Roosevelt argues, however, that averaging is inappropriate for a cave floor that was repeatedly occupied for 1200 years, as it wouldn't point to the beginning of the occupation, but the middle. The average date also ignores the stratigraphy at the site, says Roosevelt. The oldest dates came from stone tools and burned seeds at the bottom of the earliest layer of the floor, while more recent dates came from artifacts just above them. And the oldest seeds produced a cluster of six dates contemporary with Clovis, with standard deviations ranging from 135 years to 300 years, which is less than the error bars on many dates from Clovis sites.

An argument over a rough 700-year spread may seem like splitting hairs, but that split is the difference between saying the people of Monte Alegre were among the first Americans themselves or descendants of the Clovis people. Haynes says: "My bias is they are descendants of Clovis." Those centuries may have been enough time for the Clovis settlers to move south, changing their tool kits and diet as they adapted to new terrain, he says. And there is archaeological evidence that people who made points similar to Clovis made it as far south as Panama, perhaps as early as 11,000 years ago, says Temple University archaeologist Anthony Ranere.

Other archaeologists, however, think that Haynes is cutting things too close. Even though Tankersley supports the younger dates for Monte Alegre, he says that Roosevelt's site is the latest in a series that shows humans using diverse tools and displaying diverse behavior at too early a time to be derived from the Clovis tradition. New technologies, he says, take more time to develop. Differences in tool kits found at sites in North and South America—including Hell Gap, Wyoming, Mill Iron, Montana, and Monte Verde, Chile—support the idea that there was more than one group of Paleoindians in America during this general period and that their ancestors may have come over in a different wave from that of the first Clovis people. Roosevelt agrees: "This is not Clovis. We haven't got the whole story. Something else was going on."

Although archaeologists may disagree about the initial occupation of Monte Alegre, they do concur that the cave adds other important details to the prehistory of the Americas. "This shows there were people living in the tropical rain forest before agriculture," says Gustavo Politis, an archaeologist at the University of La Plata and the University del Centro de la Provincia de Buenos Aires. For decades, many scientists thought no one could live in the jungle before agriculture because there wasn't enough starch in the plants to give them the calories they needed to survive. But the site shows that the people of Monte Alegre had a rich and varied diet from gathering fruit and nuts, fishing, and hunting animals in the forest. And over time, their descendants became increasingly sophisticated at surviving in the forest, setting up fishing villages on the shores of the river, developing pottery, and cultivating trees and crops on the uplands.

This cultivation, over thousands of years, has had an effect on the forest itself. "What's exciting about this is that it shows humans have been changing the forest from early on," says Dincauze. The clustering of plants, such as cashews, Brazil nuts, and certain palms, in parts of the forest today may be the result of prehistoric human activity, says Tulane University anthropologist William Balée. The so-called "virgin" forests of Amazonia may, in part, be the product of human hands.

–Ann Gibbons

PLANETARY SCIENCE

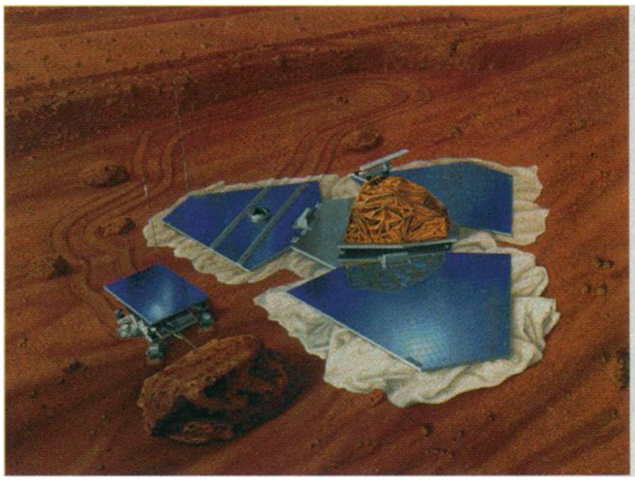
Gambling On a Martian Landing Site

Call it an exercise in anxiety. In a little over a year the Mars Pathfinder mission will land a small roving robot on Mars, giving planetary scientists their first close-up look at the Martian surface in 20 years. Unlike the Viking missions of the 1970s, done in costly style with two lander-orbiters, Pathfinder is arriving alone on a bulletlike trajectory. That leaves one chance to get the choicest scientific data about the planet's surface—and one chance to lose the entire mission if the lander falls on a steep slope or on a large rock. Last month, after two-and-a-half years of balancing considerations of scientific interest and safety, the Pathfinder project scientists finalized their choice of a landing site.

The effort was "fairly daunting," says Pathfinder project scientist Matthew Golombek of the Jet Propulsion Laboratory in Pasadena, California, who headed the selection process, and not just because so much is riding on the choice. "We just don't have any direct information on what the site looks like on a meter scale, which is what you're interested in for landing," says Golombek, despite 20 years of analysis of data from the Viking orbiters and landers. "It's terribly frustrating. So what you use is a suite of remote-sensing tools that let you infer something about the surface."

These inferences have led the Pathfinder team to a spot called Ares Vallis, where billions of years ago a huge flood burst from a narrow channel. What the probe will find there, team members hope, is a flat plain strewn with a geological treasure-trove of rocks from Mars's early days—but not so many rocks that they will endanger the lander. If the team has struck the right balance of prudence and curiosity, they will be richly rewarded. The craft might even encounter signs of now-vanished life. If they're wrong, they'll pay in lackluster data or a failed mission.

The design of the mission, the first in a series of landings and orbital observations whose ultimate goal is to return a bit of Mars to Earth in 2005, gave the researchers some severe constraints to start with. To be launched this December, the quarter-billion-dollar Pathfinder mission belongs to NASA's Discovery program, a series of "smaller, faster, cheaper, better" missions to the planets. Once it arrives at the red planet, "cheaper" will make for a thrill-packed descent: Instead of relying on expensive retrorockets to brake it to a soft landing, as the Vikings did, Pathfinder will streak into the upper atmosphere like a meteor, unfurl a parachute, briefly fire three small solid-rocket motors, and then free-fall the last 12 meters to the surface cushioned by airbags. The parachute is supposed to slow its speed from 1450 kilometers per hour to 155 kilometers per hour, but for the parachute to generate enough drag to do its job, the landing site has to be at a low altitude, where the atmosphere is thickest.



JPL

If all goes as planned... Roving robot will emerge from the Pathfinder lander, which rests on deflated air bags.

That took much of the planet out of the running, and other considerations eliminated most of the rest. The Pathfinder lander and its bread box–size robotic rover, nicknamed Sojourner, both rely on solar panels for generating electrical power. When the lander arrives next July, the sun will be strong enough to generate enough power only in a narrow band of latitude, between 10°N and 20°N. Add to that the requirement that high-resolution Viking observations be available for a candidate site, and "there are only four tiny little spots on Mars you can land," says Golombek.

He and his colleagues set to work deciding which of the four would be safe but scientifically interesting. Rocks—their size, type, and number—would be crucial to meeting both requirements. "The preference among scientists is to look not at soil but at rocks," explains Golombek. At the same time, he adds, rocks "are exactly what you don't want too many of" when Pathfinder makes its final drop onto the surface—especially not rocks roughly a meter in diameter, the size that could rupture Pathfinder's airbags.

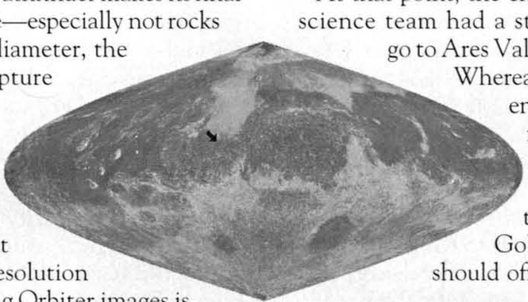
But the site selection group had no way of knowing for sure what kind of terrain awaits at each site. The best resolution in 20-year-old Viking Orbiter images is just 30 to 40 meters. Hopes of getting a sharper view from the Mars Observer orbiter, which would have provided images at 1.5-meter resolution, faded with the demise of that spacecraft in 1993 (*Science*, 3 September 1993, p. 1264). And although another potential source of detailed images, Mars Global Surveyor, will be launched at about the same time as Mars Pathfinder, carrying spare instruments left over from Mars Observer, Surveyor will take a longer route and won't arrive until months after Pathfinder.

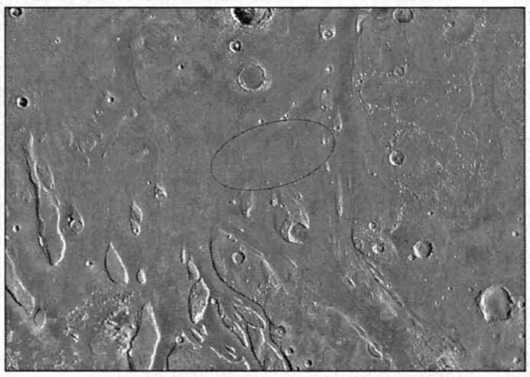
That left Golombek and his colleagues with no choice but to fall back on indirect clues to the character of the surface—its color, for example, and Viking Orbiter measurements of its thermal inertia. How quickly the Martian surface warms at dawn or cools at dusk depends on how much of the surface is covered by rocks rather than dust. A layer of loose dust acts like insulation, slowing the rate at which heat is conducted downward from the surface, so it warms and cools quickly; a rocky surface is much slower to change temperature.

As the researchers applied such strategies, two of the spots began to fall out of the running. One looked distinctly dustier than the others, says Golombek, and its elevation was a little high as well. The other site lost out because of its color in Viking Orbiter images, he says. Its rock surface appeared to be heavily weathered and oxidized, which would obscure the unaltered rock that geologists want to analyze.

The remaining two sites had to pass another test—examination by Earth-based radars. Pathfinder will be carrying a radar altimeter that will determine the split-second timing required for air-bag inflation and retrorocket firing. If the altimeter failed to get a strong radar reflection from the surface, as Earth-based radars do from a few "stealth" areas on Mars where thick dust may be absorbing the signals, Pathfinder would be in trouble. Exceptionally rugged terrain could also fool the altimeter, not to mention rough up the lander and present formidable obstacles for Sojourner. Earth-based radar cannot directly image hazardous cliffs and scarps, but it can give an indirect measure of the slope steepness, based on how reflections vary with viewing angle. Both sites passed these radar tests, appearing reflective enough and not too rugged.

At that point, the choice was easy. "The science team had a strong preference to go to Ares Vallis," says Golombek. Whereas the other site, an enigmatic knobby terrain of unknown origin, struck many people as "scientifically boring," says Golombek, Ares Vallis should offer a smorgasbord of rock types washed down in the great flood from the highlands to the south. "If we're fortunate, we could characterize a huge part of Mars—how it formed, what the early environment was like—all from landing at a single point."





JPL

Bullet's target. Pathfinder will aim for a great flood's outwash plain (arrow, *top*; 200-kilometer ellipse, *bottom*).

Nevertheless, says Golombek, the flood plain "is not the safest site" of the four considered. The thermal inertia data from the Viking orbiters suggest that the Ares Vallis site is about 20% covered with rock, several times more than some of the other candidate sites. By combining that rock coverage with the range of rock sizes at the Viking lander sites and at sites of catastrophic flooding on Earth, the group estimated that rocks larger than 0.5 meter cover about 1% of Ares Vallis. "That's lots of rock but not as bad as it can get on Mars," says planetary geologist Larry S. Crumpler of Brown University, who has recently been studying the geology of the Viking lander sites. "You'd have to be pretty unlucky" to hit a mission-ending boulder in Ares Vallis, agrees Golombek.

But even after a safe landing, the site may prove disappointing, says Raymond Arvidson of Washington University in St. Louis, a prominent planetary geologist who was imaging team leader for the Viking Orbiter extended mission. Volcanic eruptions may have transformed the flood plain beyond recognition, burying the diverse rocks that the selection team is banking on, he says. "I have a bet with Matt Golombek that he won't be able to tell [the Pathfinder site] from the Viking Lander 1 site," which Arvidson considers to be the remnants of a lava field. Kenneth Tanaka of the U.S. Geological Survey in Flagstaff, Arizona, disagrees: The features that Arvidson believes are lava flows are actually flows of debris from the time of the great flood, he says. But Tanaka concedes that in general, orbital geology leaves "a lot of room for interpretation; there's a lot of ambiguity."

Another worry is that the dust that the team tried so hard to avoid in its site selection may be inescapable. "It's hard to imagine a place as dusty as Mars is," says Crumpler. "Everything is coated with fine, flourlike dust. It could be a problem." Adding to the concern is something Arvidson has noticed in Viking Lander images: The sun glints off the rocks whenever it is low in the sky behind them.

At first that suggested a glossy coating like the "desert varnish" found on rocks in arid regions on Earth, but in recent weeks Arvidson has examined images with a low sun shining from the other direction—behind the lander camera—and found an exceptional brightening. Only a dust coating, not a glossy varnish, could create both effects, says Arvidson. Rocks at both Viking Lander sites show the effects, so Arvidson expects the same dust coating will turn up on the rocks of Ares Vallis as well. If so, Sojourner's elemental analyzer could end up determining the composition of a uniform coating of globally distributed Mars dust rather than a diversity of rock types.

Golombek agrees that there's room for disappointment: "If all the rocks on Mars are weathered or dust covered, that's what you'll measure." But as with all the other geologic pitfalls his team has considered, "we won't know until we get there."

–Richard A. Kerr

Additional Reading

Mars Pathfinder World Wide Web Page at http://mpfwww.jpl.nasa.gov/

E. A. Guinness *et al.*, "Specular scattering from rock surfaces at the Viking Lander sites," *Lunar Planet. Sci.* **XXVII**, 471 (1996).

M. Golombek, "Mars Pathfinder landing site selection," *ibid.*, p. 429.