# The PLANETARY REPORT

Volume XXIII Number 3 May/June 2003

Return to Mars

A PUBLICATION OF THE PLANETARY SOCIETY

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Number 3

May/June 2003

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## From The Editor

We are entering the year of Mars. It begins not with the calendar year but with the launches of four spacecraft in June: the European Space Agency's *Mars Express*, carrying the British *Beagle 2* lander, and the twin *Mars Exploration Rovers*. Already on its way is the Japanese *Nozomi* orbiter. In Earth's early winter, the spacecraft will arrive at their destination, where they will join the *Mars Global Surveyor* and *Mars Odyssey*, already in orbit. Never before have so many spacecraft converged on one planet at the same time.

The reason for all this is simple geometry. In August, Mars reaches opposition, the point in its orbit directly opposite Earth from the Sun. Spacecraft can then travel between Earth and Mars using the least amount of fuel. This is too good an opportunity to pass up.

The Planetary Society also is taking advantage in every way we can. Mars Watch is under way, encouraging people around the world to get out and view the Red Planet at its brightest. Our Red Rover Goes to Mars students will join NASA's rover team. And when the first rover sets down on Mars, we will hold Planetfest '04, on January 2 to 4, to celebrate all this exploration and more.

This is a great time for Society members. Each one can participate in some way in each of these events. Check our website and watch these pages to learn how you can personally experience the year of Mars.

*—Charlene M. Anderson*

### On the Cover:

In less than a year, Mars will play host to an international party of visitors. The European Space Agency's *Mars Express* (with the British *Beagle 2* lander) is scheduled to get to the Red Planet in late December 2003 or early January 2004—the same month that NASA's twin *Mars Exploration Rovers* and Japan's *Nozomi* will arrive. Here, *Mars Global Surveyor*'s Mars Orbiter Camera reveals our ruddy neighbor's north polar cap as it appeared in May 2002. Seasonal dust storms swirl around the cap's edge in this mosaic of daily global images. Image: JPL/NASA/MSSS

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*The Planetary Report* (ISSN 0736-3680) is published bimonthly at the editorial offices of The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106-2301, 626-793-5100. It is available to members of The Planetary Society. Annual dues in the US are $30 (US dollars); in Canada, $40 (Canadian dollars). Dues in other countries are $45 (US dollars). Printed in USA. Third-class postage at Pasadena, California, and at an additional mailing office. Canada Post Agreement Number 87424.

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# Members' Dialogue

## Continuing to Explore

I share your shock and grief at the loss of the space shuttle *Columbia*, and also your determination that human space flight must continue. But I disagree strongly with Louis Friedman's statement that it "is not our role to investigate the causes of the accident or how to fix the shuttle. NASA will do that and will do it well." (See the March/April 2003 issue of *The Planetary Report*.)

First, it is precisely NASA's competence (among other things) that is in question. Gross negligence, dereliction of duty, and sheer wishful thinking contributed to the *Challenger* tragedy of 1986. It is still too early to tell whether NASA management deserves such harsh condemnation this time around. But it most certainly is part of the business of a public interest group such as The Planetary Society to scrutinize the effectiveness of the agencies that are supposed to make space exploration possible.

Second, while the interested public is not in a position to offer detailed technical analysis of the space shuttle, it is not only appropriate but necessary for the public to question whether our spacecraft are suited to the overall goals of the space program.

Engineering excellence flourishes best in a demanding climate of intense public scrutiny and professional self-criticism. "Father knows best" is not good enough—especially when father has already dropped the baby once before.

—KENT A. PEACOCK,
*Lethbride, Alberta, Canada*

Despite being an aerospace engineer and having a lifelong interest in space exploration, I couldn't sign the Society's declaration of support for space flight because it implied a continuing support for the shuttle and the International Space Station [ISS]. I can't support putting another group of such highly trained, dedicated people in so much danger, at such enormous costs, to achieve so little.

It doesn't help to know that they knew the risks that they faced. It doesn't help to know that space exploration is not a zero-sum game. Even if only a small fraction of the [shuttle and ISS] money could be spent on missions such as *Deep Space 1* and the *Near Earth Asteroid Rendezvous*, I would be all for it.

—RONALD HANSEN,
*Ottobrum, Germany*

*The Planetary Society is taking a strong position on the future of human space transportation, and how it affects exploration beyond Earth orbit. The questions raised here are addressed in that position, although we will not offer opinions on the accident itself. Our conclusions are posted on our website (go to* planetary.org/workshop/*) and will be covered in the next issue of* The Planetary Report*.*

*—Louis D. Friedman,*
*Executive Director*

## On Interstellar Flight

As a solar sail enthusiast, I am fascinated by the January/February 2003 issue of *The Planetary Report*, particularly by the explanation of how to get to Alpha Centauri and back. By the time we get to Proxima Centauri, whether it takes 250 or only 100 years, space-based telescopes will have improved to the point where we will know as much about its satellites as we know about Jupiter today. That being the case, the purpose of the mission can't just be to send back photos. The purpose will be to send back material and to learn things that require being there.

To project what technology will be like 250 years from now is highly speculative. Physics doesn't change, but our knowledge of it does. It is even more speculative to guess what the human condition will be in 250 years.

We can't answer these questions, but we know that a space expedition that exceeds a human lifetime will be a one-way trip for the participants. To attract people, it must offer them the hope of a good life while traveling and a better life for their children. That is a tall order. For the present we can only leave it to science fiction.

—RICHARD H. MACNEAL,
*Pasadena, California*

The January/February 2003 issue of *The Planetary Report* is, by far, the best of the best to date.

—JON TROVATO,
*Morristown, New Jersey*

## We Make It Happen

I would like to congratulate Bruce Betts for *The Planetary Report*'s new regular feature, "We Make It Happen!" I think it is very important to keep the members well informed about all the Society's projects, and covering two or three projects in every issue will keep us informed over the year.

*The Planetary Report* is the main source of communication and information to the members, and it is the main vehicle for presenting the latest developments on all the Society's projects.

We make it happen! And we want to know . . . everything!

—JOAO MIGUEL MATOS,
*Setubal, Portugal*

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# We Make It Happen!

by Bruce Betts

## Red Rover Goes to Mars

In this, the column's second installment, I am starting individual project updates to let you know what you are making happen. At this time, when the buzz is all about the *Mars Exploration Rover* (*MER*) launches, I am focusing on our involvement with the *MER* mission, namely our Red Rover Goes to Mars (RRGTM) project. RRGTM is one of our largest projects, and one of our most exciting. You facilitate it, as does our partnership with the LEGO Company.

Our connection with *MER* represents unprecedented public involvement with a NASA mission. The two *MER* spacecraft, scheduled to launch in early and late June 2003, are being sent to serve as robotic geologists on Mars. Like the science instruments aboard *MER*, RRGTM is an officially selected part of the mission. For more on RRGTM's history and diverse aspects, see the November/December 2002 issue of *The Planetary Report*. In addition, our project website, *redrovergoestomars.org*, is loaded with information about RRGTM and the *MER* mission. Here I mention some key updates.

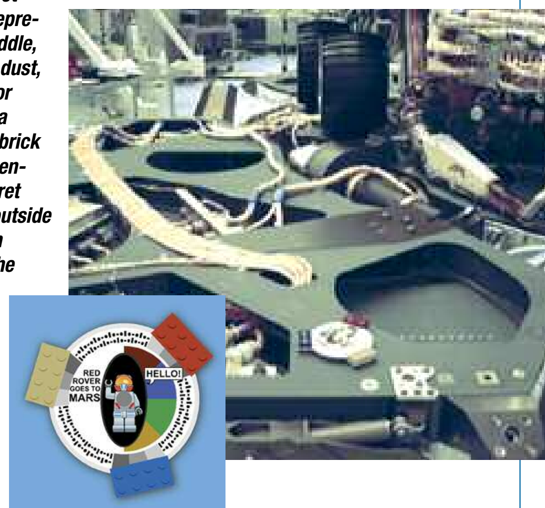
### *Millions of Names (Including Yours) Head for Mars*

The Planetary Society provided a mini-DVD and associated mounting hardware to each spacecraft. These will carry to the surface of Mars the names of nearly four million people who submitted their names to fly to Mars. The list includes the names of all members of The Planetary Society as of November 2002.

The task seems simple: provide a DVD and mounting hardware to the mission. In reality, developing, producing, and testing a mini-DVD and assembly that can survive the rigors of space and a violent landing is actually nontrivial, as is creating the paperwork trail required by the Jet Propulsion Laboratory (JPL) and NASA. The assembly had to go through the same expensive testing as any other instrument, including violent shaking and shocks. It also had to withstand bake outs at high temperatures that are part of NASA's planetary protection requirements. These bake outs are intended to kill any tiny critters on the spacecraft so we don't "forward contaminate" Mars with life when we're looking for signs of life. A normal DVD wouldn't survive, so we used a silica glass mini-DVD, on which a company in France named Plasmon specially etched the data.

Our original DVD design also had to change several times to accommodate the violent shocks and bake out. Visionary Products, Inc. built the DVD assemblies for us and produced the reams of backup documents required by JPL for every item of spacecraft hardware, even a humble DVD and assembly. The tale of this simple piece of spacecraft hardware reminds us that space exploration is neither easy nor simple, but it is rewarding.

*The Planetary Society's mini-DVD (inset) will hitch a ride to the Red Planet on board each* Mars Exploration Rover *spacecraft. The image below shows one of the DVDs mounted in position on one of the spacecraft's lander petals. After landing on Mars, the rover will capture an image of the DVD before it drives away from the lander. Each DVD carries the names of The Planetary Society's members. Each also features engaging designs leading to other activities. These include the "astrobot" LEGO mini-figure representation in the middle, magnets to collect dust, colors to study color appearance under a Martian sky, LEGO brick representations to engage kids, and secret codes around the outside to be decoded from images on Mars. The DVD will remain on the lander as a time capsule for a future generation.*




*Lander photo: JPL/NASA; DVD image: The Planetary Society*

### *Astrobots: Martian Explorers Tell Their Tales*

Wouldn't it be great to learn about spacecraft missions in a fun way that makes you laugh? That's what we thought. A new breed of explorer is on board the two *MER* spacecraft—astrobots Biff Starling and Sandy Moondust (winning contest names from Cindy Rossetto of Grants Pass, Oregon), who are part of The Planetary Society Astrobot Corps. Biff and Sandy are LEGO mini-figure representations suited up for space. They appear on each of the DVDs on the *MER* spacecraft. Their job: tell their stories to the world through a series of entertaining online communications between themselves and the ground. Come follow these first-person accounts of a planetary mission at *redrovergoestomars.org/astrobots*. Join laid-back Biff, the last-minute replacement who would rather be home watching *Junkyard Wars*, and uptight Sandy, the knower of all, who'd rather be nowhere else, except maybe correcting grammar or taking a test.

### *Student Astronauts*

The Planetary Society is a very real player in the *MER* mission in a different way. We will have a team inside mission operations doing real mission tasks. Twenty talented international students, called Student Astronauts, will go to JPL over the course of the missions and work inside mission operations in teams of two. These student pairs will work with the sundial educational experiment and the magnet team, and they will attend all key meetings. Perhaps more important, they will communicate their experiences to members and the world, explaining what it is really like to be inside operations.

Students from more than 25 countries competed for the opportunity to be part of this prestigious team through a challenging essay contest. We've announced our finalists on our website, and in the fall we will announce the actual Student Astronauts who will go to JPL. This type of individual, hands-on competition with international public involvement is unprecedented in a NASA mission. It's going to be fun, so stay tuned.

### *"Younique"*

Through such tools and programs as DVD hardware, student astronauts, and our official selection, we are involved in a Mars mission in ways no citizen group ever has been. In addition, our DVD hardware is only the second privately funded hardware on a NASA planetary mission (our Mars Microphone was the first). We're taking what is inherently a fun and interesting activity and directly involving our members and the public in the fun and excitement. So when people ask you "what's new," tell them that your name and your efforts are going to Mars.

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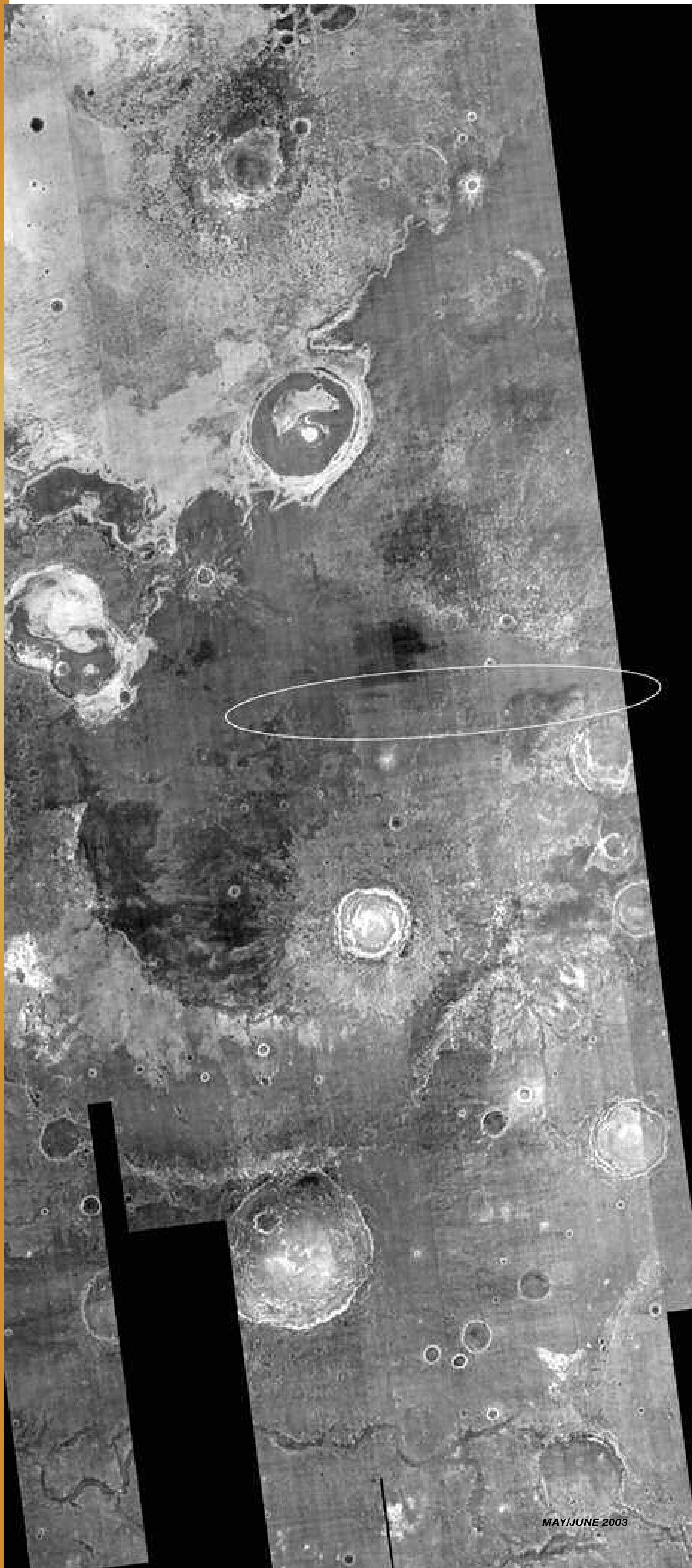
*Bruce Betts is director of projects for The Planetary Society.*

> **FIRST LEGO League**
>
> FIRST LEGO League is a yearly robotics competition for junior high school-aged kids. This fall's theme is Mars—specifically Mars rovers. The Planetary Society has collaborated with FIRST (For Inspiration and Recognition in Science and Technology) on the content of this year's competition and provided Mars materials to the 50,000 worldwide participants. This is a powerful partnership that allows us to greatly extend our reach with a limited amount of resources. For more about FIRST LEGO League, visit *www.firstlegoleague.org*.

# A Place to Call Home:

## SELECTING THE NEXT MARS LANDING SITES

BY EMILY STEWART LAKDAWALLA



On January 4, 2004, the first of two planned *Mars Exploration Rovers* will land on Mars' surface, marking the first time that a highly mobile suite of powerful instruments will be used to study Martian rocks. The information obtained could answer scientists' questions about the history of water and, perhaps, life itself on the Red Planet.

Scientists are understandably excited about this opportunity, but there is a problem—each of the two rovers can land on only one spot on Mars. This problem leads to further questions: How are those two spots to be chosen? What questions will be addressed, and which will be left for the next mission?

In the past, we had little high-resolution data (photographs or topographic measurements) to use in selecting a landing target. In the 37 years since *Mariner 4* first beamed its fuzzy pictures of Mars back to Earth, only three successful landings have been made on the Red Planet. Two of those landings, part of the *Viking* program, were in 1976, when our understanding of the planet's geology was still very primitive. A string of failed orbiter missions, including the heartbreaking loss of *Mars Observer* in 1993, meant that the third lander mission, *Mars Pathfinder*, had only *Viking* and ground-based data to guide its descent. In the meantime, an entire generation of planetary scientists has had to be content with the *Viking* images of Mars.

Since 1997, though, famine has turned to feast as *Mars Global Surveyor* (*MGS*) has brought its powerful instruments to bear on the Red Planet, returning terabytes of data in the form of images, elevation measurements, and spectrometer and magnetometer readings. As *MGS*'s life draws to an end, 2001 *Mars Odyssey* is stepping up to fill in the resolution gaps between *Viking* and *MGS*.

These spacecraft have revealed a much more complex Mars than had been envisioned previously, and academic debate has heated up over many exciting questions: Was Mars ever warm and wet, or was it always cold and dry? How recently has liquid water flowed on the surface? What about life on Mars?

Scientists think they know a lot more about Mars now than they did in 1976, but all this knowledge is based on observations made from an orbit hundreds of kilometers above the surface. Until geologists or robotic explorers can verify the remote observations with data collected on the ground, there's no way to know if interpretations of orbital data are correct.

***Left: This view of Mars' Meridiani Planum is a mosaic of infrared nighttime images taken by the Thermal Emission Imaging System (THEMIS) on board* Mars Global Surveyor *(*MGS*). The image covers an area about 240 kilometers (150 miles) by 420 kilometers (260 miles) centered near 2 degrees south and 353 degrees east. North is toward the top. This is a temperature map of the surface—bright areas are warmer, while darker areas are cooler. The white ellipse shows the area in which one of the* Mars Exploration Rovers *is targeted to land. Scientists are especially interested in this area because of its abundant gray crystalline hematite, an iron oxide that most likely formed in liquid water.*** *Image data: JPL/NASA/ASU; mosaic: Emily Stewart Lakdawalla*

That's where the *Mars Exploration Rovers* (*MER*s) come in. The *MER*s will be able to act as remote geologists. Like *Pathfinder*, each *MER* mission includes a mobile rover. Most of *Pathfinder*'s scientific instruments were mounted on the immobile lander, however; the little *Sojourner* rover carried only two instruments and could not navigate out of sight of the lander. *MER*s will carry all the mission instruments, including eight cameras in four pairs that give the rover stereoscopic vision fore and aft and from the top of a high mast, one microscopic imaging camera on the end of a robotic arm that can be used like a geologist's hand lens for close examination of rocks and soils, spectrometers and magnets for chemical and elemental analysis, and a rock abrasion tool, or RAT, that will allow its operators to expose fresh rock surfaces. In addition, these robust rovers will be able to travel up to 100 meters per day (about what *Sojourner* traveled in its entire life) in search of interesting rocks and geologic features.

## A SAFE SITE FOR THE LANDING

As in previous landing site selection activities, safety is the most important factor, and candidate sites must satisfy a host of safety requirements. The choice to use a flat, nonpivoting solar cell array constrains the landings to within a 25-degree band of latitude around the Martian equator so that the Sun will always be at a high angle. The descent will be slowed by a parachute, so the landing must occur at a low elevation to provide the longest possible path through the thin Martian atmosphere.

The *MER*s will arrive with the same bouncing-ball landing technique that worked successfully with *Pathfinder,* so the landing site must be flat, not sloping (or the lander will bounce and roll more), and free of large rocks (to prevent damage to the lander as it bounces and rolls as far as 1 kilometer from its initial impact site). Too many rocks near the landing site would make it difficult for the rover to navigate once it is on the ground. Too much dust could obscure rock compositions and, by settling on the solar panels, shorten the rover's life. Finally, because of targeting uncertainties and dispersions of the lander through the atmosphere, all these constraints must be satisfied for a "landing ellipse" covering an area about 20 kilometers by 120 kilometers. Flight planners are more than 99 percent sure that they can get the spacecraft to land within an area this size.

## SCIENTISTS GET THEIR SAY

In the end, the landing sites for the two rovers were chosen by Edward Weiler, NASA's associate administrator for space science, based on recommendations made by the *Mars Exploration Rover* mission team. In an effort to get the most possible science out of the $800 million mission, the landing site proposal and selection process was thrown open to the whole planetary science community.

Scientists received an open invitation to attend four landing site meetings, at which they could make their

***The Rock Abrasion Tool on the rover's robotic arm will spin around and grind circular patches off the surface of rocks, exposing their interiors to scrutiny by scientific instruments.*** *Illustration: JPL/NASA*

***Earthbound scientists controlling the* Mars Exploration Rovers *will enjoy much more freedom than did their predecessors on* Sojourner*. Each rover can roam up to 100 meters a day in search of interesting geologic specimens.*** *Illustration: JPL/NASA*

cases for preferred sites. NASA Headquarters chose Matt Golombek (project scientist on the *Mars Pathfinder* mission) and John Grant (of the Center for Earth and Planetary Studies at the National Air & Space Museum), two independent scientists, to cochair the meetings and oversee the process.

Preliminary analysis of the available orbital information performed late in 2000 resulted in a list of 185 potentially "safe" landing sites. (The preliminary number for *Pathfinder* was just 10.) At the first Landing Site Workshop, held in January 2001, approximately 25 areas were selected for closer examination by *Mars Global Surveyor*, which has subsequently spent two years obtaining as many image strips crossing potential *MER* landing site areas as its orbital path will allow. By October 17, 2001, when more than 60 scientists, engineers, and educators gathered for the second Landing Site Workshop, the list of potential sites had been winnowed to 17.

Each team of scientists presenting at the workshop attempted to convince their peers that their chosen location would satisfy the mission's guiding objectives: to determine the history of climate, water, and rock at a place where conditions may once have been favorable to life. Most of the presenters had spent years or even decades studying satellite data, recording observations, and developing theories about the geologic history of features and regions they thought had the most scientific merit. Naturally, their desires to do true fieldwork resulted in passionate pleas and arguments for the various sites.

Nathalie Cabrol, of the NASA Ames Research Center, argued for a landing in Gusev crater, where she has found evidence for repeated formation and draining of a crater lake due to flooding from a channel called Ma'adim Vallis. Tim Parker, of NASA's Jet Propulsion Laboratory (JPL), proposed a landing at the bottom of Valles Marineris, on deposits that appear to have formed in water. In addition, the site contains arguably the most spectacular scenery on the planet. Phil Christensen, of Arizona State University, wanted to see at closer range the gray hematite deposits in Meridiani Planum that he and his collaborators discovered from orbit; this kind of hematite, an iron oxide, could have formed in liquid water. Larry Crumpler, of the New Mexico Museum of Natural History and Science, targeted the edge of Isidis Basin, where the *MER* could encounter material washed down from the Martian highlands during ancient episodes of running water. Other presentations advocated more crater lakes, canyons, valley networks, and channel mouths, a seemingly overwhelming array of morphologic and geologic diversity.

## DIVERSITY—GOOD OR BAD?

The scientists' discussions and debates following the presentations centered on how well the sites could address the science objectives of the mission. One question that came up: would the mission objectives be better accomplished by a landing in a site with a diverse array of rock types and landscapes, or one that was typical of one kind of rock or process?

The *Mars Pathfinder* landing site was chosen so that the lander and rover could gather data on as many types of Mars rocks as possible in a small area. For *Pathfinder*, this was particularly important because so little was known at the time of *Pathfinder*'s arrival about what rock types existed on the surface of Mars. *Pathfinder* provided the first look at the chemistry and mineralogy of Martian rock. Because of that legacy and the thermal emission spectrometer instruments aboard *MGS* and *Mars Odyssey*, the *MER*s will be much better prepared to understand the rocks they observe. However, as tempting as the "grab bag" approach might be for the *MER*s, it's not the best choice if the goal is to "ground-truth" remote observations. It would be better to land in an area where we know we can match the rocks observed with a morphology observable from space. Scientists can then generalize the *MER* observations to other, distant locations on Mars that *MGS* and *Odyssey* images show as being similar to the landing site.

Many scientists argued the merits of a particular site on the basis of the variety of different environments present within the 120-by-20-kilometer (75-by-12-mile) landing ellipse. But each rover will not sample the entire landing ellipse, just a small part of it within a few hundred meters of a landing point within that ellipse, selected by fate. For instance, the ellipse in Gusev crater contains evidence for at least three different episodes of lake formation, each under different climatic conditions, but the *MER* will land atop only one set of these deposits.

More worrisome, the Melas Chasma site in Valles Marineris contains fascinating outcrops of layered deposits, pancake-like features, material washed down from the canyon's steep walls, as well as some dune fields. If the *MER* lands in the middle of a field of sand dunes, the mission could be a scientific failure, as the rover would trundle in vain down dune troughs in search of any rocks, unable to see over the dune ridges.

Another topic of debate developed around the span of geologic history observable at the landing site. Volcanic materials forming the bedrock at the Athabasca Vallis site are some of the youngest on Mars, promising relatively easy interpretation of a straightforward geologic history and a landscape that should be pristine and relatively less modified by long meteorite bombardment or later water or wind processes. On the other hand, a landing site deep within Melas Chasma could contain rocks transported there from hundreds of kilometers away—or from just up the hill—lying atop the ancient bedrock exposed in the canyon floor. This environment might be more difficult to understand but could lead to insight into a greater variety of Mars' geologic history and environments. Canyon sites also provide the opportunity to snap breathtaking photos of landscapes—images that may not have much intrinsic scientific value because of their low resolution but that would have great public appeal.

As this workshop drew to a close, a straw vote was held to determine whether any consensus had developed during the days of discussion. The first vote revealed Meridiani Planum and Melas Chasma as clear favorites, leaving scientists contending for two remaining positions. In the end, the collected scientists favored Athabasca Vallis, an ancient dry channel near Elysium Mons, and Gusev crater. Two other locations—Isidis Basin and Eos Chasma—were relegated to the status of backup sites, to be considered in the event that one of the prime four had to be eliminated.

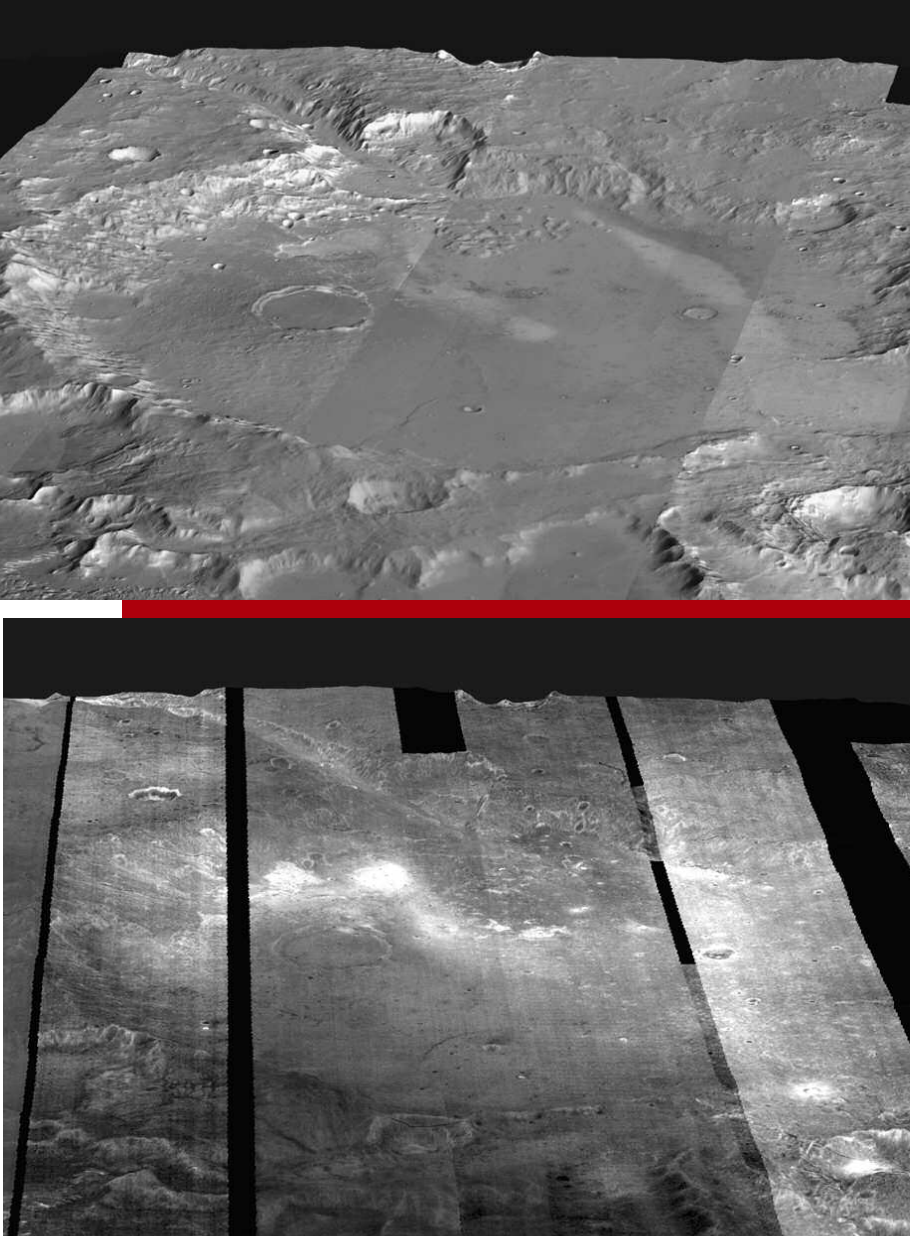
## IS IGNORANCE BLISS?

Five months were spent obtaining better *MGS* Mars Orbiter Camera coverage of Meridiani, Athabasca, Elysium Mons, Gusev, Isidis, Melas, and Eos Chasma. In addition, *Mars Odyssey* started returning new data. The topography and surface roughness characteristics of each of the sites were carefully investigated, and scientists tapped other sources of data, new and old, to learn everything possible about the seven sites. Results of these intensive analyses were presented at a third workshop, held in March 2002.

The results of the new studies were not promising. "The more we learn about the sites," Mission Manager Mark Adler reported, "the more scared we get." The scariest results came from mathematical models of wind speed and direction. The wind models predicted that at local midafternoon, when the rovers will land, winds will be screaming down the trough of Valles Marineris. The result: Melas and Eos Chasma were out.

Albert Haldemann, of JPL, presented his analysis of Goldstone and Arecibo radar observatory data of the Martian surface. Radar data had revealed rocky surfaces at Athabasca Vallis that, although topographically flat, are as rough and jagged as Hawaiian lava flows. This kind of surface roughness would quickly trap the rover's wheels and, in *MER* Principal Investigator Steven Squyres' words, "turn our rover mission into a lander mission." Athabasca was out.

It seemed that every new analysis precluded at least one of the sites, except for Meridiani, leading many to wonder: at what point is ignorance bliss? Primarily because spacecraft design turned out to be much more



*Phil Christensen and his team at the Arizona State University Mars Space Flight Facility layered several infrared THEMIS images of Gusev crater over* MGS*'s Mars Orbiter Laser Altimeter topographical data of the same region. Published for the first time here, these views depict the first* Mars Exploration Rover *landing site during the day (top) and at night (bottom). Comparing infrared day and night images shows the differences in the temperatures of the surface features, thus revealing what is rock and what is dust. Dust is warmer in the daytime and therefore brighter than rock, but rock retains its heat and is warmer and brighter at night.*

*Image: JPL/NASA/ASU*

susceptible to winds than previously thought, only three sites remained on the list by the end of the meeting: Meridiani, Gusev, and Isidis. Mission planners were nervous: what if further analysis of more data caused more sites to be eliminated? Would they find themselves with two $400 million rovers and nowhere to land them? They decided reluctantly to go back to the original 185 sites and select from them one backup site that would, without doubt, satisfy all the safety constraints, even if a landing there wouldn't necessarily further the science goals of the mission. Elysium, the selected "wind safe" site, is a transitional surface between the highlands and the lowlands.

## THE FINAL RECOMMENDATION

Now the scientists needed to decide on the final two sites to recommend to the mission on the basis of the potential scientific return. (The mission would consider the recommendation along with the site safety considerations.) At the March 2002 meeting, Steve Squyres explained that the decision would be made based on what hypotheses could be tested at each site using the science instruments on the rover. The rover has many capabilities but also limitations. It can analyze the chemistry and mineralogy of rocks or soil, but it is not designed to detect life. Squyres asked the scientists to draw up a list, after the meeting, of what hypotheses could be made about each site and how they would be tested using the suite of rover instruments.

The scientists returned to present their lists at the fourth and final Landing Site Workshop, held on January 8–10, 2003. After the presentation, a straw vote showed nearly unanimous support for the selection of Meridiani Planum and Gusev crater. The community's years of study and description of the possible sites had made the decision easy. Squyres forced the scientists to consider the possibility of the failure or loss of one of the two spacecraft on the launch pad. In that case, they decided, again nearly unanimously, to send the one remaining rover to Meridiani rather than Gusev.

At the conclusion of the workshop, Squyres addressed the crowd of scientists. He thanked them for their years of work on the landing site selection process, which could not have been performed by the actual mission scientists, who had been too busy building and calibrating the scientific instruments to spend much time studying the landing site question. "We've been working for seven years to make this mission happen," he told them. "A year from today we'll be embarking on what I think will be the most exciting mission in the history of space exploration, and to the extent that it will be successful scientifically, we owe thanks to you."

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*Emily Stewart Lakdawalla is The Planetary Society's science and technology coordinator.*

# TO LAND ON *Mars*

### BY MATT GOLOMBEK

More than two years of research and analysis incorporating the broad participation of the planetary science community has led to selection of the landing sites for the upcoming *Mars Exploration Rovers* (*MER*s). On April 14, 2003, NASA announced that the first landing will be targeted to Gusev crater on January 4, 2004, and the second landing will be targeted to Meridiani Planum on January 25, 2004.

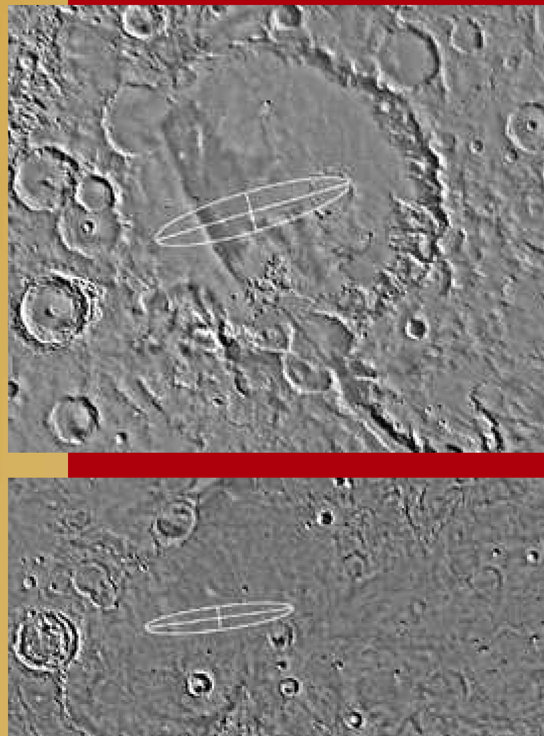
Landing on Mars is one of the most difficult tasks attempted in planetary exploration; more than half of the attempts have failed. Selecting landing sites revolves mostly around the safety of the site and satisfying the engineering constraints that result from the lander's design and the entry, descent, and landing scenario. This approach is forced by the simple fact that no science can be done unless the landing is successful—no one wants to gamble with hundreds of millions of dollars worth of precious spacecraft hardware. This forces people on the project to do everything humanly possible to ascertain that potential landing sites are safe. The *MER* landing sites have been characterized to an unprecedented level by the explosion of new information provided by the *Mars Global Surveyor* and *Mars Odyssey* orbiters.

Even though the prospective landing sites are the best-imaged, best-studied locations in the history of Mars exploration, gaps in our knowledge of important parameters exist and ambiguities remain concerning the extrapolation of orbital remotely sensed data to the "ground-truth" view provided after landing.

Four landing sites were investigated in exhaustive detail for selection of the final two. Surface and atmospheric characteristics of all four sites generally satisfy the engineering constraints. Entry, descent, and landing simulations show that most of the simulated landing events at all four sites are within the design specifications of the landing system, based on the three most important safety criteria: winds, slopes at the scale of the airbags, and rocks.

The landing simulations also show, however, slightly fewer landing events within specifications at ellipses in Gusev crater and Isidis Planitia (consistent with the potentially higher winds, slopes, and rocks at these sites) than at Meridiani Planum and Elysium Planitia. The evaluation of Meridiani and Elysium as the two safest landing sites must then be tempered by the relevance and importance of the potential science results at the sites.

Assessment of detailed, testable hypotheses traceable to the specific observations made by the rover instruments indicates that the Meridiani and Gusev sites most directly address the *MER* scientific objectives (to search for evidence of past aqueous activity and to assess the past habitability of the environment). These sites, respectively, have strong mineralogical and geomorphological indicators of liquid water in their pasts.



*The landing ellipses for the first and second* Mars Exploration Rovers *are shown in their geologic contexts in these* Viking *images of Gusev crater (top) and Meridiani Planum.*

*Images: JPL/NASA*

The selection of Meridiani Planum was straightforward. It is the safest location investigated on Mars, and Thermal Emission Spectrometer results (see "Mars Infrared," page 12) indicate coarse-grained, crystalline hematite, suggesting precipitation from liquid water or a hydrothermal deposit. Selection of the other site was not so straightforward. Should the next-safest site—Elysium Planitia—be selected, even though it may not directly address the scientific objectives of the mission? Or should the site with high science priority, Gusev crater, be selected? It shows strong evidence of being a crater lake with interior sediments deposited in standing water, directly addressing the scientific objectives of the mission, but the site may be slightly less safe.

In a sense, the decision centers on how much risk can be prudently taken to land at a location where evidence suggests answers might be found to the fundamental questions of the entire Mars exploration program: Did life start on Mars? Was the environment conducive to the formation of life? The selection of Gusev crater (with its slightly higher risk) as the other *MER* landing site is entirely appropriate for an exploration program that is striving to answer a question as compelling as "Are we alone in the universe?"

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*Matt Golombek, a research scientist at Jet Propulsion Laboratory (JPL), is the JPL Mars Exploration Program Landing Site Scientist, cochair of NASA's Mars Landing Site Steering Committee, a member of the Athena Science Team, and a* MER *Science Operations Working Group Chair. He was the chief scientist of the* Mars Pathfinder *mission that landed and roved successfully in 1997.*

# *Mars* INFRARED

BY PHIL CHRISTENSEN, WITH MATTHEW SHINDELL


*Hematite, a mine*
*liquid water has*
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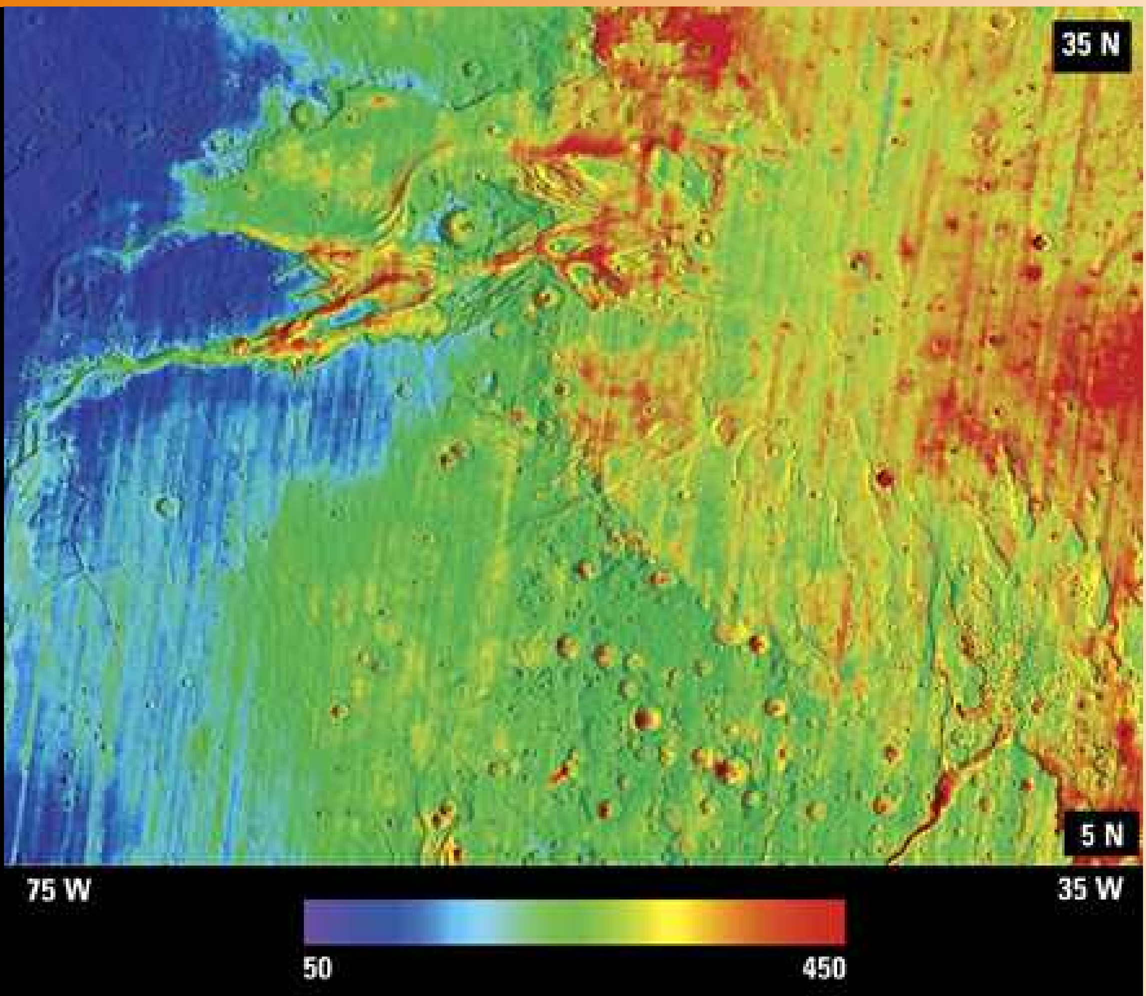
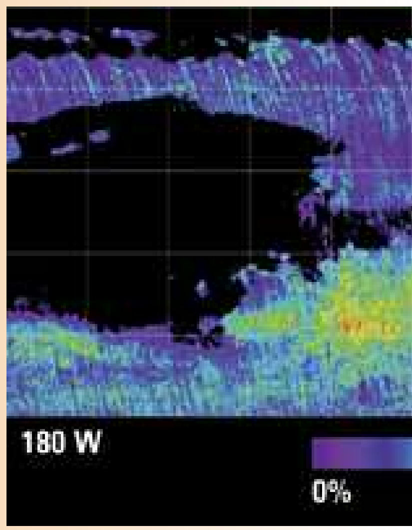
*image is enlarge*
*Map: JPL/NASA/ASU*

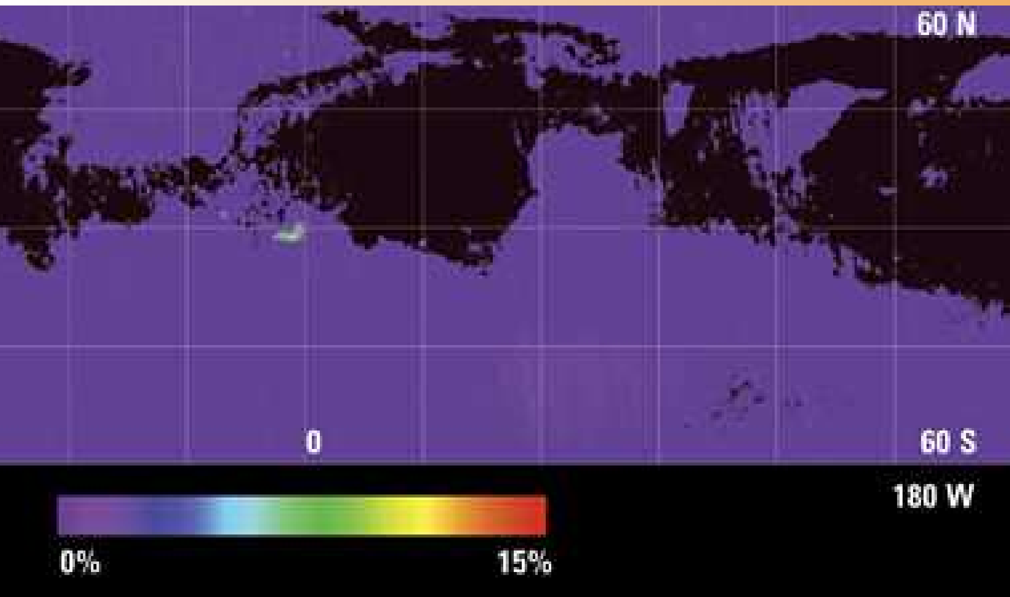



*Thermal inertia (a measure of resistance to temperature change) maps of Mars help determine the distribution of rock, gravel, sand, and dust. In this map of Kasai Valles, we placed Thermal Emission Spectrometer (TES) data over a topographical map of the region constructed from data gathered by the Mars Orbiter Laser Altimeter (MOLA) on* Mars Global Surveyor *(MGS). The finished product distinguishes rocky features from those covered in layers of dust and sand. This has aided in the assessment of possible landing sites. It also gives us an idea of how the features in the MOLA map are composed as well as how erosional processes may have worked on them over time. Lower inertias (blue) change surface temperature more easily and are indicative of dust. Higher inertias represent areas with more sand, gravel, and/or rock.* *Map: JPL/NASA/ASU*

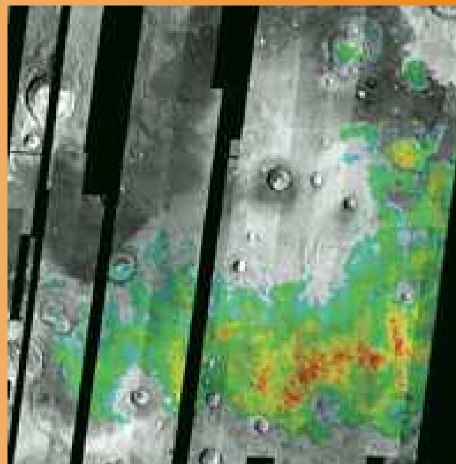



Geologists who focus on Mars are constantly reminded of how terrestrial geologists take their position for granted. Just about any geologist on Earth can pick up just about any rock and give you a rough classification based on not much more than what he sees and feels. Give him an afternoon, maybe let him hit it with a hammer, and he can tell you how that rock was formed, what it tells him about the history of the region in which it formed, and how the processes in that region fit into the overall story of terrestrial geology.

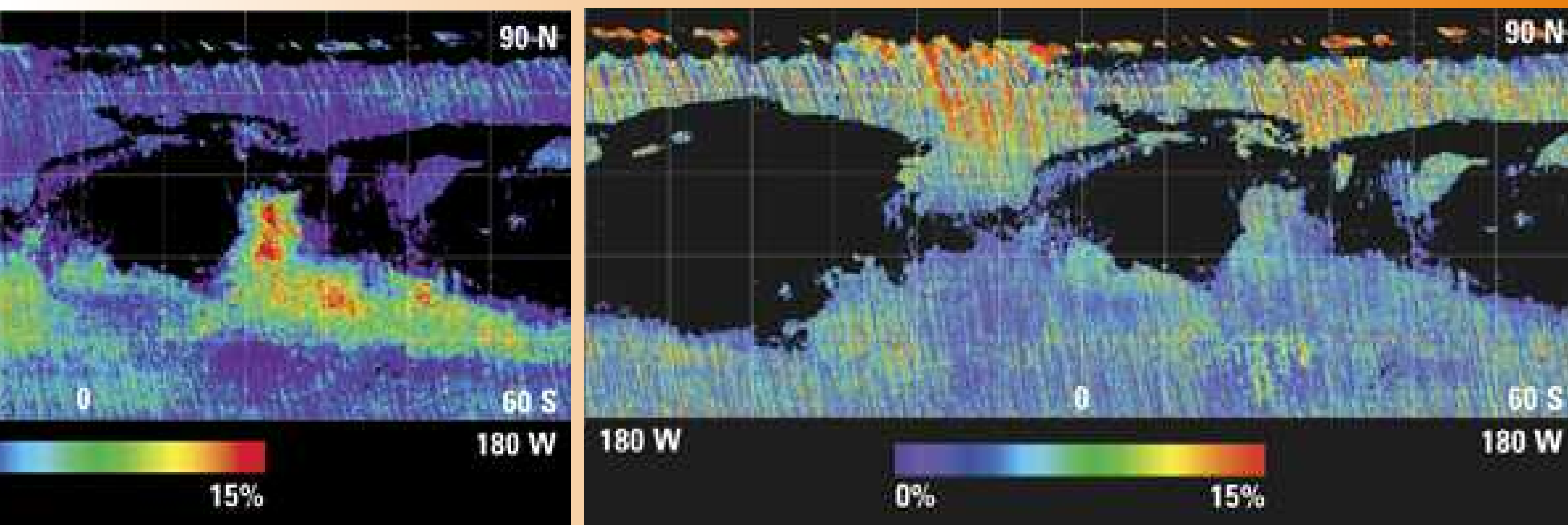
If planetary geologists could spend an afternoon or two on Mars, we could probably answer many of the questions Mars geologists have been debating for the last 30 years—were Mars' layered deposits created by wind, water, or




*eral most commonly formed in liquid water, is right now the most promising geologic evidence that s played an active role on the Martian surface. TES found hematite confined to only a few regions on lars. It is not yet clear how the hematite formed. Scientists hope that more intense exploration of ealed by TES will help unlock the mystery of water on Mars. The hematite region in the center of this ed in the image at right and is targeted as one of the* Mars Exploration Rover *(*MER*) landing sites.*
*u*



*TES data showing a hematite deposit at Sinus Meridiani were one reason that location was chosen as one of the* Mars Exploration Rover *(*MER*) landing sites. Here you can see TES data laid over a mosaic of several infrared images captured by the Thermal Emission Imaging System (THEMIS) on board* Mars Odyssey*. Notice the way craters on the deposit, and their ejecta, do not show hematite. This may indicate that the deposit is a thin layer—evidence of some past geologic event—that was recently excavated.* *Image: JPL/NASA/ASU*




*These global maps, derived from data gathered by TES on* MGS*, highlight the regional differences in distribution of basalt and andesite, two types of volcanic rock. The basaltic unit (left) occurs predominantly in the southern hemisphere and the andesite unit (right) predominantly in the northern lowlands. This difference may represent two different periods of volcanic eruption from a compositionally different mantle, or instead the andesite in the north may be a weathering product of what also began as basalt.*

*Future work with these rocks may help to answer the larger question of the global dichotomy—why the northern lowlands are younger and have a thinner crust. It should also help give us a picture of what role surface or subsurface water played in the evolution of this dichotomy. The areas masked in black are regions where high dust content obscures the surface and makes it difficult to take spectral measurements.* *Map: JPL/NASA/ASU*

ash? Did glaciers or permafrost play a part in shaping the planet's surface? Unfortunately, on Mars, the answers are not so easy.

Mars geologists have had to find comfort in the fact that the next best thing to being there is "seeing there." We've had to develop ways of classifying rocks and features just by looking at them—most of the time from great distances or at poor resolution. Orbiting satellites, including instruments that look at the surface and atmosphere of Mars in wavelengths other than visible light, have been a great help. These instruments allow us—if we only get to look at the rocks—to at least look at them in as many wavelengths as possible.

As designer and principal investigator of the Thermal

Emission Spectrometer (TES) on board NASA's *Mars Global Surveyor* spacecraft, and then later the Thermal Emission Imaging System (THEMIS) aboard *Mars Odyssey*, I have spent a lot of time trying to work out Martian mineralogy using infrared data. It's a part of the electromagnetic spectrum we don't normally see but one that can be very revealing when it comes to mineralogy.

Using TES, my colleagues and I made the first global mineralogical maps of Mars' surface. Using THEMIS, which has greater spatial resolution than TES (TES pixels were 3 by 6 kilometers (2 by 4 miles) and THEMIS pixels are 100 meters, meaning you can fit 1,800 THEMIS pixels in one TES pixel), we have gotten a good start on revisiting some of the more interesting spots TES revealed to us.

We might not yet have sent a human geologist to Mars, but we've taken significant steps toward understanding Mars geology. If nothing else, we hope we have created data sets that can be used for years to come—even after human missions reach Mars.

With the 2003 *Mars Exploration Rovers* (*MER*s), we'll be continuing our study. Each of the *MER*s is equipped with a suite of scientific instruments designed to perform many of the tasks of a geologist in the field. The rovers are even designed to do some things geologists are able to do only in the lab. One of the instruments aboard the *MER*, the Mini Thermal Emission Spectrometer, is the miniature version of TES. To understand what sorts of science will be done with Mini-TES and what we hope to learn, in this article we reflect on how its predecessor, the original TES instrument, works and what it has already told us about Martian geology.

## HOW TES WORKS

The Thermal Emission Spectrometer, as the name says, is a spectrometer that is finely tuned to infrared light—thermal emissions—from rocks. Like any spectrometer, TES contains two major components: a mechanism to separate light into different wavelengths and a detector. TES uses a device called an *interferometer* to separate infrared light into a spectrum, and the detector then measures the emissivity (strength) at different points (wavelengths) in the spectrum. In the case of TES, this spectrometer is specifically designed to be sensitive to the wavelengths characteristic of different key geologic materials, wavelengths that occur within the thermal infrared (IR).

Normally, we experience heat through our sense of touch. However, objects not only transmit heat via touch, they also radiate energy—electromagnetic radiation that for most planetary temperatures occurs at wavelengths

***An image like this one was the "Rosetta Stone" for translating the origin of the gullies on Mars. In that image, Phil Christensen could see both the gullies and the snowpacks that were "pasted on" to the crater wall. "An* Odyssey *image made it all suddenly click," said Christensen, "because the resolution was high enough to identify these features and yet low enough to show their relationship to each other in the landscape."***
***Image: JPL/NASA***

## Snow Report for Mars

Phil Christensen has devoted much of his career to studying Mars geology in infrared. In February 2003, though, Christensen discovered evidence in visible light of something he wasn't even looking for—Martian snowpacks.

Christensen's snowpacks may help to answer an important and, until now, puzzling question in Mars geology. In 2000, Michael Malin's Mars Orbiter Camera (MOC) on board NASA's *Mars Global Surveyor* spacecraft captured some surprising images (see the September/October 2000 issue of *The Planetary Report*). In better resolution than ever before, what MOC revealed were 10-meter-wide gullies, too small to be seen by previous instruments, on slopes and crater walls. It was not clear what had carved them, but water seemed the most likely agent.

The major difficulty in explaining the gullies has been in modeling a process that could carve gullies on a Mars similar to the Mars we see today—one that is incredibly cold and dry. Most other water-carved features, such as the catastrophic outflow channels and valley networks, have been explained as the remnants of processes that ceased perhaps billions of years ago, when possibly a warmer, wetter time on Mars came to an end.

The small MOC gullies are too young to be explained as ancient remnants. They carve their way through older features, sit on the slopes of young, small craters, and have crisp morphologies. They may be only thousands of years old rather than billions.

Models proposed over the last three years have not been universally accepted. These models relied on subsurface aquifer runoff and the melting of ice stored in the pores of the soil. These models might work in areas near the equator, which get more sun, but the gullies occur in Mars' colder midlatitudes (between 30 and 70 degrees) and on isolated surfaces. Uncovered liquid water would not survive long in these regions, and groundwater seepage would be unexpected.

According to Christensen, snow doesn't have these problems. Icy snow will not melt, but dirty snow will. A snow layer provides a greenhouse effect. Beneath the surface, snow can melt even when temperatures at the surface are below freezing. The melting amounts to a trickle of water similar to a garden hose left running—about 10 cubic meters a day, enough to fill a backyard swimming pool. After several thousand years, the trickle carves a gully. When the overlying snowpack is removed, the gully is revealed.

Christensen's model relies on pictures of Mars taken with MOC and with the visible-light camera of his own Thermal Emission Imaging System (THEMIS). In these images, Christensen claims, are remnant snowpacks clinging to the edges of gullies and crater walls.

The snowpacks are essentially fossilized, buried, and preserved beneath a thin layer of desiccated dust, where they can neither melt nor sublimate. Gullies visible to MOC and THEMIS in these same crater walls reveal places where the process was active. Looking at the features side by side, Christensen sees a weathering process frozen in time.

"The image shows a crater about 20 kilometers (12 miles) in diameter that on the pole-facing side has this 'pasted-on' terrain," said Christensen, describing the first image in which he noticed the snow. "As you come around to the west there are all these gullies. I saw it and said, 'Ah-ha!' It looks for all the world like these gullies are being exposed as this terrain is being removed through melting and evaporation."

Christensen's snowpacks, in addition to providing a mechanism for gully formation, are the first direct evidence of the snow predicted by the currently accepted obliquity model. This model tells us that Mars wobbles like a top, its axis moving from a 15-degree angle to a 35-degree angle over periods of millions of years. When the wobble is at its most severe, bringing the axis to its greatest angle of tilt, Mars' poles grow warmer thanks to the extra sunlight. Water vapor comes off the poles and is redistributed to the midlatitudes, where the surface has grown colder. Here the water vapor freezes and snows down. A blanket of up to 10 meters of snow can be generated in this way every 50,000 to 500,000 years. *—MS*

longer than visible light in the "thermal infrared."

The minerals in rocks emit, absorb, and reflect thermal IR light of different wavelengths depending on their composition. This is because every mineral has a unique crystal structure and elemental composition. As the bound atoms move, or vibrate, in the crystal lattice, they give off a unique wavelength of IR light. Similar to the way we use the uniqueness of our fingerprints to identify individual people, we can use IR signatures to accurately identify individual minerals. By this method, we can detect and differentiate types of carbonates, sulfates, phosphates, silicates, oxides, and hydroxides—minerals that are important in constructing the geologic history of a planet.

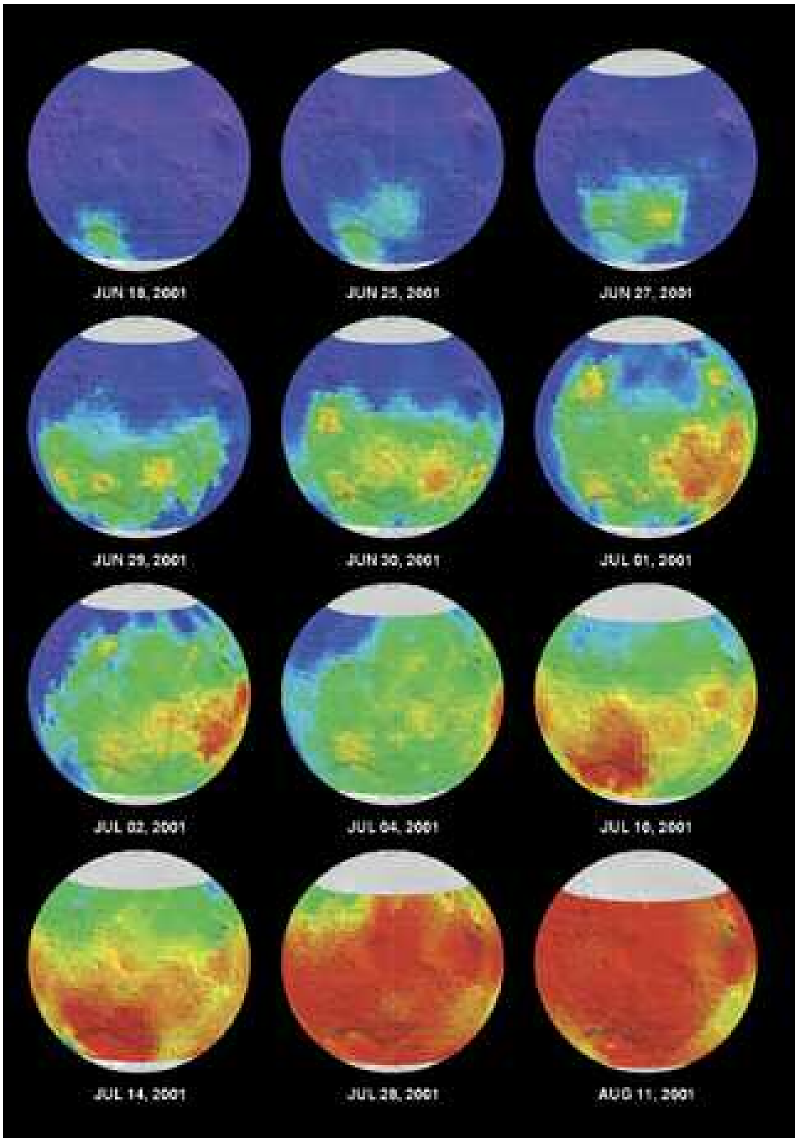
## WHAT TES SHOWED US

With TES, we were able to assign spectral signatures to 3-by-6-kilometer patches of the Martian surface. By the end of the TES mapping mission in February 2001, we had collected 91,572,072 of these signatures and had mapped the entire surface. With these, along with more than 55 million spectra gathered before and after the mapping phase, we learned a lot about surface mineralogy and the Martian atmosphere, as well as the processes at work in the Martian polar regions.

In terms of water, surface mineralogy tells us Mars probably has had a cold, dry climate for billions of years. On Earth, water—in the form of rainfall, streams, rivers, and glaciers—has been the major geologic agent in shaping the landscape. It drives the chemical weathering of the Earth's surface. TES found very little evidence of chemical weathering of the Martian surface. For example, TES found lots of unweathered olivine. Even in the driest deserts on Earth, olivine left exposed on the surface would chemically weather fairly quickly due to water. Most of the weathering that has occurred on Mars (and that continues to this day) seems to have been mechanical, most likely wind-driven.

The presence of minerals that would have weathered on a wet planet is not our only clue to Mars' dry history. TES also found little evidence of carbonates—minerals you would expect to find on a planet where surface water has played an active role. Carbonates commonly form when liquid water and carbon dioxide come into contact with each other. On Earth, the presence of liquid water allowed for much of our early atmosphere (which at one point may have been 40 times thicker than it is today) to be locked up in carbonate rock. While TES can't detect small patches of carbonates (that's where the detailed THEMIS images will come in handy), we can conclude from TES data that large-scale deposits of carbonates are not currently exposed at the Martian surface. This lack of evidence is consistent with models for early Mars in which carbonates never formed in large volumes.

We did, however, find isolated regions where surface or near-surface water has probably played an active role.




***TES followed the life of a global dust storm that raged from June to August in 2001. It is not unlike the global dust storm scientists observed when*** **Mariner 9** ***first turned its TV cameras on Mars. These TES-derived images show the storm first beginning to rise out of Hellas Basin. By the time it ended, it had covered the entire planet.*** *Images: JPL/NASA/ASU*

This is evidenced by the presence of gray, crystalline hematite (iron oxide). Hematite on Earth is known to form in a number of processes, most of which involve water. These water-related processes include hydrothermal processes (such as hot springs), and the conversion of other minerals deposited in standing bodies of water. In hydrothermal systems, for example, iron dissolves in hot water and then precipitates as it cools. Hematite can also form through the dehydration of goethite, a hydrated iron oxide ooze.

We found hematite in three sedimentary rock formations. These units provide evidence that liquid water was stable for a long time on or near the surface of Mars at some point in Martian history. In fact, TES hematite evidence at one site, located in Sinus Meridiani, led to the selection of this area as a MER landing site (see "A Place to Call Home," page 6).

Evidence of water and rock interaction was definitely something we were looking for in surface mineralogy, but we were also looking for clues about Mars' geologic history and composition. Clues like this might help us answer such questions as what caused Mars' global dichotomy—the younger northern plains and the ancient southern highlands. The heavy cratering seen in the southern highlands has been erased or buried in the northern plains. The crust in the plains is much thinner and the elevation a few kilometers lower than in the south.

We found some wonderful geologic clues. Thanks to TES, we were able to determine for the first time the precise nature of the volcanic rock that covers Mars. In our mineralogical maps, we found Mars to be covered basically by two types of volcanic rock: basalt and andesite. Excitingly, the distribution of these two rock types is regional and is consistent with the dichotomy. Basalt occurs primarily in the southern highlands and andesite mostly in the northern plains.

The distribution and ages of these volcanic materials provide important clues to how the upper portion of the Martian mantle (the zone below the crust and above the core that is the likely source region for Martian lavas) may have evolved over time. Andesite, for example, suggests that at one point, Mars may have had a wet mantle. Further spectral investigation is needed to help us answer whether this andesite is indeed itself a volcanic product and not simply weathered basalt.

With further study, we should be able to arrive at likely explanations for the evolution of Martian magmas. With this work, we will eventually progress from mineralogical maps to accurate geologic models.

By combining spectral signatures with TES recorded surface temperatures, we have already mapped the distribution of dust, sand, gravel, and rock on the surface. We map this distribution by looking at the thermal inertia (a measure of the rate at which objects heat and then cool) of surfaces. The surfaces of rocks, which have high thermal inertia, change temperature slowly. This is because heat can be transported easily into or out of their interior.

In contrast, dust has very low thermal inertia: the surface heats and cools quickly because heat transport downward is not efficient. For a surface of similar brightness, a rocky surface will be warmer at night and cooler in the daytime compared to a dusty surface, with sand and gravel in between (this is why rocks feel warm at night and cool during the daytime on Earth as well). By comparing day and night IR images (essentially temperature images), we can tell which surfaces have higher or lower thermal inertias.

These IR maps will be used to aid in the geologic mapping of the surface. For example, we can study how rocks are eroded to sand and dust, and how this eroded material is transported, by observing the distribution of dust, sand, gravel, and rocks over time. These maps have already been helpful in the selection of landing sites. They have been used to determine where the rockiness or dustiness of the surface would be hazardous for the landers.

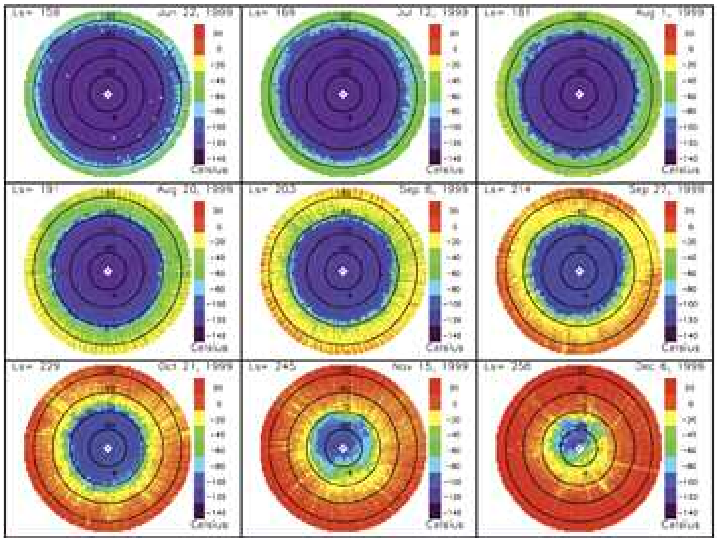
We have also used TES to study the nature and processes of the Martian atmosphere. TES can measure atmospheric temperature by measuring the absorption of heat by the carbon dioxide in the atmosphere. Overall, we have mapped surface and atmospheric temperature throughout two Mars years. The atmospheric temperatures have contributed to the study of the current weather, including winds and jet streams.

With TES, we've been able to observe and record the life cycles of five regional dust storms. The amounts of dust these storms throw into the air have a significant effect on the atmospheric temperature structure. The storms have been observed to increase the temperature of the upper atmosphere by up to 50 degrees Celsius (90 degrees Fahrenheit), while cooling the lower atmosphere by about 5 degrees Celsius (9 degrees Fahrenheit). The dust simultaneously absorbs sunlight and heats the upper atmosphere, while blocking sunlight from reaching the surface. These dust storms also seem to cause the Martian atmosphere to expand outward toward space.

What we've seen from the dust storms so far is that they appear to start in certain regions each year, such as Hellas. We are not yet sure why this might be. It may be because Hellas' depth allows for a thicker atmosphere where winds are more effective at picking up and carrying dust. The dust storms also seem to begin at the same time each year. As the dust from the initial storms drifts around the planet, it appears to generate intense storms in new locations. In 2001, we watched as these storms grew to encircle the planet.

TES results also told us about Mars' frozen poles, features we have known about pretty much since the beginning of Mars observation. As in earlier studies with other instruments such as the Infrared Interferometer Spectrometer (IRIS) and the Infrared Radiometer (IRR) of the *Mariner* missions, as well as the *Viking* Infrared Thermal Mapper (IRTM), TES revealed that the poles are covered in seasonal carbon dioxide ice. What TES told us about this ice is that it occurs in three forms: fine-grained, coarse-grained, and slab ice. Different regions within each pole seem to be marked by these differences in $CO_2$ grain size. Most of the condensation of $CO_2$ seems to occur at the surface, not in the atmosphere. In other words, it does not snow on the polar caps. Instead, carbon dioxide gas goes from gas to solid on the polar surface, in some cases forming meter-thick crystals of $CO_2$ slab ice.

Multiple TES observations showed us that the condensation could change on a daily basis. Also, because we were able to observe the Martian poles over several seasons for the first time, we could determine their incredible regularity from year to year. Comparing TES observations to those of *Viking* 22 years ago, we found that there is little difference in the seasonal cycle. The caps seem to extend and contract to pretty much the same latitudes on pretty much the same time scale.



***TES was able to observe the regular advance and retreat of the polar caps. This series of images shows the shrinking of the south polar cap from June to December in 1999. There is quite a difference in size between summer and winter. In winter, it extends as far as 60 degrees south latitude. It may even reach Hellas Basin during this time. Temperatures indicative of polar cap carbon dioxide ice are shown as dark blue.*** *Images: JPL/NASA/ASU*

## LOOKING AHEAD

My students, my colleagues, and I are very excited to see the *MER*s explore the Martian surface up close. Thanks to the TES results, as well as initial THEMIS results, we are ready to tackle many questions. For example, results from Mini-TES, along with work we are doing in the lab at the Arizona State University Mars Space Flight Facility, may hold the key to unlocking the mystery of how hematite formed at Sinus Meridiani. This and other findings will make the mission worthwhile and lead to a more complete understanding of Mars geology.

Because rocks contain the history of the planet on which they form, they are the planetary history books —virtual time machines that give us insight into the early conditions of the planet. We want to open these books, to see the planet that once was, and to help draw the timeline to the planet we see today. We are glad to continue to play a role in this truly exciting time for Mars exploration.

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*Phil Christensen is the Korrick Professor of Geologic Sciences at Arizona State University (ASU), where he heads ASU's Mars Space Flight Facility. Christensen is also the designer and principal investigator of NASA's Thermal Emission Spectrometer (TES) on the* Mars Global Surveyor *spacecraft, as well as the Thermal Emission Imaging System (THEMIS) on board the* Mars Odyssey *spacecraft. His instrument, the Mini Thermal Emission Spectrometer (Mini-TES), will fly on board NASA's two* Mars Exploration Rovers *this summer. Matthew Shindell is a freelance science writer with degrees in science and writing. Shindell is currently a graduate student of the history and philosophy of science in ASU's Center for Biology and Society.*

# Questions and Answers

***How are the sizes, temperatures, and compositions of planetary cores determined?***
**—S. O'Rourke,**
**Nantucket Island, Massachusetts**

Determining the size, temperature, and composition of any planetary interior is, obviously, a challenging process—it's impossible to drill to core depths to take direct samples or measurements. Therefore, these characteristics must be determined using indirect methods.

The best approach to studying the physical properties of Earth's core is to measure seismic waves. These waves, generated predominantly by earthquakes, move at differing rates through various materials. By recording lots of seismic events and then cross-correlating the planet's seismic response at various depths, it is possible to build models that accurately demarcate the boundary between Earth's liquid metal core and its solid silicate mantle. These models show, for instance, that the core-mantle boundary is located about halfway to our planet's center. They also indicate that Earth's core appears to be consistent with the seismic properties of iron (with some lighter materials mixed in).

However, we have no operational seismometers on other planets at the present time. To estimate the interior structures of other planets, we must make inferences based on a planet's mass, size, and moment of inertia. The moment of inertia is a measure of how a body's mass is spatially distributed: the closer a body's mass is located to its rotation axis, the lower the moment of inertia. For example, if an ice skater (such as Brian Boitano) is in a spin, he would minimize his moment of inertia by pulling his arms in close to his sides. From measurements of mass and size, we can determine a planet's mean density. If the mean density of a terrestrial planet is far greater than that of typical mantle materials, we know that even denser materials exist in the planet's interior.

To determine how a planet's mass is distributed throughout its interior, we use estimates of its moment of inertia. These estimates are typically generated from measurements of perturbations in a planet's rotation, such as precession or libration (variations in the location of the planet's rotation axis—like the wobble of a spinning top). Such measurements are far more difficult to make than measurements of total mass or planetary radius but are necessary to characterize the planet's interior. For example, on Earth the moment of inertia is relatively low, indicating that high-density material is located near the planet's center. This makes sense: we know from seismology that Earth has a sizable metallic core.

It's not until we combine measurements of mass, size, and moment of inertia that we can build models of a planet's interior. In these models, we can vary the location of the core-mantle boundary and the densities (and, therefore, compositions) of the core and mantle materials. We are then able to map out the range of possible planetary interiors that reasonably support the measurements.

When it comes to estimating interior temperatures, we rely on other planetary attributes. These can include surface geology, measurements of heat flux, cratering dynamics, and planetary magnetic field generation, to name a few. Each of these can provide important constraints on the planet's interior.

Using such constraints, we build models of a planet's interior thermal state and its thermal evolution. Interior temperatures result from a balance between heat generation and heat loss. Planets are cold at their surfaces, where they radiate heat away to space, and then become hotter at increasing depths due to thermal blanketing and compressional effects from overlying material. In addition, long-lived radioactive elements in the mantle or core can strongly affect a planet's thermal evolution.

One goal of NASA's upcoming *MESSENGER* mission to Mercury is to provide detailed information about the size, temperature, and composition of that planet's core. *MESSENGER* will make precise measurements of Mercury's rotational properties and its magnetic field. With these findings, scientists will attempt to determine whether Mercury's large metallic core is still partially liquefied and whether the core hosts an active magnetic dynamo. Such information will provide tighter constraints for future models of Mercury's interior composition, temperature, and thermal evolution.

—JONATHAN AURNOU,
*University of California, Los Angeles*

***A few dozen Moon and Mars meteorites have been found on Earth. Have any been found from Venus, Mercury, or any moons other than our own?***
**—William Laub,**
**Denver, Colorado**

There are currently no known meteorites from Venus, Mercury, or moons of other planets. The working hypothesis for the class of meteorites known as *eucrites* is that they came from the asteroid Vesta. That hypothesis seems reasonable because eucrites are volcanic rocks, and it takes a large body, at least the size of Vesta (530 kilometers, or 330 miles, in diameter), to support volcanism. There is also some similarity in the spectral signatures of these rocks and Vesta. Some scientists, however, suggest that the eucrites might be from Venus—they question the similarity of the spectral signatures between Vesta and eucrites and believe the oxygen isotopic signature of eucrites might be consistent with Venus.

We recognize meteorites from the Moon because we can compare them to lunar rocks collected on the *Apollo* missions. On the other hand, we believe the "Martian" meteorites are from the Red Planet in part because they have gas contents that are similar to those measured by the *Viking* landers on Mars. Also, they are igneous (volcanic) rocks, and we know that there are volcanoes on Mars. Because we don't have known samples from Venus or Mercury, we don't know for sure what the rocks on the surface of those planets are like; therefore, there's no way to be certain that an unusual meteorite is not from one of those planets.

Volcanoes and volcanic features on images of Venus and Io lead us to expect that a "Venusite" or "Ioite" might be volcanic. We also expect that they would be different from a lunar or Martian volcanic rock, but at this point, we can only speculate on what that difference might be.
—RANDY L. KOROTEV,
*Washington University, St. Louis*

# Factinos

Using the Hubble Space Telescope, scientists have, for the first time, observed the atmosphere of an extrasolar planet evaporating into space. Much of this planet eventually may disappear, leaving only a dense core. The scorched planet called HD 209458b orbits "only" 7 million kilometers (about 4 million miles) from its yellow Sun-like star, HD 209458. By comparison, Jupiter orbits 780 million kilometers (almost 500 million miles) from our Sun. The star HD 209458 is 150 light years away in the constellation Pegasus.

A mainly European team led by Alfred Vidal-Madjar of Paris' Institut d'Astrophysique reported this discovery in the March 13, 2003 issue of *Nature*. "We were astonished to see that the hydrogen atmosphere of this planet extends over 200,000 kilometers" (125,000 miles), said Vidal-Madjar.
*—from the European Space Agency*

Marine geologists at Rice University have discovered that a colossal collision in the asteroid belt some 500 million years ago led to intense meteorite strikes across Earth's surface.

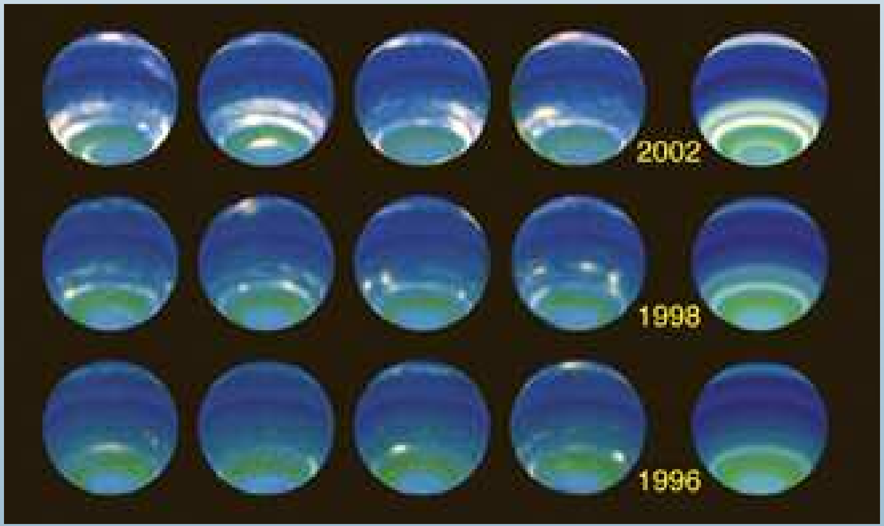
The research, which appears in the May 9, 2003 issue of *Science*, is based on an analysis of fossil meteorites and limestone samples from five Swedish quarries located as much as 500 kilometers (310 miles) apart. The limestone formed from sea bottom sediments during a span of 2 million years, about 480 million years ago. The process sealed the intact meteorites, as well as trace minerals from disintegrated meteorites, in a lithographic time capsule.

"What we are doing is astronomy, but instead of looking up at the stars, we are looking down into the Earth," said lead researcher Birger Schmitz, of Sweden's Göteborg University. (Schmitz conducted his analysis as a visiting professor at Rice.)
*—from Rice University*

Hubble Space Telescope observations are revealing an increase in the brightness of Neptune's southern hemisphere (see images below). Astronomers consider this increase a harbinger of seasonal change. The observations, made over the course of six years by a group of scientists from the University of Wisconsin, Madison, and the Jet Propulsion Laboratory, show a distinct increase in the amount and brightness of the clouds encircling the planet's southern hemisphere.

"This change seems to be a response to seasonal variations in sunlight, like the seasonal changes we see on Earth," says the University of Wisconsin's Lawrence A. Sromovsky.

The scientists reported their findings in the May 2003 issue of *Icarus*.
*—from the Space Telescope Science Institute and the University of Wisconsin, Madison*




***These individual, color-composite Hubble Space Telescope views of Neptune were processed to show how the planet's southern hemisphere has gradually brightened since 1996. The first four columns display views of the planet at zero, one-, two-, and three-quarter rotations to show the distributions of features. The last column is a longitudinal average of the images to better show the increase in brightness.***

*Images: NASA, L. Sromovsky, and P. Fry, University of Wisconsin, Madison*

# Society News

**Global Volunteer Leader Announced**

The Planetary Society is very pleased to announce Lonny Baker as its new Global Volunteer Leader—a new position focused on strengthening the volunteer network. Lonny will be the point person for all Planetary Society volunteers around the world.

Lonny has been a member of The Planetary Society since 1981, and since 1988 she has been involved in the Society's Bay Area Volunteer Network (TPSBAVN), where she has served as coordinator since 1994.

Each year, the TPSBAVN coordinates major events such as panel discussions featuring local or visiting scientists, events to support Planetary Society or NASA missions, tours of local research facilities, star parties, and potluck membership meetings.

If you are interested in volunteering, or if you are now a volunteer and would like to introduce yourself, please e-mail Lonny at *tps.lb@planetarysociety.org*.

*—Vilia Zmuidzinas,*
*Events and Volunteer Coordinator*

**Proceeds from Card Game Help the Society**

The Planetary Society membership comprises individuals with diverse backgrounds and talents. One example is Society member Brad Curtis of Shoreline, Washington, who has started a company called HomeStar Games, which produces quality space science educational games that are fun to play.

Brad's first product is called "Planetaire™—The Grand Tour." This unique card game of exploration and discovery of the solar system features one of the largest card collections of images, photos, and artwork of the solar system in print. It also features artwork by renowned astronomical artists (and Society members) Don Davis, Don Dixon, and Ron Miller.

Brad has dedicated HomeStar Games to helping support the Society's programs by donating 10 percent of the net proceeds from the sale of each game to the Society. The game will be available for purchase this June. Society members can get a preview of the game and reserve their first edition copy at *www.homestargames.com* or call Brad toll free at 1-866-HST-Games.

*—Linda Kelly,*
*Program Development Manager*

**Planned Giving**

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

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

If you would like more information about estate planning, call or e-mail Andrea Carroll at (626) 793-5100 or *tps.amc@planetary.org*.

*—Lu Coffing, Financial Manager*

**Member Names Fly on *Cosmos 1* Mission**

As a special "Thank You," all Planetary Society members on our membership rolls as of June 1, 2003 will have their names placed on a special CD to fly on *Cosmos 1*, the first solar sail flight, which will take place late this year. This is truly a once-in-a-lifetime opportunity to be an integral part of a pioneering mission of exploration.

For more details on the *Cosmos 1* solar sail mission, including information on the CD of member names, please visit the solar sailing section of our website at *planetary.org*.

*—Monica Lopez,*
*Web Marketing Coordinator*

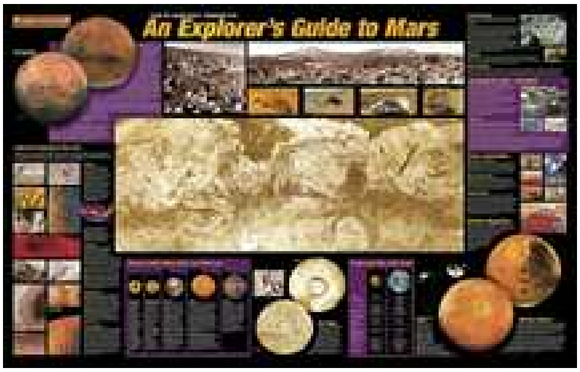
## Discover the Galapagos Islands

*November 15–25, 2003*

Join Society members as The Planetary Society explores the Galapagos Islands, November 15–25, 2003! The 11-day trip offers an exceptional opportunity to see the wildlife, plants, and geology of one of the most exceptional places in the world. Galapagos was also one of the sites used to introduce astronauts to features they might encounter on Moon landings.

We will travel for eight days on board M/V *Santa Cruz*, one of the finest vessels in the Galapagos fleet. We will also swim with sea lions; explore the historic city of Quito, a UNESCO World Heritage Site; and swim, snorkel, and bask in the sun on one of the world's ultimate journeys! The trip fee starts at $3,495 per person plus airfare. For information, phone (408) 252-4910, fax (408) 252-1444, or e-mail *Kristi@betchartexpeditions.com.*

# A CLOSER LOOK AT MARS




**An Explorer's Guide to Mars Poster**
Images from *Mars Global Surveyor*, speculative paintings of the Red Planet's past and future, informative captions and charts, and images of Mars' surface from the *Pathfinder* and *Viking* spacecraft enhance a detailed US Geological Survey map.
24" x 37"  1 lb.  **#505  $15.25**


**Mars in 3D Poster**
Put on your red/blue glasses and step onto the Martian surface, where Mars *Pathfinder* still rests today. Red/blue glasses included.  12" x 39"
1 lb.  **#306  $13.50**


**Carl Sagan Memorial Station T-Shirt**
This T-shirt displays the triumph of Mars *Pathfinder's* July 4, 1997 landing with a color image of the undeployed rover on the Carl Sagan Memorial Station. Adult sizes: M, L, XL, XXL
1 lb.  **#581  $16.75**

***Pathfinder* Images of Mars**
This collection features some of the most notable *Pathfinder/Sojourner* images, including the color panorama and images of *Sojourner* at work.
20 slides.  1 lb.  **#215  $7.50**

**Panoramic View of Mars Poster**
10" x 36"  1 lb.  **#328  $13.50**

**"Is Anybody Out There?" Poster**
16" x 39"  1 lb.  **#320  $13.50**

**Future Martian T-Shirt**
Child sizes: S, M, L
1 lb.  **#565  $13.50**

**"Is Anyone Out There?" T-Shirt**
Adult sizes: S, M, L, XL, XXL
1 lb.  **#586  $19.95**

**Pale Blue Dot Poster**
This poster features Carl Sagan's timeless words and the full frame of the profound image captured by *Voyager 1*.  12" x 30"
1 lb.  **#326  $10.00**

**Explore the Planets Poster**
34" x 22"  1 lb.  **#310  $11.50**

***Winds of Mars* and the Music of Johann Sebastian Bach**
This audio CD features digitally simulated sounds of the winds of Mars heard between 17 of Bach's finest compositions, played on piano. Liner notes explain the production of the Martian sounds and offer a general history of Mars exploration.
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**Solar System in Pictures**
Nine 8" x 10" mini-posters. Each includes detailed information and a scientific description of the planet.
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***Cosmos 1* Team Jacket**
Adult sizes: M, L, XL
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***Cosmos 1* T-Shirt**
Adult sizes: S, M, L, XL, XXL
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1 lb.  **#695  $3.00**

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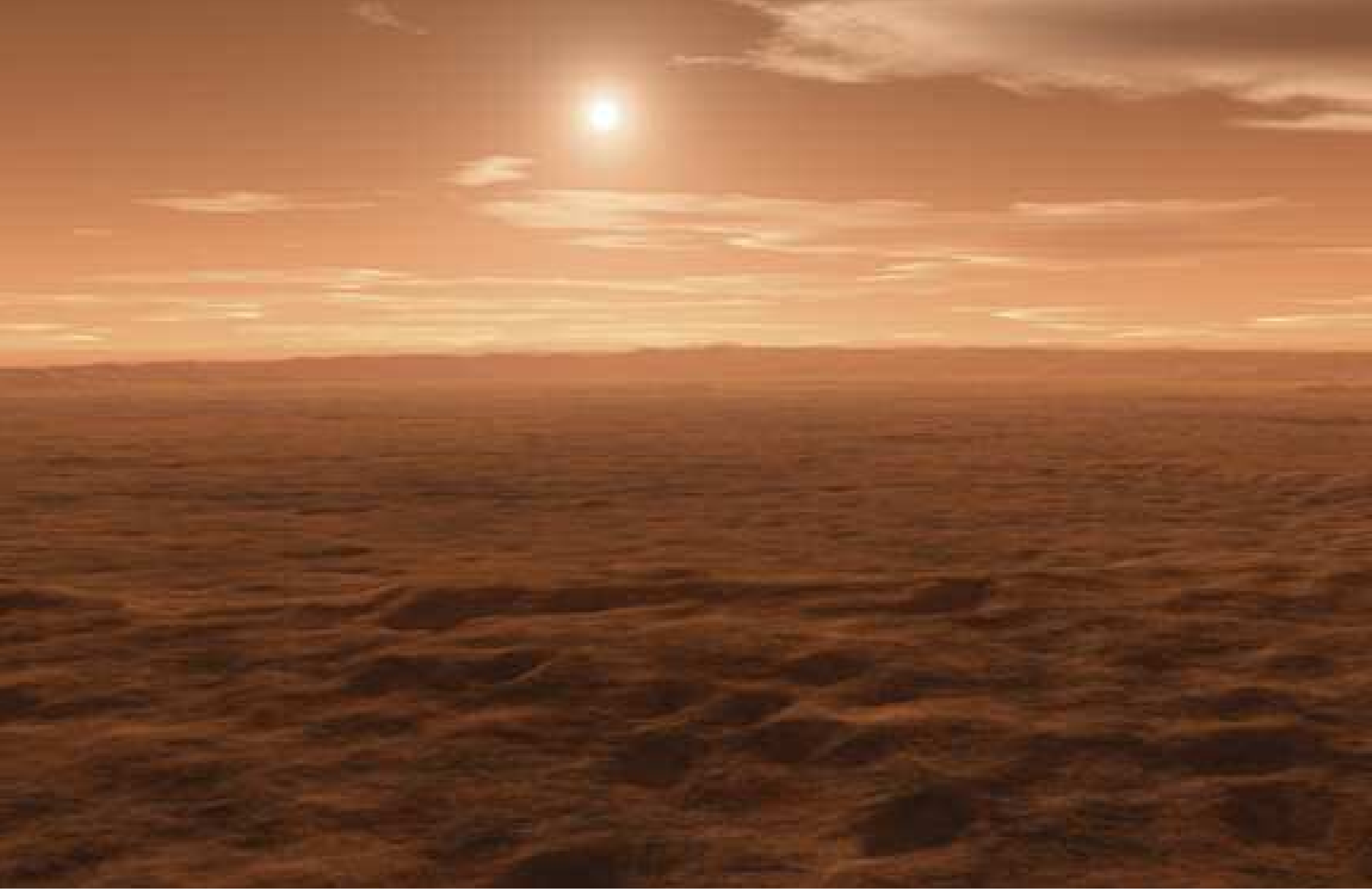

*Sunrise Over Gusev Crater* depicts the dawn of a new Martian day in more ways than one. Somewhere on this crater floor, the *Mars Exploration Rover* will be busy examining rock samples and searching for evidence of water. Rick Sternbach created this computer-generated landscape using data from the Mars Orbiter Laser Altimeter on board *Mars Global Surveyor*. This view is from about 3 kilometers altitude, looking east across the crater toward the higher-elevation walls of Gusev.

Rick Sternbach has been a space artist since the early 1970s, with interests in both traditional painting media and computer graphics. His clients include NASA, *Sky & Telescope, Smithsonian, Astronomy,* and Time-Life Books. His media credits include *Solaris*, the *Cosmos* series, and 15 years as senior illustrator on *Star Trek*. He is a founding member and Fellow of the International Association of Astronomical Artists (IAAA) and is editor of the IAAA newsletter, *PULSAR*.


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PRINTED ON RECYCLED PAPER

Printed in USA