carbonates. Moreover, since the PAHs are relatively insoluble in water, it is possible that a substantial amount of the PAHs that were thought to have bound themselves to the carbonates may, in fact, have been floating undissolved in the water. Certainly, no other Antarctic meteorites have PAHs at the level seen in ALH84001, suggesting that contamination from Antarctic water is not a significant problem.

Despite the presence of PAHs in Antarctica, it appears most likely that those in the meteorite came from Mars. Of course, they may have been brought to Mars by meteorite impacts, or they may have been formed by non-biological processes and have nothing directly to do with life.

A second, intriguing form of carbon has been found within ALH84001 by Monica Grady (British Museum of Natural History) and her colleagues. They heated up a piece of the meteorite and, using a mass spectrometer, detected organic molecules coming from it. These organics are much more abundant than the PAHs, but their exact composition and nature are unknown. Can these be Martian organics?

Kevin Hutchins and I calculated the ratio of carbon-13 to carbon-12 that would occur in Martian organic molecules if they formed from biological processes, and at the same time we calculated the ratio that would occur if the organics formed from non-biological processes in hydrothermal systems simulating environments on ancient Mars. The results, combined with the evidence from the geochemistry of the deposits, suggest that the isotope ratio observed in these organics is not consistent with Martian biota; rather, it is consistent either with organics produced in Martian hydrothermal systems or with terrestrial contamination.

Ever Smaller Worlds to Explore

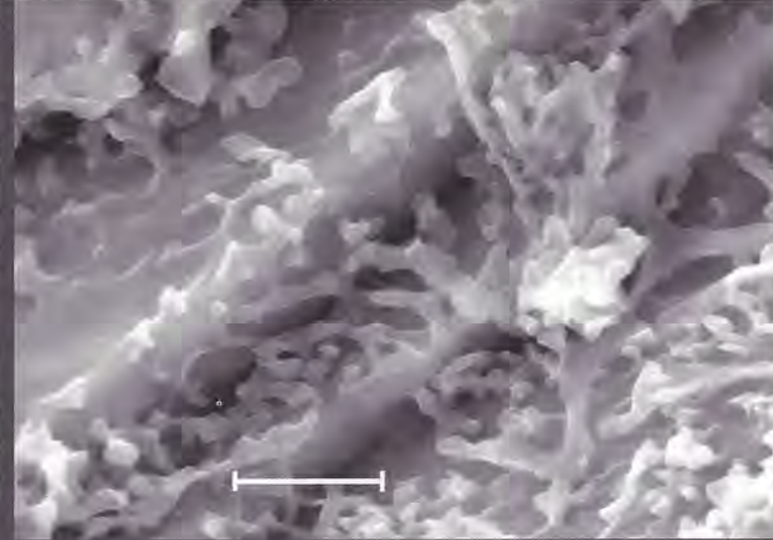
The remarkably small size of the bacteria-like structures has been the subject of much discussion. The typical volume of the Martian structures is about 1/2,000 the volume of the smallest bacterium on Earth. Can a structure this small contain enough "equipment" to pass on its genetic information to offspring? This question was raised early on and still has not been answered satisfactorily.

Several investigators have noted that if these Martian structures had a wall consisting of a double layer of lipids like that which forms membranes in terrestrial organisms there would be almost no volume left inside the structures. Ken Nealson (University of Wisconsin) noted that if some of the molecules used in terrestrial life were used by Martian life and were present in the same concentrations, the number of molecules within the structure might be as small as one (or none)! Perhaps Martian organisms can make do with membranes made of a single layer or of a double layer substantially thinner than those in terrestrial organisms.

On the other hand, McKay and colleagues noted a similarity in size to "nannobacteria," structures found in Earth rocks by Robert Folk (University of Texas). There is no agreement at all as to whether the terrestrial nannobacteria are living entities, so this comparison does not help us much yet.

The NASA group has identified another feature of possible biological origin in the ALH84001 meteorite. They see struc-

On Earth, some microorganisms secrete filmy polymers called biofilms that look remarkably similar to filmy threads found near some carbonate globules in ALH84001. These structures seem to be enriched in carbon when compared to nearby materials.



This lacy texture is found on the fracture surface of a grain within ALH84001. Scientists found similar features on several different grains within the meteorite, although they are not common features of the Martian rock. The white line indicates a measure of one micron (a micron = one millionth of a meter).
Photos: David McKay, Johnson Space Center

tures that resemble terrestrial biofilms, which are polymers or chains of organic molecules that are secreted by microbes. Although the Martian features resemble biofilms and appear to contain carbon, it is not yet clear whether they had to have been produced biologically.

What to Look For Next

So where does all of this leave us? Very few people would argue that the issue has been settled, either in favor of or against possible Martian life. This should not be too surprising: we're looking at features within a rock—whether they are biological or geochemical—that are at a different physical scale than we have ever explored before. In the 1960s, when fossils of individual cells were first found in Earth rocks dating back billions of years, it took 10 or more years to understand and characterize the non-biological features at that scale and eliminate contamination that was introduced in laboratories. We should expect the same "breaking-in" period in analyzing these Martian rocks.

Working from what we know about terrestrial microfossils, we would need to make several distinct observations to claim convincing evidence that the structures in ALH84001 were once living things. We would want to see a range in sizes consistent with a "life cycle" of the organisms. It would also help to find some in the act of reproducing—in the act of splitting. It is unlikely that a DNA-like molecule could survive on Mars for billions of years without degrading, but detecting a membrane in the bacteria-like structures would be a significant step toward certainty.

Within the carbonates, a complete determination of the isotope abundances would also be of substantial value. Determining the true range of carbon and oxygen isotope ratios in the carbonates and the degree of terrestrial contamination (based on carbon-14 abundances) would narrow down the possible explanations for the various features observed. Determining the isotope ratios for hydrogen, carbon, and nitrogen in the PAHs and in the rest of the organics may allow us to answer certain questions definitively—especially with regard to terrestrial contamination and biological versus non-biological processes.

A new, joint research program funded by NASA and the National Science Foundation will support an intensive round of investigations into the Martian meteorites this year. The selected investigators, about 15 in all, should provide some strong additional constraints on the occurrence of fossil life.

Ultimately, though, we may be unable to answer the big question with this single rock. Andy Knoll (Harvard University) collected 1,200 carbonate and unoxidized shale rocks from Spitsbergen, an island off Norway, that might have contained evidence of life. While about 90 percent contained some evidence for life (organic molecules, isotope ratios that suggest life, and so on), only 5 percent contained identifiable microfossils of bacteria. ALH84001 just may not have the answers within it.

Even if we can demonstrate a complete absence of life within ALH84001, the logic that points to life on Mars does not change. The warmer environment on early Mars, the presence of liquid water at the surface or beneath the surface throughout the planet's history, and the availability of geothermal energy to drive biological processes all argue that life could exist there.

The real answer probably will not come without a detailed exploration using spacecraft and, if necessary, humans. We need to land at the places where life was most likely to have existed in the past and where the evidence is most likely to have been preserved. We need to collect rocks. Certainly, the rocks will have to be analyzed in laboratories back on Earth.

The Mars Surveyor program of spacecraft missions has as its goal the determination of whether life ever existed on Mars. The current plans call for rover missions to be launched in 2001 and 2003. These will collect rocks to be returned to Earth by a vehicle launched in 2005. However, it is not clear that these missions will have the instruments necessary to choose the best places to search and the best samples to bring back. If we are lucky, we might have our answer about a decade from now. If we are extremely lucky, we might find convincing evidence for life within one of the Martian meteorites in the near future. Either way, finding out about the existence (or lack) of life on Mars will tell us much about the possible distribution of life throughout our galaxy.

Bruce Jakosky is a Professor of Geology at the University of Colorado in Boulder and a member of the Mars Global Surveyor *science team. His book* The Search for Life on Other Planets *will be published in 1998 by Cambridge University Press.*

The Man Passing By on His Way to

How do you memorialize a man who really was a legend in his own time? A traditional obituary, recounting a life and deeds in solemn prose, does not seem to us at the Planetary Society as a fitting way to remember Gene Shoemaker.

The man was a phenomenon. He almost single-handedly invented the field of planetary geology. He identified impact cratering as a major force in shaping all rocky bodies in our solar system—including our own Earth. He trained the *Apollo* astronauts to explore the Moon, even though a medical condition prevented him from joining their ranks. He pioneered the systematic search for near-Earth objects and raised awareness that these objects pose a threat to life on our planet. He was singular in the depth and breadth of his scientific accomplishment. And there was still so much he might have done. As Edward Bowell, his colleague at Lowell Observatory said, "I am stunned to think of the store of unique knowledge that has perished with him."

Those fortunate enough to have known Gene will, more profoundly, miss the friend. If there was an original man with a twinkle in his eye, Gene was it. His laugh would fill a room and carry you away with his merriment. His enthusiasm for life, the universe, and everything in it imbued all who knew him.

So how do you remember a legend? Many are immortalized in ballad form. We were fortunate that Gene's friend and colleague, Bevan French, composed just such a ballad in honor of Gene's retirement from the United States Geological Survey's Branch of Astrogeology (which Gene founded) in 1993. It seemed to us to capture the essence of the man better than any traditional obituary could. This is how we remember Gene. — *CMA*

VERSE 1:
He was born in a Basin
that's now called L.A.
He decided quite early
that he wouldn't stay.
The Moon shone down on him,
there were rocks all around.
And in that combination,
his life's work was found.

He'd lie in his cradle
and smile at his mother,
With a hammer in one hand
and a rock in the other.
And late in the evening,
you might hear him croon,
"I'm just passing by
on my way to the Moon."

CHORUS:
He's done coesite and stishovite
and asteroids and dinosaurs,
He's discovered the craters
with which Earth is strewn.
He's done missions and
committees and management
and bureaucrats,
All the things that you do
on your way to the Moon.

VERSE 2:
He started with field work
like all Survey hands,
But salt and uranium
were not in his plans.
It was Meteor Crater
and all of its kin
That changed our whole view
of the world that we're in.

Then he hooked up with NASA
and worked with Apollo,
'Cause where astronauts went,
geologists could follow.
And in conference or meeting,
he'd sing the same tune,
"I'm just passing by
on my way to the Moon."

CHORUS:
He's done coesite and stishovite
and asteroids and dinosaurs,
He's discovered the craters with
which Earth is strewn.
And all these catastrophes
are non-Uniformitarian,
That's what you learn
on your way to the Moon.

VERSE 3:
So to all young geologists
who are new on the scene,
If you want to do well,
take your lessons from Gene.
Stay close to your field work,
but leave your mind free,
And don't sit at home when
there're new worlds to see.

For the young are not finished
with the worlds that we know.
They've heard all our stories,
and they're eager to go.
It won't be next August,
or the following June,
But one day they'll pass by
on their way to the Moon.

CHORUS:
He's done Ranger and Surveyor
and Voyager and Clementine,
He's explored, and he's taught,
and he won't slow down soon.
For in spite of committees and
all of those bureaucrats,
There'll be folks passing by
on their way to the Moon.

REPRISE:
That's not bad for a man
on his way to the Moon.

If you have Internet access, you can hear this ballad sung by Bevan French at: http://wwwflag.wr.usgs.gov/USGSFlag/Space/Shoemaker/GeneObit.html.

the Moon by Bevan M. French

Top: A very young Gene Shoemaker gets down to work at the California Institute of Technology.

Right: Gene dreamed of someday flying in space, but Addison's disease prevented him from becoming an astronaut. With a rocket belt, he did test another way to fly.

Below: Gene and Carolyn Shoemaker watch images arrive from the Hubble Space Telescope as their comet, Shoemaker-Levy 9, crashes into Jupiter.

Photos: USGS Flagstaff

Glossary

1 and 2. Coesite, stishovite
High-pressure forms (polymorphs) of the common mineral quartz (SiO_2), generated by the shock waves produced by meteorite impacts. Gene Shoemaker and his colleagues discovered these minerals at Meteor Crater, Arizona, and the Ries Crater, Germany, thus providing unequivocal evidence for the origin of these two structures by meteorite impact.

3. Asteroids
Small leftover planetary objects, mostly located safely out of the way between Mars and Jupiter, but including a few NEAs (Near-Earth Asteroids) that like to play "Chicken" with the Earth. They sometimes lose, making new meteorite impact craters.

4. Dinosaurs
Ancient, often huge, reptiles with impressive muscles and little brain. Highly regarded by people today because they are big, fierce, and safely extinct. Highly allergic to asteroids (see 3).

5. Mission
In NASA usage, a collection of equipment (sometimes containing human beings) set up to look at the universe or shoot out into the solar system to explore other worlds at close range.

6. Committee
A collective life form, essential for the creation and operation of missions (see 5). Exact details of its operation are obscure; illuminating discussions exist by Mark Twain and Alan Sherman.

7. Management
Major activity of bureaucrats (see 8), when not participating in committees (see 6).

8. Bureaucrat
An organizational life form that migrates between committees (see 6) and management (see 7). Believed by some to be essential to missions (see 5). By others, compared (unfavorably) to dinosaurs (see 4).

9. Non-Uniformitarian
Counter to the scientific and philosophical doctrine of Uniformitarianism, which holds that geological changes are caused by the long-term and continuous action of processes that we can observe going on around us. Holders of this view have trouble relating to large meteorite impact events. However, the dinosaurs (see 4) know better.

10. *Ranger*
A pre-*Apollo* exploration mission that sent television pictures just before crashing into the lunar surface in 1965, showing more, even smaller, impact craters.

11. *Voyager*
A long-term exploration of the outer solar system by two spacecraft (1977 to 1989+) ("Four Planets in Only Twelve Years!") that demonstrated (among many other things) that all solid planetary surfaces in the outer solar system have impact craters.

12. *Clementine*
A long-overdue post-*Apollo* mission that made an orbital survey of the Moon.

Society Initiates Shoemaker Grants

The Planetary Society commemorates Eugene Shoemaker and his commitment to better understanding of near-Earth objects (NEOs) with a new program, the Gene Shoemaker Near-Earth Object Grants. Former Planetary Society Advisor Harrison Schmitt announced the first grant recipients at the Celebration of Life service honoring Shoemaker at the US Geological Survey Flagstaff Field Center in Arizona on October 11, 1997.

The grants, totaling more than $35,000, were awarded to four astronomers who are operating programs to search for NEOs. **Gordon Garradd** operates the only NEO observing program in the southern hemisphere. He received $15,500 to complete a 45-centimeter (18-inch) Newtonian telescope and to acquire a CCD (charge-coupled device for imaging). **Kirill Zamarashkin** is the project coordinator for a joint Russian-Ukrainian search program at the Crimean Astrophysical Observatory. His $13,000 grant will be used to help construct the first stage of an automatic complex to search for NEOs. University of Chicago astronomer **Walter Wild**, who will lead a group of amateur astronomers at Yerkes Observatory in Wisconsin, was awarded $6,400 to refurbish their 24-foot telescope and bring their spectrograph to operational capacity. **Bill Holliday** is an amateur astronomer based in Texas who supplies additional data to professional astronomers making orbit predictions for NEOs. He will use his $3,000 grant to upgrade his home-built rotating roof-top observatory. —*CMA*

Basics of Spaceflight: Where Are They Now?

by Dave Doody

In the final two installments of Basics of Spaceflight, we'll check in on several of the interplanetary robots that we've talked about throughout the series, and we'll see where they are, what they are doing today, and what their future is likely to be. In the final column, we'll also see what the future holds for some exciting, new unpiloted missions being planned.

Cassini's prime launch window has come by the time you read this. At writing time, the *Cassini* Saturn orbiter and its passenger, the *Huygens* probe bound for the atmosphere of Saturn's large moon Titan, are being moved. The disk containing signatures of more than half a million well-wishing people was just installed on the spacecraft in a clean room at the Kennedy Space Center. With this finishing touch completed, the spacecraft is on its way out to the launch pad, called Space Launch Complex 40, to board the waiting launch vehicle for its boost to Saturn.

Cassini's Titan IV-B is an expendable rocket with two stages in its central column called Stage 1 and Stage 2. Both these stages burn hydrazine and nitrogen tetroxide to produce thrust. Attached to the central column's sides are two solid-fuel rocket motors that comprise Stage 0. Atop the Titan is a Centaur upper stage, whose propellant tanks hold liquid hydrogen and liquid oxygen. The Centaur's function is to accelerate *Cassini* and *Huygens* into a temporary "parking" orbit and then re-ignite at the right moment, sending them free of Earth's gravity toward Venus for the first gravity assist en route to Saturn.

The Titan's Stage 0 ignites first, lifting the stack from Earth's surface with a combined force of 3.4 million pounds of thrust. Stage 1 ignites in flight, just when the "solids" burn out and are jettisoned, and applies over half a million pounds of thrust. Once the launch vehicle is above Earth's atmosphere, the fairing that protects the *Cassini/Huygens* space vehicle from aerodynamic forces is no longer needed, and its useless mass is jettisoned while Stage 1 continues to accelerate. Next, Stage 2 separates and fires its 106,000-pound thrust engine, and then the Centaur separates and executes its first 33,000-pound-thrust burn. After the Centaur fires its engine for the second time, the spacecraft itself separates, to begin its long free-fall to Saturn alone. To prevent the expended Centaur from also free-falling along *Cassini*'s path, the Centaur executes a maneuver to place it on a trajectory that will not interfere—it too has escaped Earth's gravity and will circle the Sun as a tiny planet.

But just where is *Cassini* right now? While you are reading this, *Cassini* should be falling along its modified Hohmann transfer trajectory toward Venus (see Basics of Spaceflight, March/April 1995) and will be only slightly closer than Earth to the Sun, just starting out on the first leg of nearly seven years' free-falling to reach Saturn. In late April or early May 1998 (depending on the actual launch date), *Cassini* will fly by Venus for its first gravity assist (see Basics of Spaceflight, May/June 1995), followed by another Venus gravity assist in June 1999 and an Earth gravity assist two months later. These provide *Cassini* with the energy it needs to finally leave the inner solar system. *Cassini* will obtain one final gravity assist from Jupiter the day before the millennium closes (December 30, 2000), and then *Cassini/Huygens* will enter orbit around Saturn in July 2004.

Galileo's Extended Mission

Galileo, launched by the space shuttle *Atlantis* in October 1989, also flew a gravity-assist trajectory using flybys of Venus and Earth to reach Jupiter, which it now orbits. Recall that when *Galileo*'s high-gain antenna did not deploy as expected early in 1991, a shock went through everyone involved in the mission. A number of measures were implemented to ensure that its data could be returned from Jupiter. Data from the atmospheric probe were never in danger, since they could easily be returned by the low-gain antenna. But images and other voluminous data were depending on the high-gain antenna's rate of 134,000 bits per second. The Deep Space Network engineered new computerized receivers and new ultra-low-noise waveguides. They developed ways to link antennas in arrays spanning the continents (see Basics of Spaceflight, July/August 1997). Programmers on the *Galileo* flight team improved the spacecraft's onboard error-correction algorithms and invented new ways to select and compress data by commandeering one of *Galileo*'s attitude-control computers. These and other measures permitted the mission to return over 70 percent of the originally planned data.

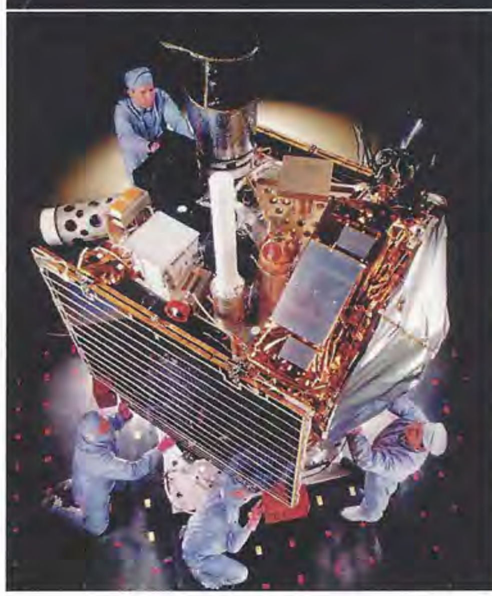
Galileo's highly successful two-year primary mission ends as you read this issue at the end of 1997. The last encounter of its primary mission is with Europa on November 6, and over subsequent weeks it will return images and other data from this encounter, using all the improvements that have made it possible to send large amounts of information with only a low-gain antenna.

It would be an awful waste to abandon a beautifully functioning spacecraft in orbit at Jupiter, and so an extended mission has received approval from NASA. This mission will operate *Galileo* for two more years, albeit with a reduced staffing level, entirely from the money saved by improvements made in mission operations during the primary mission—no new funds will be needed! The extended mission is known as GEM—*Galileo* Europa Mission. The spacecraft will be making eight more consecutive encounters with Europa, as it continues looping in orbit about Jupiter. While these Europa encounters will probably not tell us for certain whether a life-bearing ocean lies below the moon's crustal ice, it will provide additional data on puzzling features such as the dark lines that appear near fractures in the ice. One Callisto encounter will be included, and then, for a grand finale, another shot at Io, Jupiter's volcanic, innermost large moon. *Galileo* first flew close by Io for a gravity assist needed for entering orbit at Jupiter in December 1995, but it could not return images due to a tape recorder problem (which has since been remedied). Approaching Io is dangerous, though. It means entering Jupiter's radiation belt again, which will be a major risk to the spacecraft. But that's what extended missions are for, and the calculated risk should be worthwhile. The finale will occur, amid celebration no doubt, in December 1999.

Aerobraking at Venus and Mars

We took risks with another extended mission not long ago. After *Magellan* had completed radar mapping the whole surface of cloud-hidden Venus in 1993, we commanded the spacecraft to dip into the upper reaches of Venus' atmosphere during the close-approach (periapsis) part of its orbit. Turning the solar panels to face the oncoming wind created enough drag to slow the spacecraft's travel slightly, so that it could not climb all the way out to its previous high point in orbit (apoapsis). Doing this repeatedly for about 700 orbits gave the desired result: a nearly circular orbit, from which *Magellan* could conduct a new study of Venus, mapping its gravity field to "see" where mass is concentrated on and under Venus' surface. When this final task was completed in October 1994, we intentionally flew *Magellan* to its demise in Venus' dense atmosphere, meanwhile gathering even more data about the atmosphere's density and structure.

Background: Magellan *deploys from the space shuttle in preparation for its voyage to Venus.* *Photo: NASA*



Left: Technicians prepare the Mars Global Surveyor *in a vacuum chamber at Lockheed Martin Astronautics in Denver, Colorado.* *Photo: Lockheed Martin Astronautics Corp.*

Below: The Cassini *spacecraft is now on its way to the Saturn system, where it will release the probe* Huygens *to explore the intriguing moon Titan.* *Painting: JPL/NASA*

Having learned from *Magellan* how to aerobrake to change an orbit's dimensions, mission planners designed *Mars Global Surveyor* (MGS) from the start to do the same at Mars. The spacecraft even has special flaps out at the ends of its solar panels to add more drag for aerobraking. Aerobraking from an elliptical orbit on arrival to a circular orbit for mapping saves a huge amount of propellant—and not having to carry lots of heavy propellant meant that MGS was able to launch on a Delta launch vehicle and save money. Right now, MGS should be in the midst of aerobraking, bringing the apoapsis of its orbit down from 56,000 kilometers (34,800 miles) above Mars' surface to about 400 kilometers (250 miles), from which it can begin mapping Mars' surface in March 1998.

Having executed a spectacularly successful primary mission designed to last 30 days, the *Mars Pathfinder* lander, now named the Carl Sagan Memorial Station, continues to communicate with Earth at this writing. Its remote-controlled *Sojourner* rover also continues to operate well, taking images and X-ray spectra from surfaces and rocks that the ground crew selects. But the conditions on Mars are very hostile, and every day that *Mars Pathfinder* manages to survive into its extended mission brings the gift of new data from the Red Planet.

Where are the *Pioneer* spacecraft, which gave humanity our first close-up views of Jupiter and Saturn? Where are the *Voyagers,* which examined those planets in greater detail and continued past Uranus and Neptune? What of *Ulysses*, whose mission explored the Sun's polar regions? What new robotic missions are coming along? These will be among the topics for the next (and final) installment.

Dave Doody is a member of the Jet Propulsion Laboratory (JPL) Advanced Mission Operations Section and is currently working on the Cassini *mission to Saturn.*

If you have access to the World Wide Web , be sure to look in on JPL's *Basics of Space Flight* manual, on-line at http://www.jpl.nasa.gov/basics/.

News and Reviews

by Clark R. Chapman

The *New York Review of Books* may seem an unlikely place for Planetary Society members to find a "must read" article, but its September 25 issue is just that. This bimonthly tabloid publication is not, and never has been, a collection of book reviews. Instead, it publishes essays, often (but not always) loosely structured around books or, as in this edition, around events like museum exhibits. (For example, this issue includes a review of the Boston Museum of Science's Leonardo da Vinci exhibit, which planetary scientists wandered around during the opening night of last July's annual meeting of the Division for Planetary Sciences of the American Astronomical Society. Now closed in Boston, the exhibit has moved on to Singapore through February 1, 1998.)

Normally, the *New York Review of Books* treats science in a limited way. Its pet subjects are evolution (articles by Stephen Jay Gould and his detractors) and the possibilities for artificial intelligence. The wonders of the cosmos occasionally intrude. This issue features an important essay by one of the best popular astronomy writers, Timothy Ferris. His latest book, *The Whole Shebang: A State of the Universe(s) Report*, is a critical success.

In the essay, Ferris describes NASA as the emperor wearing no clothes. With a brief, non-standard review of the history of NASA from JFK's 1961 speech that initiated *Apollo* through the recent American cooperation in the problematical Russian space station *Mir*, Ferris sets us up for a fresh look at today's space program. In his view, the space shuttle (sold, he says, with a military rationale), *Mir*, and the would-be international space station are all grossly expensive solutions to problems that don't exist.

Can the Public Love (and Support) Robots?

The common wisdom is that the public loves astronautic adventures and that robotic planetary missions can be supported only by leftover funds from the human-flight program. "No clothes!" Ferris retorts, citing evidence that the recent successes of *Mars Pathfinder*, and its cute rover, captured the public imagination more than almost any post-*Apollo* human-flight extravaganza. Indeed, the other big, positive NASA headlines lately have come from *Galileo* and, especially, Hubble Space Telescope. The much-vaunted astronautic repair of the defective Hubble a few years back was a case, according to Ferris, of the robotic telescope enhancing public appreciation of astronauts rather than the other way round.

Ferris believes that inevitable cost-overruns by the international space station will, in the current fixed-budget atmosphere, undermine the future of robotic exploration of the solar system and the cosmos.

He looks with hope but little confidence to NASA's Administrator, Dan Goldin, who survives in a political jungle and espouses scientific exploration for the cosmic context of our biological beginnings. In a conversation I had with Goldin in his office a few years ago, occasioned by criticisms I voiced in this column, the administrator expressed precisely Ferris' view that the shuttle program and space station would starve NASA's more important programs. Political realities being what they are, Goldin has since given in and now oversees a human-flight program that, whatever one might *wish* and despite Goldin's reformist efforts, seems to many to be headed toward massive failure.

In his essay, Ferris examines Robert Zubrin's new book, *The Case for Mars: The Plan to Settle the Red Planet and Why We Must.* I recently heard an interview with Zubrin, formerly a Lockheed Martin engineer and more recently the founder of Pioneer Astronautics, on National Public Radio's "All Things Considered." A few days later, looking more like a Xerox repairman (whom we sorely need in our office!) than NASA's savior, the unassuming fellow pushed past me in search of Alan Stern, who manages our Southwest Research Institute office in Boulder.

Free-Market Capitalism in Space

Zubrin, following Goldin's litany of "faster, cheaper, better," argues that astronauts can explore the surface of Mars—inspired by a government-sponsored "free enterprise" reward—for a tiny fraction of the cost of earlier NASA estimates. Ferris, a writer and a scientist, wisely refrains from an explicit endorsement of Zubrin's direct-to-Mars technology (for details, see Zubrin's article in the May/June 1990 *Planetary Report)*. After all, engineering is an entirely different kettle of fish.

Surely, a less risk-averse approach to exploring the outer frontiers would be much cheaper. But NASA is still recovering from the horror of the *Challenger* accident in the mid-1980s. I doubt that the public, recently irrationally concerned about a plutonium hazard from launching *Cassini*, could ever reaffirm the dynamics of the dangerous era of *The Right Stuff.*

With a free-enterprise, lasso-and-claim-an-asteroid mission now offered by investment-seeking entrepreneur Jim Benson (for details, visit this Web site: www.skypub.com/benson/prize.html), and with the once-vaunted Russian space program near demise, we must look for alternatives. Risky-cheap versus reliable-expensive is one choice before us. Another is human-flight versus robotic. Still another is low-Earth-orbit versus deep space. I don't know what the right answers are. But I agree with Ferris that the public has been more interested, for quite a while, in the robotic accomplishments of *Voyager*, Hubble, and *Mars Pathfinder* than it has been in the boring exploits of each successive space shuttle launch. It is time that NASA abandoned its pretense that the public enthusiasms are otherwise.

Clark R. Chapman is arranging a Cratering Symposium in Flagstaff, Arizona, dedicated to Gene Shoemaker, whose tragic death in a car crash in Australia robbed us of the premier Earth-and-space scientist of our times.

World Watch

by Louis D. Friedman

Washington, DC—A year ago, NASA's future looked grim. The agency had just gone through the budget process on Capitol Hill, suffering a $100 million cut for 1997. The view ahead appeared even more glum. The White House was proposing to lop another $700 million from NASA in 1998 with additional reductions thereafter.

By February, everything had changed. President Clinton announced a new budget for NASA, adding $500 million to his earlier proposal for a total of $13.5 billion—still a $200 million cut from current spending. Significantly, the budget included more money for planetary exploration to ensure a robust series of missions to Mars, leading to a sample return mission in 2005. NASA was given the green light for the Origins program, which seeks to answer the fundamental question, "Are we alone in the universe?"

While the new budget did not stabilize spending, it was enough to keep NASA afloat and obviate the need to shut down critical science programs. The Planetary Society played a role in this turnaround, actively engaging the White House to support NASA and specifically the planetary missions. Now, the Society turned its attention to Congress, urging members to follow the administration's lead.

The House of Representatives passed an authorization bill that boosted spending for NASA $300 million above the administration's request—an about-face from the year before, when members vied to reduce spending for the space agency. What had changed? The national economy, stronger than expected, was generating a windfall in tax revenue. The boom was even big enough to finance a five-year plan for balancing the national budget.

As 1997 comes to a close, NASA once again has survived the budget process with just a few nicks and bruises. There is growing concern about the space station, which is now experiencing cost overruns. The overruns could cause NASA to raid internal budgets, including science, if Congress does not appropriate additional money.

Total funding for the space agency continues to shrink. What the five-year balanced-budget plan will mean for NASA remains unclear. One analysis shows federal spending for science and technology on a downward spiral, a very troubling trend if substantiated.
—Bill Livingstone, Washington Consultant for the Planetary Society

Russia—The Russian Space Agency has been totally focused on *Mir* and international space station development, trying to meet technical and budget requirements in those programs. As a result there is little priority and less budget for space science. In 1997, meager funds were allocated for planetary exploration—basically just for development of the lidar flight experiment for the US *Mars Surveyor* 1998 lander. This will be the first-ever Russian instrument to fly on a US planetary mission, and the Planetary Society is part of it. Our Mars Microphone will be incorporated within the lidar. (Lidar is a laser used like radar to study atmospheric properties.)

Without government funding, all development for future missions stopped this year, including work on the *marsokhod* rover. A *Mars 2001* mission is still a possibility if funded by the end of this year. It would be part of the US-Russian initiative "Mars Together."

US, Europe, Japan—With little fanfare, comet and asteroid missions are being conducted around the world. Flying right now is the Near-Earth Asteroid Rendezvous, which encountered the asteroid Mathilde last June (see the September/October 1997 *Planetary Report*). Next year *Deep Space One*, the first of the US New Millennium technology missions, will be launched to the asteroid McAuliffe and comet West-Kohoutek-Ikemura. The mission is the first test of solar-electric propulsion for interplanetary missions.

A Discovery mission, *Stardust*, will launch in 1999 for a flyby of comet Wild 2, collecting a sample of cometary dust and returning it to Earth in 2006.

Another New Millennium mission, *Deep Space Four*, is slated to rendezvous with and land on comet Tempel 1 in late 2005 and collect a sample of cometary ices and dust for return to Earth in 2010.

The European Space Agency's *Rosetta* mission will rendezvous with comet Wirtanen in 2011 and deploy a French-German probe to land on the surface the following year.

The Japanese Institute for Space and Astronautical Sciences (ISAS) is planning the first post-*Apollo* interplanetary sample return with its *Muses-C* mission to be launched in 2002. The spacecraft will rendezvous with the near-Earth asteroid Nereus (named by members of the Planetary Society in a contest suggested by its discoverer, Eleanor Helin) and also deploy a NASA/JPL-built nanorover on the asteroid's surface.

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

Questions and Answers

How is it that Earth meets the Perseid meteors at the same time every year? I know that the meteors cannot be stationary, since everything in the solar system is moving.
—Michael Marinelli
Hammonton, New Jersey

Meteors, or shooting stars, are streaks of light that flash across the sky when dust-like particles (meteoroids) drifting through space strike Earth's atmosphere. A typical meteoroid is about the size of a grain of sand and hits the upper atmosphere at a speed of around 60 kilometers (40 miles) per second.

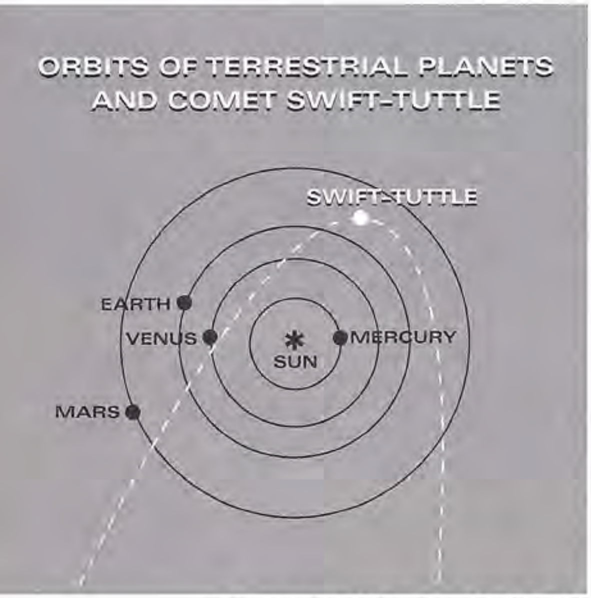


Illustration courtesy of Rob Maddock and Paul Chodas/JPL

Most meteors are random and unpredictable; astronomers call these "sporadics." Meteor showers, however, occur when Earth passes through the orbit of a comet. The nucleus of a comet is essentially a "dirty snowball," a mixture of ices and dust a few kilometers in diameter. As a comet enters the inner solar system, it is heated by the Sun. The outer layers of the icy nucleus sublimate, releasing the dust particles trapped within. Pushed away from the nucleus by radiation pressure from the Sun, this dust produces the brightest part of a comet's tail. But the liberated comet dust continues to follow the comet's orbit, which is fixed in space.

Every year, around the 11th and 12th of August, Earth crosses the orbit of a comet called Swift-Tuttle. When our planet passes through the train of dust left over from Swift-Tuttle's last visit to the inner solar system, a meteor shower occurs. The rate of meteor sightings during the Perseid meteor shower is generally about 40 to 50 per hour.

On November 18, 1999 astronomers expect Earth to pass through the thickest part of the comet debris train responsible for the annual Leonid meteor shower. It's possible that on that night we may witness a rare meteor storm. During a meteor storm, thousands of meteors per minute are sometimes seen, an awe-inspiring display of celestial fireworks you wouldn't want to miss.
—ANDRE BORMANIS,
Planetary Society Special Consultant

How large would an object striking Earth have to be to significantly alter its orbit? What would happen next if the orbit were affected?
—Ron Matejcek,
Claremont, California

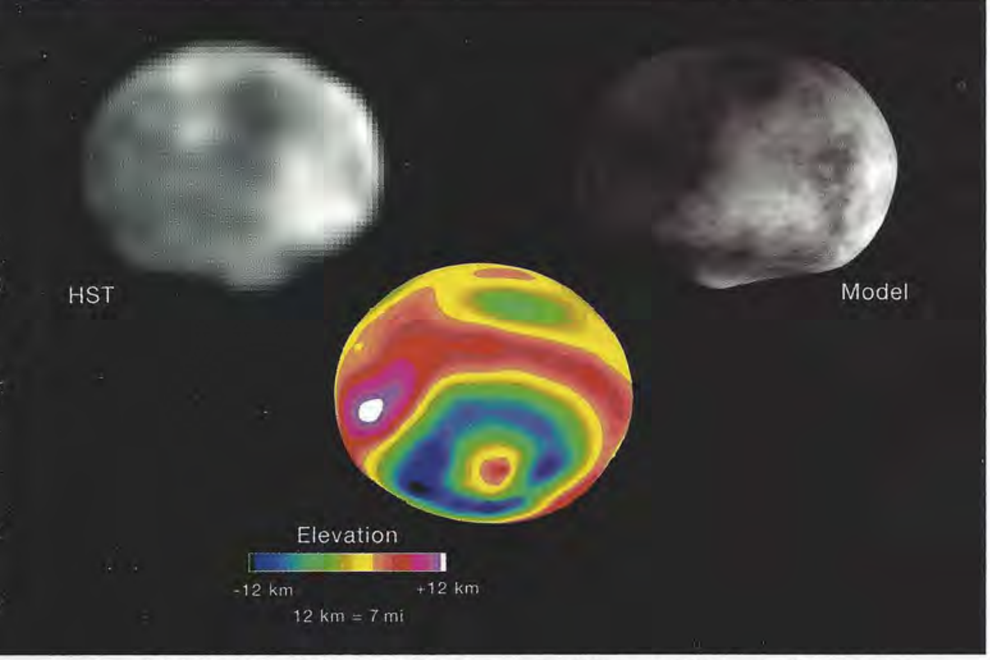
In some sense, this experiment has already been done. Our Moon was probably formed when a Mars-sized body plowed into Earth near the end of its formation, perhaps some 50 million years after Earth began accreting (see the September/October 1997 *Planetary Report).* Because the planets must have formed on nearly circular orbits, and because Earth's orbit is still very nearly circular, we know that even a catastrophic event as large as the Moon-forming impact did not change our planet's orbit much.

But what *would* it take to significantly change Earth's orbit, let's say raising its aphelion (point furthest from the Sun) to where Mars is now or lowering its perihelion (point nearest the Sun) to Venus' position? This would require a change in speed of about 3 kilometers (1.9 miles) per second to Earth's current orbital speed of about 30 kilometers (19 miles) per second.

Numerical models by Stan Love of the Jet Propulsion Laboratory show that the largest change in speed a collision can give a gravitationally bound object like a large asteroid or planet is about equal to the object's escape speed. In the case of Earth, that's 11 kilometers (about 7 miles) per second, so Earth should be able to survive an impact capable of changing its orbital speed by 3 kilometers per second. But this would be an *enormous* impact indeed, requiring a projectile nearly the size of Earth itself!

Our planet continually suffers impacts from smaller asteroids and comets, and although some of these impacts can cause environmental and ecological calamities, they fall far short of being able to affect Earth's orbit. Even the largest asteroid, Ceres, is less than one tenth the size of Earth.

Love estimates that such an orbit-altering impact would permanently blow off about 15 percent of Earth's mass. It would thoroughly heat and melt the entire planet and dredge molten iron from Earth's core. Much of this planet's mass might not be blown away forever but would be thrown onto long suborbital trajectories, slamming back down all over the world at speeds of 8 kilometers (5 miles) per second or so. (Picture continent-sized masses of molten lava splashing down all over the planet at meteor speeds for a few hours.)



Above left: In May 1996 the Hubble Space Telescope captured this image of Vesta when the asteroid was 177 million kilometers (110 million miles) from Earth. The asymmetry of the asteroid and "nub" at the south pole suggest a large impact.

Center: This color-encoded elevation map of Vesta clearly shows the giant 459 kilometer (285 mile) diameter impact basin and "bulls-eye" central peak.

Right: This is a 3-D computer model of the asteroid synthesized from HST topographic data. The crater's 13 kilometer (8 mile)-high central peak is clearly visible near the pole. The model's surface texture is artificial and is not representative of the true brightness variations on the asteroid. Vesta's elevation features have not been exaggerated. *Image: NASA/HST*

This image is the first view of Mars captured by the* Mars Global Surveyor *orbiter camera. It was taken on July 2, 1997 when the spacecraft was 17.2 million kilometers (10.7 million miles) and 72 days from encounter. This image was taken to show the* Mars Pathfinder *landing site (19.4 degrees north and 33.1 degrees west) about 48 hours before the celebrated landing.

Mars' north polar cap is visible at the top of this picture, while the dark feature Acidalia Planitia appears in the center, with the brighter Chryse plain right below it. Notice the highland areas along Mars' equator, including the canyons of Valles Marineris (which are bright in this image due to atmospheric dust). The south polar hood (atmospheric fog and hazes) is visible at the bottom of the picture. *Image: JPL/NASA*

The oceans and atmosphere and most of the lighter, more volatile elements would be lost. The remaining Earth might have a thick, temporary atmosphere of vaporized rock and iron. The prospects for life would appear, shall we say, dim. Also, Earth's spin could be stopped, reversed, or doubled.

As a consolation, we might get a new moon. Since the escape speed from Earth at the Moon's orbital distance is 1.5 kilometers (0.9 miles) per second, a 3-kilometer-per-second kick to this planet would cause Earth to leave our current Moon behind. Pelted with debris from the nearby collision, the Moon would continue orbiting around the Sun, with a slight eccentricity to its orbit depending on where it was in its orbit when Earth got hit. Projectile and target debris escaping the remaining Earth's gravity would also go into solar orbit and would continue to hit the Moon (and probably Mars and Venus as well) for many millions of years.
—DANIEL D. DURDA,
University of Arizona Lunar and Planetary Laboratory

Factinos

Scientists have used the Hubble Space Telescope to discover a giant impact crater on the asteroid Vesta (see image at left). This crater is a link in the chain of events believed to be responsible for forming a distinctive class of tiny asteroids as well as some meteorites that have reached Earth. The crater is 459 kilometers (285 miles) across—nearly equal to Vesta's 530 kilometer (330 mile) diameter. On our planet, a crater of proportional size would fill the Pacific Ocean basin.

Researchers had predicted the existence of one or more large craters on Vesta, reasoning that if it is the true "parent body" of some smaller asteroids then it should have the mark of a major impact catastrophic enough to knock off big chunks. Even so, the crater proved larger than expected, as the team reported in the September 5, 1997 issue of *Science.* "In hindsight we should have expected finding such a large crater on Vesta," says Peter Thomas of Cornell University. "But it's still a surprise when it's staring you in the face."

"This is a unique opportunity to study the effects of a large impact on a small object," says Michael Gaffey of Rennselaer Polytechnic Institute. "This suggests that more asteroids from the early days of the solar system may still be intact."
—from the Space Telescope Science Institute

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Mars Global Surveyor's first look at Mars is revealing a world with "only the memory of a magnetic field," according to Jack Connerney, co-investigator of the magnetometer/electron spectrometer team. Mars "no longer has a global magnetic field generated by an internal energy source, like Earth and the other planets," Connerney said. "It appears that the crust of Mars is strewn with multiple magnetic anomalies, which may represent the solidification of magma as it was coming up through the crust and cooling very early in Mars' evolution."

Mars Global Surveyor, after going into orbit on September 11, 1997, detected the weak magnetic field within a week of its arrival. Magnetometer data returned since that time indicate that Mars' magnetic field is localized in particular areas of the crust, said Daniel Winterhalter of JPL. "The identification of these magnetic anomalies and their correlation with surface features may enable us to trace the history of the planet's interior, just as we are able to trace the history of Earth's interior using the magnetic anomalies that have been imprinted on the ocean floors," remarked Winterhalter.
—from the Jet Propulsion Laboratory

Society News

Society Launches SETI Web Site

The Planetary Society has launched its newest site on the World Wide Web—*Search: The Site for the Search for Extraterrestrial Life and Intelligence*, which features live data from Harvard University's Project BETA (the Billion-channel Extraterrestrial Assay) and information about SETI efforts supported by the Society. The Web page debut coincided with the US opening of *Contact*, the motion picture adapted from the Carl Sagan novel. Since its premiere, the site has become one of the Society's most popular electronic efforts. The site allows visitors to submit messages to extraterrestrials, offers the latest debate on whether or not SETI is likely to succeed, and provides links to other related sites. Visit the site at http://seti.planetary.org or via the Society's main page at http://planetary.org.

—Michael Haggerty, Electronic Publications Manager

Erratum: *Contact* Calculations Corrected

In a September letter sent to members about the Society's Search for Extraterrestrial Intelligence (SETI) program, I made a serious mistake in misquoting Carl Sagan. Words about the probability of extraterrestrial life in our galaxy spoken by Jodie Foster in the motion picture *Contact* were not the words of Sagan, as I attributed them, but rather a speech written specifically for the film by its screenwriters, who took artistic license with the Drake Equation, which provides an estimate of the number of possible civilizations capable of interstellar communications.

Dr. Ellie Arroway's words in the film, taken literally, would multiply three separate one-in-a-million chances for intelligent civilizations in the galaxy. That would give a probability of one in a million-trillion, yielding only a one-in-two-million chance of any one star in the galaxy having an intelligent civilization—just the opposite of the conclusion Dr. Arroway makes.

Had it been stated consistently with the Drake Equation (as Dr. Sagan and Ann Druyan urged), Arroway's statement would have been more like: "There are 400 billion stars in our galaxy. If one in three has planets [this seems consistent with what we are learning about extrasolar planets], and if life arises on just one in ten planets [this corresponds with—maybe even understates—what we observe in our own solar system], and if one in even 10,000 of these planets develops intelligence and the associated ability of communication, then there are more than a million civilizations that have reached the stage of interstellar communications." The one-in-10,000 number is completely unknown; it could be much less. If one in a million life-sustaining planets developed intelligence and communications, that would still yield more than 10,000 civilizations reaching the stage of interstellar communication.

—Louis D. Friedman, Executive Director

Society President Honored by AAS

Planetary Society President Bruce Murray will receive the first Carl Sagan Medal from the American Astronautical Society (AAS) during its annual meeting, December 3 to 5, 1997 at the Pasadena Hilton in Pasadena, California. The medal will be given annually to individuals who have demonstrated leadership in research or policies that advance the exploration of space. The medal will be presented to Murray by Sagan's wife and collaborator, Ann Druyan. Murray, who is a professor at the California Institute of Technology and former Jet Propulsion Laboratory Director, will be a guest lecturer at the AAS meeting. Murray, Sagan, and Louis D. Friedman started the Planetary Society in 1980.

—Bill McGovern, Production Editor

More News

The Mars Underground News:
Pathfinder's latest images and what they are telling us about the Red Planet.

The NEO News:
The Society announces grant recipients in a new program to encourage NEO detection.

The Bioastronomy News:
Life, the evolution of intelligence, and creating the language of SETI.

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

You're on Your Way to a Comet!

The comet-sampling *Stardust* spacecraft will carry the names of every Planetary Society member as of November 1997. This is the *Stardust* mission team's way of thanking the Society and its members for helping to collect the names of 300,000 people for inclusion on a microchip to be attached to the spacecraft as it is prepared for its journey to comet Wild 2.

Stardust will be the first spacecraft to return a sample of a comet's coma to Earth. The coma is the cloud of dust and gas surrounding a comet's nucleus. As a bonus, the spacecraft will also collect interstellar dust that has blown into our solar system. With its precious cargo safely stowed in a capsule, *Stardust* will return the samples to Earth, where they can be carefully studied in terrestrial laboratories.

The mission is set for launch on February 6, 1999. It will encounter comet Wild 2 on January 2, 2004 and return to Earth on January 15, 2006. And as it makes its journey through the solar system, Planetary Society members will be flying along with it. *—LDF*

Holiday Gift Guide!

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"Spacefield II 1996" by Victor Raphael is an Iris ink jet print of a Polaroid photograph embellished with metal leaf. Many of this artist's works begin as Polaroids taken from images of stars, comets, novas, eclipses, and other astronomical phenomena. In some of his works, metals are added to the ink jet print, which means that those metals will eventually oxidize. As the artist observes, "The surface of my work will change over the years—a piece literally has a life of its own."

Victor Raphael lives and works in Los Angeles, California. His award-winning work has appeared in a wide variety of solo and group exhibitions. He has also produced, co-produced, and directed several video and multi-media productions.

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