Rover-driving scientists eager to "follow the water" on Mars next year are struggling with the tightening constraints of safety-conscious engineers

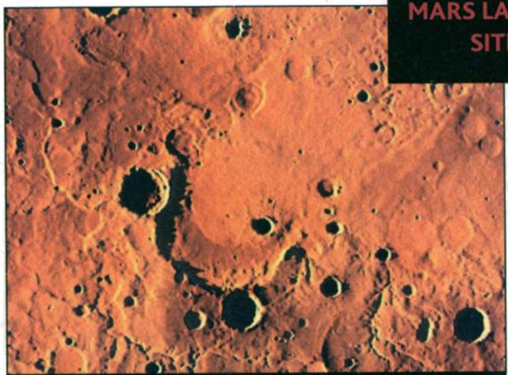
Safety Versus Science On Next Trips to Mars

ARCADIA, CALIFORNIA—The sound of huge posters peeling off the walls and flopping to the floor might have been a warning. The planetary geologists filling a hotel meeting room here near the Jet Propulsion Laboratory (JPL) had come to recommend two sites on Mars where the engineers of JPL should set down instrument-laden rovers in January 2004 on the next leg of NASA's program to seek out the planet's potentially life-supporting water. The scientists had duct-taped posters around the room portraying their six favorite potential landing sites—from what may be the exposed roots of ancient hot springs to a chasm harboring bizarre "fried egg" structures that make any geologist salivate.

But JPL engineers were warning the scientists that the proposed landing sites had more problems than mere duct-tape failure. There was a real danger, they announced, that of the four sites under final consideration and two backups, only one would prove safe enough to risk a $300 million landing attempt. Although the scientists had already narrowed down 185 possible sites to four, the engineers warned that they had better start looking around for more safe places. Finding ones that are safe but not geologically boring was up to them. After 3 full days of discussion, the geologists had no choice: They made no final recommendations and began looking for alternative sites.

There has always been tension between maximizing the chances for a successful landing on another planet and pursuing the most enticing science. An engineer's ideal landing site would be smooth, flat, and featureless. Geologists, on the other hand, love rocks. They naturally gravitate to boulders, cliff faces, and mountainsides. In the past, safety has largely dictated planetary landing site selection, including the three successful U.S. landings on Mars and most of the Apollo landings on (and takeoffs from) the moon. The engineers told the scientists what it would take to get there in one piece, and the scientists chose among the meager possibilities.

TOP FOUR PROSPECTIVE MARS LANDING SITES



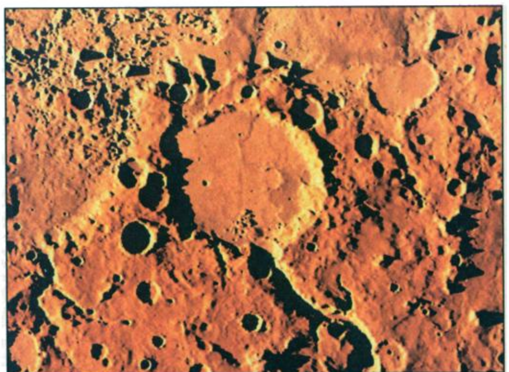
Site #1: Terra Meridiani (hematite site)
Pros: Hematite mineral could mark site of early martian life
Cons: Practically perfect but for some possible wind

The two Mars Exploration Rovers (MERs) scheduled for launch in mid-2003 seemed different. Well into the landing site selection process, limitations imposed by spacecraft design and the martian environment still allowed a variety of intriguing geologic targets. That is, until the engineers took a closer look. "Fear is the great motivator," MER landing site engineer Mark Adler of JPL told the workshop in late March. And the stakes are high: MER will be the first attempt at a Mars landing after two failures at Mars, and it's a central part of a 15-year Mars exploration program. "We knew there are no perfect landing sites, [but] there are new data on the [martian] environment that bring all the sites into question," Adler said. "The more we learn, the more we get scared. I'm concerned if we don't consider new sites, we may not end up with two acceptable sites." Mars scientists are concerned that they may have to go to a "big, flat, ugly, and boring" site, as JPL geologist Matthew Golombek, co-chair of the MER landing site steering committee, described possible alternative sites.

Limits of bouncing to Mars

Getting down to four plus two sites proved to be a fairly straightforward application of site-selection procedures developed for the landing of Mars Pathfinder in 1997 (*Science*, 19 April 1996, p. 347). The MERs will arrive on Mars bouncing across the landscape cocooned in airbags, the same way the spectacularly successful Pathfinder lander did. At the time, this approach—a bulletlike atmospheric entry, a parachute descent, a 20-meter drop to the surface, and 2 kilometers of beach-ball action—seemed like a Rube Goldberg engineering demonstration unlikely to be repeated. But after the Mars Polar Lander mysteriously failed in its classic sci-fi approach of landing on the flaming tail of big retrorockets and three legs (*Science*, 10 December 1999, p. 2051), NASA went back to its successful Pathfinder approach.

Although the more robust airbag landers can go where no Viking-style lander has gone before, they have their limits. The elevation of the landing site can't be too high or the parachute won't grab enough atmosphere to slow the lander. That eliminates almost all of the ancient highlands that cover most of the martian southern hemisphere. The slope of the land can't be too steep or the airbag-encased lander could have a dangerously long drop from its parachute or fail to fire its small retrorockets before impact. That rules out landing anywhere near the geologist-magnet slopes of a large impact crater or chasm wall. And rocks can still be a problem: If they're more than half a meter

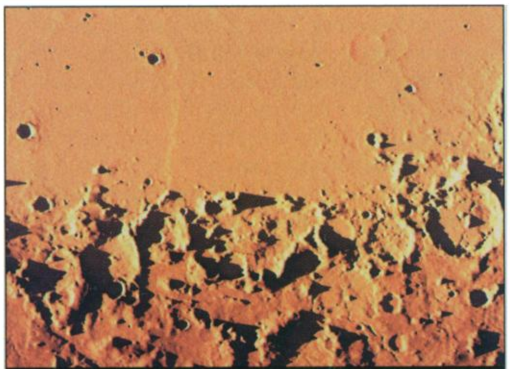


Site #2: Gusev Crater
Pros: An ancient lakebed where signs of life may be found
Cons: Access to sediments not assured

CREDITS: KEES VEENENBOS

high, they could rip the airbag, so the lander must avoid areas more than 20% covered by rocks. These include tempting places where water erosion has scattered debris.

Landing aside, the MERs impose their own limitations. Energized by sunlight, they must operate in a sunny 20° band of latitude near the equator or risk an energy crisis. Rovers wouldn't like plowing through deep dust, nor would geologists want to scrape off obscuring dust to get a look at rocks, so dusty regions of the dust-laden planet are out.



Site #3: Isidis
Pros: Strewn with ancient rocks possibly weathered in early warm and wet climate
Cons: Possibly windy

What remained after this whittling down of landing site prospects was small—perhaps 10% to 15% of the planet—but still interesting. Geologically enticing prospects included Terra Meridiani (where orbital surveys detected the possible hot spring mineral hematite), several former crater lakebeds, water-washed chasms or canyons, and canyon outflow debris deposits. But the engineers weren't finished. Mission navigators can't guarantee delivery to a specific spot. They can only promise, with a certain probability, that the lander will come down within a long, narrow target area, the landing ellipse. Positioning landing ellipses is a great deal like fitting a cookie cutter on the dough while excluding any imperfections.

The cookie-cutter exercise eliminated an early favorite of the geologists, the former crater lake Gale and its well-exposed layered sediments, because the roughly 20 kilometer by 160 kilometer ellipse wouldn't fit in without including overly steep crater walls. The landing ellipse also presents a problem for the Athabasca site, currently one of the backups. One of the top four coming out of the previous workshop, it was bumped down when Earth-based radar showed extreme roughness in that area, making roving likely impossible. But that roughness is probably confined to the lava flows at either end of the landing ellipse, not in the intriguing central channel, which was swept in recent geologic time by waters gushing from the great crustal cracks of Cerberus Fossae (*Science*, 30 November 2001, p. 1820).

Might the engineers ease off on the size of the landing ellipse? geologist Alfred McEwen of the University of Arizona in Tucson inquired without much hope. McEwen is the leading proponent of the cramped Athabasca site. Landing ellipses as drawn are "3 sigma" size, promising a 99% chance of landing within them, he noted. Might not a 2 sigma ellipse suffice? In a word, no, replied Adler. A 99% ellipse is "baseline" that offers a "safe" landing, he said.

Push comes to shove

The geologists might have been feeling a bit cramped, but the real bad news was yet to break. The weather expected at the sites under consideration was looking iffy, the engineers reported. In particular, the proposed Melas Chasma site, which geologist Timothy Parker of JPL called the "best landing site on Mars" because of its weird "fried eggs" terrain that may have formed beneath 3 kilometers of water, would in all likelihood be too windy for an airbag landing. Winds kicked up by the midday sun would blow down the canyon at up to 50 kilometers per hour, according to new computer simulations.

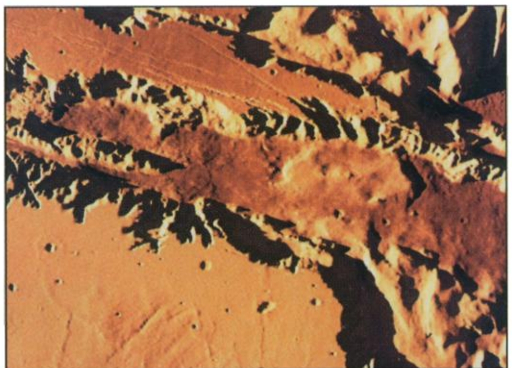
"Winds are now more of a concern than rocks and slopes," observed Adler. "Melas is definitely not safe by this [criterion]," said engineer Wayne Lee of JPL. Both Gusev and fellow contender Isidis, just inside a great impact crater on an apron of ancient rocks washed down from the highlands, are "probably on the borderline," said Lee. Even the hematite site—as flat and featureless a place as anyone has found—is now suspect. There's no topography there to help stir higher winds, but its relative darkness could mean extra solar heating and strong afternoon churning of the atmosphere.

Ironically enough, the weather problem has cropped up because the engineers were told to address another safety concern. When Mars Polar Lander disappeared without a trace, it could send no word back about what went wrong; radio communication was impossible once it entered the atmosphere. NASA was determined not to let that happen again. But to have communications from the spacecraft during entry, parachute descent, and landing, the landing site must be visible from Earth for direct radio contact. That dictates a midafternoon landing, the warmest, windiest, most dangerous time of day on Mars. The Pathfinder landed at 3 a.m. Mars time, about the quietest time of day, but no one was thinking much about the effect of wind on the airbag landing system back then. Now engineers are running some of the first fine-scale simulations of martian weather ever made.

Given that such cutting-edge, and rather uncertain, weather modeling was threatening to wipe out all the interesting sites, one geologist asked whether the requirement for communications during entry, descent, and landing might be relaxed, at least for one site. In a word, no, replied MER project manager Peter Theisinger of JPL: "Your discussion is biased by [thinking] the spacecraft will work, mine by [thinking] it won't. … I would love to push the envelope, [but] we are in a completely different game from Mars Pathfinder." Moreover, he warned, "the fear factor will only increase [as we move] forward."

Taking stock

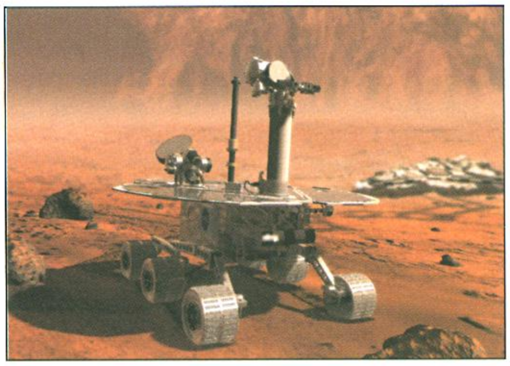
The mounting safety concerns gave workshop scientists pause. "I'm really worried there aren't any safe sites," said Melas Chasma advocate Parker. "We may have no choice but to eliminate [all] sites and go to the moon." No one laughed. The enticing geology of Melas Chasma, more than once referred to as "the scary site," had been ruled out by high winds, but it also has 40-meter cliffs and offers a 50–50 chance of landing on boring sand dunes. Backup Eos Chasma suffers from similar problems. The other backup, Athabasca Vallis, looks less promising now given the uncertain prospect of finding interesting flood deposits even if the lander avoids the impassable lavas and finds the channel.



Site #4: Melas Chasma
Pros: Geologic variety possibly formed beneath a lake
Cons: Unacceptably windy; steep slopes; sand dunes abundant

The rock-strewn fields of Isidis may or may not be swept by winds falling off the highlands (the computation-intensive modeling has yet to be done), but workshop partic-

CREDITS: KEES VEENENBOS



On the move. A Mars Exploration Rover checks out the local geology in an artist's dramatic version of the ideal landing site.

ipants found a full range of other safety concerns, from big rocks to steep slopes. More of a worry, perhaps, might be the uncertain scientific payoff in looking there for rocks altered in Mars's early warm and wet climate; at an early landing site workshop, only one scientist recommended Isidis as a site, whereas 14 voted for the hematite site.

At the end of this workshop, Gusev crater ended up a distant second to the hematite site. All agreed that Gusev held a deep lake early in Mars history, but many wondered out loud whether a rover on the crater floor—limited to its 600-meter roving range—would see anything more than a vast and vastly boring plain rather than the outcrops of exposed sediment layers that geologists yearn for. The accessible surface might even just be volcanic ash blown into the crater.

With Eos, Melas, and possibly Athabasca knocked out, Gusev and Isidis uncertain, and only the hematite site an apparent winner, participants left with plenty of work to do. Fortunately, project engineers had already convinced themselves that each spacecraft would have enough fuel to delay final commitment to specific landing sites until early next year. They also will be working on a system of small, horizontally firing rockets that could help the descending lander compensate for strong winds.

The geologists, reluctantly, are looking farther afield. "Hematite is still the favorite by far," says Golombek, but he and others are considering four new possibilities, including ones that would exceed the latitude and elevation limits. The safest of the safe might be deep in Isidis basin where the European Beagle 2 lander is targeted, away from slope winds and rocks. "No one is very excited scientifically about" that area, says Golombek. More than once during the workshop, geologists called the Beagle site "boring" because it lacks an obvious scientific target. Planetary scientist Philip Christensen of Arizona State University in Tempe called it "crummy." He noted that less wind seems to mean more dust on the surface, and judging by surface brightness, which varies with the amount of dust, the interior of Isidis is dusty indeed. "You don't want to go there," he concluded.

But scientists will have to consider going to boring but safe places, if only to show NASA headquarters that going to scientifically exciting sites would be worth the risk. They'll also have to get more duct tape.

–RICHARD A. KERR

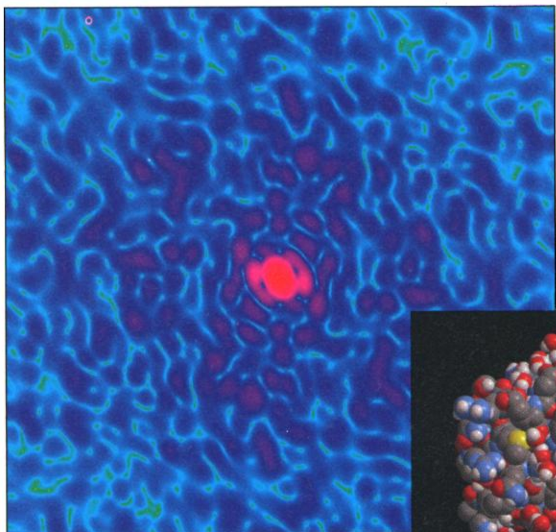
PHYSICS

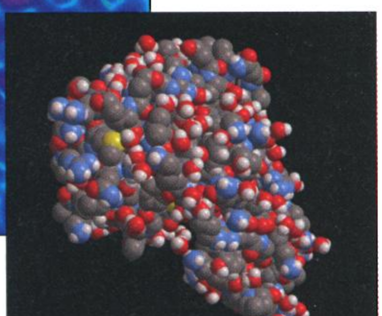
The Ultimate Bright Idea

Physicists think they can make an x-ray source 10 billion times brighter than today's best, opening new horizons in biology, chemistry, materials science, and physics. But to do it, they have to pull off a grand trick without mirrors

Some researchers are never satisfied with what they've got. In the past 2 decades, physicists have perfected the art of extracting intense beams of x-rays from synchrotrons—huge ring-shaped accelerators with circumferences of about a kilometer. Such synchrotron x-ray sources have revealed the structures of thousands of proteins, probed the intricacies of materials such as high-temperature superconductors, imaged tiny creatures only a millionth of a meter long, and advanced frontiers in a wide range of research fields. Yet even before they'd completed the latest synchrotrons, physicists dreamt of far brighter sources. Now, after a decade of planning, they are preparing to build their dream machines, x-ray sources 10 billion times brighter than synchrotrons. And to it make it possible, they're reinventing the laser.

The machines are known as x-ray free-electron lasers (X-FELs), and they promise to reveal the structures of the most recalcitrant molecules, make movies of individual atoms bonding, and produce a state of matter similar to that found in the centers of planets. And that's just for starters, says physicist Stephen Milton of Argonne National Laboratory in Illinois: "There will be revolutionary experiments that we haven't even dreamt up yet that will be done on such a machine."





X-ray portrait. Scattered X-FEL photons (simulated above) might enable researchers to reconstruct individual molecules such as this lysozyme (*right*).

An X-FEL is far from most people's image of a tabletop laser, however, so those dreams come with a hefty price tag. An X-FEL consists of a linear particle accelerator a kilometer or more long that produces an exquisitely groomed beam of electrons. The beam from the "linac" shoots through an elaborate 100-meter-long array of tightly spaced magnets called an undulator, the magnetic fields of which cause the electrons to move from side to side and emit x-ray photons (see figure, p. 1009). If the undulator and the electron beam are tuned just right, the photons and wriggling electrons will interact to generate an unprecedented blast of x-ray laser light. Building the entire rig from scratch could cost as much as a billion dollars, so two groups are looking for a way to put one together on the cheap.

Physicists at DESY, Germany's particle physics lab in Hamburg, plan to build an X-FEL alongside the lab's proposed particle physics collider, dubbed TESLA. By sharing parts and technology with the bigger machine, the DESY X-FEL should cost a relatively thrifty \$470 million and could start cranking