Oddities Both Lunar And Martian

HOUSTON—Earlier this month, planetary scientists with a particular affection for the rocky or icy bodies of the solar system met for the 31st Lunar and Planetary Science Conference. Talks touched on the man in the moon, putative martian microbes, and putting a squeeze on Mars.

Man in the Moon's Birth

For planetary scientists, the man in the moon is more than folklore; he is a conundrum. Why, they ask, did almost all of the dark lavas that outline the profile erupt on one side of the moon? The farside is a blank slate nearly devoid of dark lavas. At the meeting, geophysicists Marc Parmentier of Brown University and Shijie Zhong and Maria Zuber of the Massachusetts Institute of Technology (MIT) described how the interplay of lunar mineralogy and geophysics could have focused volcanism on one side of the moon. "There have been detailed mineralogical models, but they didn't link to the geology," says planetary geologist James Head of Brown. This approach "links plausible models for the thermal evolution of the moon with what we see on the surface." And if it's right, the new approach would solve several other lunar enigmas as well.

Planetary scientists began noticing these oddities as soon as the first spacecraft revealed the near absence of dark lava "seas" or maria on the moon's farside. Then analyses of mare rocks returned by Apollo astronauts showed a late start for the main pulse of volcanism that painted the nearside figure. Instead of beginning in the moon's first couple of hundred million years, when an ocean of magma remained beneath a thin crust, the volcanism set in a half-billion years later and went on for a billion years. And the minerals that had melted to yield these mare lavas had formed near the top of the solidifying magma ocean but somehow had sunk about 500 kilometers before melting. Then Lunar Prospector confirmed that vast subsurface deposits of a chemically distinctive rock, known by its acronym, KREEP, lie beneath the region of most abundant mare lavas but not elsewhere.

The flip side. There is only one man (or woman) on the moon, on its nearside *(top)*.

CREDIT: USGS/NASA

A plausible account of the man in the moon's birth would probably have to incorporate these lunar quirks in a single mechanism, Parmentier and his colleagues realized. The most obvious driving force was the unstable layering of rock left by the magma ocean. A light scum formed a crust on the cooling magma, while denser minerals crystallized one by one and sank to the ocean bottom. But minerals don't necessarily crystallize in the order of density; some of the densest minerals—a mix rich in ilmenite and pyroxene—would have crystallized late, forming a thin layer right under the crust near the end of ocean freeze-up.

Parmentier and his colleagues suggest that this so-called ilmenite cumulate could have slowly sunk from shallow depths through the rock beneath it, like a stone through a plum pudding, draining the still-lingering molten KREEP with it down hundreds of kilometers. Enriched in radioactive elements whose decay generates heat, the KREEP could have slowly raised the temperature of the ilmenite cumulate to the melting point and produced the needed lavas hundreds of millions of years later.

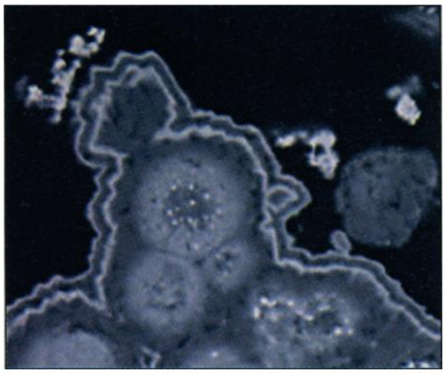
But why did these rocks melt on only one side of the moon? To answer that, the Brown-MIT researchers considered the viscosity of the moon's interior. If an outer layer of the young moon was at least as viscous as the rock beneath it, the ilmenite cumulate would sink downward in fingers all around the moon, not just on one side. But, calculated the researchers, if heat from the KREEP had softened the upper ilmenite layer until it had 1/1000th the viscosity of the rock beneath it, small fingers couldn't sink into the resistant lower layer. Only an expanse of the upper layer as broad as the width of the moon could penetrate the lower layer. This broad downwelling would drain KREEP and upper layer material from around the moon, giving the one-sided concentration of heat. As for why the man faces Earth, no one really knows.

The one-sided sinking explanation for the man in the moon got a cautious reception at the meeting. "I think what Parmentier is doing is reasonable," says geophysicist Roger Phillips of Washington University in St. Louis. "It's the first time somebody has attempted a quantitative model." As the first, it's getting its share of critical attention. "I have a great deal of difficulty seeing how" less viscous, weaker rock could be layered over stronger rock, says petrologist Timothy Grove of MIT. Warming of the upper layer could easily go too far and melt some of it, decreasing its density and preventing its sinking, he says. Planetary physicist David Stevenson of the California Institute of Technology in Pasadena has more philosophical reservations. "It's a possible but not a particularly convincing argument," he says. "There's no natural reason to expect the large change of viscosity with depth that they need." "There are uncertainties," concedes Zuber. "We aren't claiming we've found 'the' answer. This is a step in the right direction." The man in the moon still has a secret.

Martian Microbes Déjà Vu?

Almost 4 years ago, microscopic bits of minerals found in a meteorite from Mars leapt onto front pages around the world as possible signs of ancient life on another planet. The excitement faded, however, as it became obvious that none of the evidence clinched the case for life (*Science*, 20 November 1998, p. 1398). Now, researchers have cast more doubt on the data: They have cooked up much the same minerals in the laboratory with nary a microbe in sight. Many in the field see the work as a confirmation of what they've long suspected. "It all fits so well with what we see [in the meteorite] that I can't believe what happened on Mars was very different" from the lab experiments, says meteoriticist Ralph Harvey of Case Western Reserve University in Cleveland. But the fit is not yet perfect, leaving a slim opening for martian life.

Geologist David McKay and his colleagues at NASA's Johnson Space Center (JSC) in Houston built the case for traces of life in martian meteorite ALH84001 on four pillars: mineral shapes that look like fossilized bacteria, traces of organic matter, globules of minerals resembling some produced through bacterial action, and grains of a magnetic mineral similar to those produced by bacteria. The McKay group has since conceded that the buggy-looking minerals are likely artifacts or are too small to be intact bacteria. And the organic matter—called polycyclic aromatic hydrocarbons—turns out to be ubiquitous in the solar system, from soot to the inorganically produced primordial goo of meteorites. The globules of concentrically layered carbonate minerals spiked with the sulfide mineral pyrrhotite were more enticing but hardly definitive either; they could have been made by a sequence of mineral-laden groundwaters flushing rock fractures on Mars, critics said.



Echos of Mars. Layered carbonates made in the lab bear a strong resemblance to those in a martian meteorite.

The one potential mineralogical trace of former life that still held some appeal was tiny grains of the iron-oxide mineral magnetite concentrated in the rims of carbonate globules in fractures of ALH84001. Some of the magnetite grains resembled in size and shape those made by terrestrial bacteria as magnetic compasses. No one had ever reported finding inorganically produced grains that size and shape, but soil mineralogist D. C. Golden of Hernandez Engineering and JSC and his JSC colleagues—all in the same JSC division as the McKay group—decided to find out if it could be done.

First, Golden and his colleagues made the carbonate globules by heating bicarbonate solutions mixed with rock chips to 150°C. The bicarbonate decomposed, and carbonate deposited in the fractures of the rock chips. To get the ringed look of the meteorite globules, they changed the solution composition in four steps, as martian groundwater may have changed composition. Finally, they reproduced the heating that ALH84001 appears to have suffered after the globules formed, perhaps from a meteorite impact. That decomposed iron carbonates into the required magnetite and pyrite into pyrrhotite. In the end, "we were able to produce minerals very similar chemically and mineralogically to those in 84001," says Golden's colleague, soil mineralogist Douglas Ming of JSC. In particular, the magnetite produced by iron carbonate decomposition falls in a tight size range of about 35 to 60 nanometers, almost identical to the size range of bacterial magnetite.

SOURCE: D. C. GOLDEN *ET AL.*

Golden and his JSC colleagues conclude that "it is possible to synthesize carbonate globules quite similar to those of ALH84001 by simple inorganic processes that may have occurred on early Mars." "They did an outstanding job showing you could produce these globules," says mineralogist Adrian Brearley of the University of New Mexico, Albuquerque, who originally suggested carbonate decomposition as the magnetite source 2 years ago.

But the case for traces of life in ALH84001 isn't dead yet. "We've shown a potential inorganic formation," says Ming. "What we haven't done yet is show that our magnetites look biogenic." Since the McKay group first focused on one subset of magnetites as possibly biogenic, microscopist Kathie L. Thomas-Keprta of Lockheed Martin and the McKay group has looked again at ALH84001 and identified mineralogical and chemical characteristics beyond size and shape that match those of bacterial magnetite. Golden and his colleagues haven't reached a similar level of detail in characterizing their experimental magnetites. But in the meantime, many researchers are following Brearley in applying Occam's razor and concluding that ALH84001's magnetites "are all produced by the [inorganic] mechanism."

Punching Up Mars

Mars, it seems, has been beaten up by more than asteroid and comet impacts. Geophysicist Roger Phillips of Washington University in St. Louis and his colleagues reported at the meeting that the weight of the solar system's most massive volcanic outpouring not only puts a dent in one side of the planet but also pushes up the opposite side. These planetary distortions, it now appears, redirected the flow of massive amounts of water early in Mars history that carved large areas of the planet.

Planetary scientists have known since Mariner 9's arrival at Mars in 1971 that the Tharsis region, spanning more than 10 million square kilometers centered on the equator, weighs heavily on the planet. Built by eons of volcanic outpouring, Tharsis sports three massive volcanic shields rising higher than 10 kilometers above the mean elevation; mighty Olympus Mons rises 22 kilometers above its base. Earth's tallest volcano, Mauna Kea, stands only 9 kilometers above the sea floor. Geophysicists could calculate how much the whole pile of volcanics should depress the planet beneath it, but spacecraft had returned only the most rudimentary topographic data to test how well those calculations hold up. Now the Mars Global Surveyor (MGS) laser altimeter is giving them highly accurate data to work with.

When Phillips and his colleagues placed the mass of Tharsis on a 15-year-old computer model of Mars, it depressed the surface at least several kilometers over much of the western hemisphere of the planet. The MGS topography confirmed that this, indeed, occurred. But in a variant of every action having an equal and opposite reaction, the model showed that the region antipodal to Tharsis, called Arabia Terra, should be lifted up by a few kilometers. That's like punching your fist into a balloon—albeit a very stiff one—and having the far side bulge outward, says Phillips. That prediction was also borne out: MGS gravity and topographic data recently indicated that Arabia Terra had been uplifted, although the data couldn't show why.

"It's an incredibly simple model that works with almost no assumptions," says Phillips, "and it explains details all around the planet." Geophysicists such as David Stevenson of the California Institute of Technology in Pasadena tend to agree that Phillips's modeling is giving plausible results. For geologists, it's also "a reasonable hypothesis," says planetary geologist James Head of Brown University. "It's exciting to think about the implications for such a large part of the planet." For one, the planetary bulging seems to have hijacked Arabia Terra from the northern lowlands and made it, at least topographically, part of the southern highlands. As a result, geologists can see the original lowlands crust that is elsewhere covered by sediment or lavas. The uplift also explains the abrupt termination of ancient erosional valleys that trace the flow of water off the highlands more than 3 billion years ago: The rising land turned back the flow.

Around Tharsis, the ring of low ground had its own geological effects. It appears to have directed the flow of water during much of martian history, says Phillips. Great floods drained through it on the way to the northern lowlands, cutting huge outflow channels. The larger buried channels proposed on the basis of MGS gravity data (*Science*, 10 March, p. 1727) also pass through the Tharsis ring, presumably carrying the huge amounts of sediment that MGS altimetry is now showing were removed from the region. "All this happened very early in the history of Mars," says Phillips. "We're learning that the magnitude was tremendous."

–RICHARD A. KERR