MEETING GEOLOGICAL SOCIETY OF AMERICA

Geologists Take a Trip To the Red Planet

TORONTO—When more than 5000 geologists gathered here on 26 to 29 October for the annual meeting of the Geological Society of America, a highlight was Mars. The latest data from the Mars Global Surveyor lend credence to an early ocean, a new view of data from Mars Pathfinder questions whether Mars had plate tectonics, and lab work suggests a new, definitive test for life on Mars.

Mars Ocean Holds Water

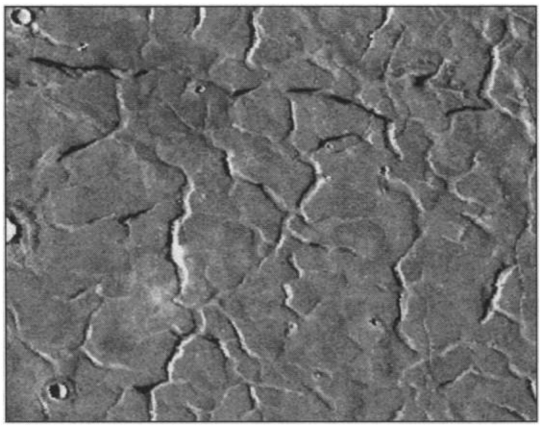
Many proposed parallels between our own planet and Mars have come and gone—canals, intelligent Martians, maybe even martian bacteria. But one putative similarity has survived a first test by the Mars Global Surveyor spacecraft: an ancient ocean on Mars.

It has long been accepted that water gushed out of the martian highlands a couple of billion of years ago, through massive channels that are still visible today. Many researchers argue that after reaching the northern lowlands, the water dispersed before it could get very deep. But some think repeated flows pooled there to form an ocean covering one-quarter of the planet before eventually seeping into subsurface deposits or evaporating and escaping to space. And so far, data sent back by Surveyor—which has been orbiting the planet since September 1997—are consistent with this provocative picture.

"I was very skeptical when I started," says Surveyor team member James Head of Brown University in Providence, Rhode Island. But after measuring the altitude of supposed shorelines, the smoothness of plains that would once have been ocean floor, and the volume of the basins, "I was surprised to see all three were consistent with predictions [of an ocean]. I don't know the answer, but it's tremendously exciting." Not everyone is caught up in the excitement, however. Planetary geologist Michael Carr of the U.S. Geological Survey (USGS) in Menlo Park, California, is still "very skeptical of the whole ocean business," saying it's unlikely that the water gushed out quickly enough to form an ocean. "There has been a tendency with Mars, if there's a simple solution versus an outrageous one, to choose the outrageous one because it's more interesting."

The outrageous possibility got a boost when Head and his Brown colleagues did three different analyses of data from the Mars Orbiter Laser Altimeter (MOLA) aboard Surveyor. One was straight altimetry—determining topography by timing a laser pulse's round trip from the spacecraft to the surface and back. That let the group test a proposal made by planetary geologist Timothy Parker of the Jet Propulsion Laboratory (JPL) in Pasadena, California, who back in the mid-1980s identified features in the northern lowlands as the shorelines of now-vanished oceans. One ocean seems to have filled the lowlands to the brim, while a later one only partly filled the depression. If the shorelines are real, the height of each one should be the same at every point.

A first look at the MOLA data suggested that the higher shoreline undulates too much to be real. But although MOLA showed that the altitude of the lower shoreline also fluctuates, mostly over a range of about 500 meters, it may have been perfectly uniform once. When the researchers removed the great bulge of the Tharsis volcanic region, which presumably pushed up the shorelines after the ocean had emptied, the altitude fluctuations fell, especially for the smaller ocean. Planetary scientist Bruce Banerdt of JPL and Parker reported similar results at the meeting.



Sea dregs? An ocean might once have filled a low spot in the northern lowlands, shown in a Viking image spanning 80 km.

Head's second test compared the roughness of the surface inside and outside the shorelines. In the Mars ocean scenario, sedimentation would have smoothed the lowlands. MOLA had already shown that the northern lowlands are as smooth at the 100-meter scale as the abyssal plains on the floor of Earth's oceans, and on a larger scale they are flatter than any other known surface in the solar system (*Science*, 13 March, p. 1634). New MOLA data show, according to Head, that the smoothness is greatest inside the lower shoreline.

In a third test, Head used MOLA data to calculate the volume of water needed to fill the northern lowlands up to each shoreline. The smaller ocean would have required only about three times the minimum amount of water thought to have flowed from the channels, he found—a plausible amount. "So far, we think the three pieces of data from the MOLA are consistent with the hypothesis of Parker," says Head, at least for the smaller ocean. "None of the three tests is unequivocal; they're just consistent."

Consistency isn't enough to convince Carr. Head "is doing the right thing," he says, but the results so far don't solve a serious problem: getting enough water into the lowlands all at once to make an ocean and keeping it from freezing solid. Many researchers now think that early Mars was too cold for standing bodies of water.

At the meeting, planetary geologist Alfred McEwen of the USGS and his colleagues noted that other processes could explain at least one oceanlike feature: the smooth lowland plains. They presented new Surveyor images of Elysium Planitia and Amazonis Planitia, two areas that lie between the two shorelines. Researchers who saw the images said they showed convincingly that Elysium and Amazonis are covered by vast fields of lava, which could account for their smoothness. "Here, it's clear the flat topography has to be due to the lava," says McEwen. "Flat topography itself is not evidence for an ocean."

McEwen is quick to add that the lava fields don't rule out an ocean, either. But "everything needs more analysis," he says. That will come next spring when Surveyor, after numerous delays, finally settles into its intended orbit close to the planet. Once it gets an even closer look, the outrageous ocean hypothesis should stand or fall.

Life's Iron Mark

To study life in the distant past, researchers rely on fossilized bones and shells. But fossils are rare, so scientists have also developed a more subtle method to detect signs of life: analyzing isotope ratios. Living things preferentially take up the lighter isotopes of carbon and oxygen, for example, leaving a "fingerprint" of life in the rock record even when no tissues have fossilized. At the meeting, geochemists added a powerful new element to their isotope fingerprint kit: iron.

Geochemists Brian Beard and Clark Johnson of the University of Wisconsin,

CREDIT: JPL/NASA

Madison, announced that they could detect bacteria's effect on iron isotopes, a fingerprint that appears to be unique to life and difficult to erase. "People have been looking more than a decade" for an iron isotopic effect, because it could be a more reliable indicator of life than carbon and oxygen isotopes, notes geochemist Richard Carlson of the Carnegie Institution of Washington's Department of Terrestrial Magnetism. "I think they've actually found one finally." Already, researchers have used iron to confirm life's role in shaping mysterious eons-old rocks, and it holds promise for tackling questions ranging from life's role on the early Earth to its possible presence on Mars.

Scientists realized decades ago that organisms would preferentially take up the lighter, rarer iron-54 over the more common iron-56 when filling their energy or other nutritional needs. And because of iron's great weight, factors such as temperature weren't expected to alter the isotopic fingerprint, as happens with carbon and other light isotopes. But iron is notoriously difficult to analyze. The very act of heating the sample to drive the iron into a mass spectrometer, for example, preferentially drives off the lighter isotopes, leaving the analyst to sort out how much of the light-isotope enhancement is due to life and how much to the machine.

Beard and Johnson finally overcame that hurdle, in part by spiking some samples with a mix of two isotopes—5% iron-58, which is only a trace component in natural samples, and 95% iron-54. By determining how much the machine skewed the proportions of these isotopes, they could correct for instrumental effects and accurately gauge the ratio of iron-56 to iron-54 in the original sample. When they analyzed an ultrapure iron sample, they reduced the analytical error by a factor of 10 from previous analyses, to ±0.25 parts per thousand (per mil). Exactly the same ratio turned up in a variety of terrestrial and lunar rocks formed from magma. "Iron isotopes just aren't fractionated by the inorganic processes" that form such igneous rocks, concludes Beard.

Life, it turns out, is a different matter. Microbiologist Kenneth Nealson of the Jet Propulsion Laboratory in Pasadena grew bacteria that use iron locked up in the mineral ferrihydrite as an energy source and then release it in soluble form. He found that the dissolved iron had 1.2 ± 0.25 per mil less iron-56 than the mineral it came from. The iron of manganese nodules from the sea floor—thought to have grown over millions of years with the help of bacteria—was similarly depleted in the heavy isotope, Beard found. He also studied a banded iron formation—a finely layered deposit of iron ore whose origin may have involved life. He found that alternate, light-colored layers are isotopically heavier, possibly due to seasonal blooms of bacteria. If the isotopic composition of any sample departs from that of magma-derived rocks, he concludes, "it probably means that iron was processed biologically."

"What they've done is great," says geochemist Ariel Anbar of the University of Rochester in New York. "It's devilishly difficult to do, but it could be a really powerful tool." Applied to some of Earth's oldest rocks, it could confirm hints from carbon isotopes that life was flourishing as long as 3.8 billion years ago. Iron isotopes in sediments laid down during the mass extinctions of 250 million and 65 million years ago could shed light on the biotic collapse in the oceans suggested by carbon isotopes. Iron should provide a new "biomarker" to be checked in any rocks that humans return from Mars. And the method may be able to detect the signature of life, if any, in the tiny iron oxide grains in martian meteorite ALH84001, which a few researchers argue were formed by bacteria. Settling that debate—Beard and Johnson's original goal in developing the method—would surely earn its keep.

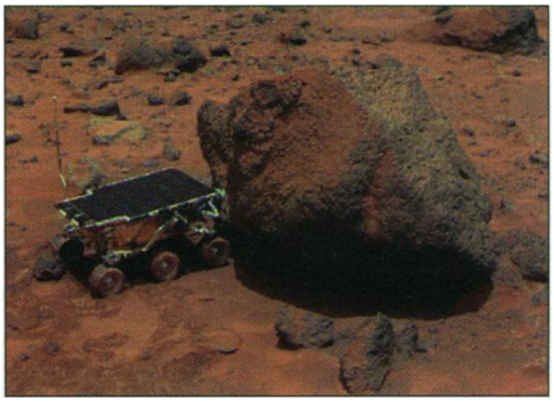
Mars Rock Not So Earth-like

When the Mars Pathfinder rover sent back word last year that some rocks on the Red Planet resemble volcanic rock from our own Andes, researchers wondered whether the similarity was a sign of a much deeper geologic kinship (*Science*, 1 August 1997, p. 638). Andesites, as they are called, form in volcanoes fueled by tectonic plates as they plunge into Earth's interior. So might Mars have had drifting plates at some time, too?

Planetary geologists were intrigued but uneasy, because Mars has no obvious signs of past plate tectonics. Now they've come up with a more pedestrian scenario for the origin of the Pathfinder rocks: that they were cooked up in the dying days of an ordinary volcano. "We haven't proved anything," says planetary petrologist Harry McSween of the University of Tennessee, Knoxville, "but we think this is a more plausible explanation than some early ideas."

Plate tectonics came up in early discussions because Pathfinder rocks turned out to be about 62% silica—the element silicon combined with oxygen—compared to the average of 45% to 50% silica expected in the martian crust. On Earth, rocks that are rich in silica form in the volcanoes of the Andes and Aleutians, which erupt over the sinking, water-laden crustal slabs of plate tectonics. The slabs' water helps distill extra silica from the rock below the volcanoes. The bit of martian andesite could have been a sign that billions of years ago, when Mars was both wetter and more geologically active, Earth-like plate tectonics shaped its surface.

But on further consideration, McSween and his colleagues find that "the best match is icelandite, not andesite." Icelandite, a volcanic rock that forms in small quantities at volcanoes like those of Iceland, Hawaii, and the Galápagos Islands, also has a high proportion of silica, making it a sort of andesite. But it has higher iron and lower aluminum abundances than Andes andesite—features also seen in the Pathfinder rocks, says McSween. The extra silica in icelandite is concentrated by the repeated cycle of melting, crystallization, and remelting experienced by magma that takes the longest possible route through a volcano late in its eruptive life—a process that does not require plate movements.



A volcano's last gasp? The rock named Yogi looks more like the last lava from a volcano than a product of plate tectonics.

CREDIT: JPL/NASA

Researchers think they have already spotted the kind of rock that could be volcanically distilled into a martian icelandite. McSween is thinking of an iron-rich basalt like the one that gave rise to the icelandites of the Galápagos, a type of rock that may have been common early in martian history. Meteoriticist Ralph Harvey of Case Western Reserve University in Cleveland has his eye on bits of magma found as inclusions in one of the chunks of Mars rock that have reached Earth as meteorites. And petrologists Michelle Minitti and Malcolm Rutherford of Brown University have cooked up something like a Pathfinder icelandite in the lab by starting with a rock matching the composition of another martian meteorite plus a bit of water.

Whatever the starting material on Mars, says Harvey, "we don't have to invoke something we have no proof of, like plate tectonics." Daniel Britt, a planetary geologist at the University of Arizona, Tucson, and a former Pathfinder team member, agrees. "You look on Mars, you see volcanism everywhere," he says, and icelandite "is what you'd expect in the last gasp of a volcano."

–RICHARD A. KERR