Martian 'Microbes' Cover Their Tracks

Researchers analyzing tiny putative microbes are finding it surprisingly hard to prove or deny past life on the Red Planet, but hope a wide net of studies will yield results soon

HOUSTON—The topics at the annual Lunar and Planetary Science Conference (LPSC) are usually strictly nonbiological. This year, however, some tiny traces of putative life muscled all the rocky planets, asteroids, and even Galileo's stunning views of Jupiter's icy moons from center stage. From a tangle of battling journal papers, talks, press releases, and hallway scuttlebutt, the planetary scientists who gathered here were trying to make sense of the extraordinary proposition published last August in *Science*: that a meteorite from Mars contains traces of ancient life on the Red Planet.

Since then, a dozen or so research groups have searched for clues to temperatures at which the potato-sized meteorite's minerals formed and puzzled over tiny "nanofossils" that might be analogous to terrestrial bacteria. At the LPSC, the conflicting findings dueled to a stalemate. To the authors of the original paper, that was good news. "I've been very pleased that in the 7 months since our paper [was published], we have not had a showstopper," says geochemist Everett Gibson of NASA's Johnson Space Center in Houston, who with David McKay of JSC and others argued in the *Science* paper that the best explanation of the evidence from meteorite ALH84001 was that life existed eons ago on the Red Planet. "We feel stronger about those conclusions now," says Gibson. But by meeting's end, most others were less sanguine, arguing that life on Mars has gained little support from other groups.

Although some research suggests that the tiny carbonate globules at the heart of the debate formed in an environment conducive to life, fine-scale measurements of isotope ratios have found hints of high temperatures—too high for life—when the microbes were supposedly at work in the rock. And crystals of an iron mineral, magnetite, also seem to require high temperatures—and may even be masquerading as the putative microbial fossils.

After hearing all this and much more, attendees asked by Timothy Swindle of the University of Arizona to put a number to "the chances that the features identified by McKay *et al.* are the results of martian life" were barely lukewarm in their support: The median of the 120 written responses was a mere 20%. Yet, few are ready to write off the idea entirely. "Anyone who tells you they know the answer is probably overstating their case," says isotope geochemist John Valley of the University of Wisconsin, Madison.

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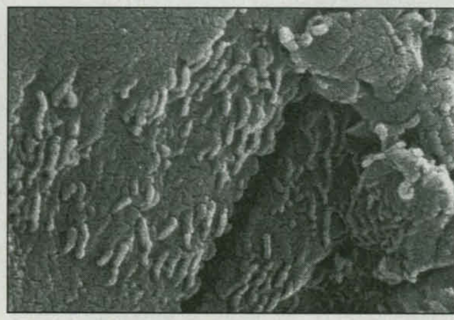

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Microbe or magnetite? Linear magnetite grains *(above)* look suspiciously like putative martian "nanobacteria" of similar size *(right)*.

Each of the five lines of evidence in the *Science* paper has plausible biological and inorganic explanations, and proving one or the other has turned out to be surprisingly difficult. In part, that is because the nanometer-scale mineral grains mixed in with the putative fossils had more complex histories than expected. Add that to the analytical problems of working with very tiny structures—"this sample is pushing the envelope," as Valley puts it—and in hindsight it seems clear that no one should have expected a decisive verdict so soon. But the LPSC debates do suggest how a new look at the putative nanobacteria might settle the issue—perhaps within the next year.

Magnetite mysteries

Because LPSC is a gathering of physical scientists, the iconic images of putative "nanofossils" got little airing, although two wall-size murals did hang in the conference center's lobby. Instead, much of the discussion centered on two lines of evidence that illustrate how hard it is to prove whether the minerals associated with the fossillike features originated in living processes or dead geologic ones.

One such potentially biogenic mineral was magnetite. McKay and his colleagues had found innumerable grains of this iron oxide, measuring about 50 nanometers across, within the 50-micrometer globules of carbonate called rosettes. Impressed by the grains' resemblance in size, shape, and crystalline regularity to magnetite produced within some terrestrial bacteria, the researchers argued that bacteria also produced the meteorite's magnetite—martian bacteria, that is. But late last year, John Bradley of the Georgia Institute of Technology, Ralph Harvey of Case Western Reserve University in Cleveland, and Harry McSween of the University of Tennessee countered that argument. In Harvey's words, "We did find the kind of magnetite described by the McKay group, but we also found a whole zoo of different [shapes] of magnetite."

In their view, this diversity of shapes points to an inorganic formation that also produced grains resembling biogenic magnetite by chance. What's more, the group said, many of these forms contain crystal defects characteristic of a high-energy environment—temperatures greater than 500°C.

At the meeting, the JSC group and its supporters tackled this argument but couldn't quite make it go away. Paleomagnetician Joseph Kirschvink of the California Institute of Technology noted that biogenic magnetite comes in a wide variety of shapes and has defects too, at least when bacteria alter their environment and so induce magnetite to form outside, rather than inside, the bacterial cell. But at the meeting, Harvey highlighted a particular defect called a "screw dislocation"—an offset of one or more atomic layers formed as the crystal grew—that has never been linked to biogenic magnetite. "The defects we're showing are not minor defects," he says. "That's going to be a very hard issue for them to overcome."

In a potentially even more damning line of attack, Bradley, Harvey, and McSween argued that the JSC group's putative "nanobacteria" are nothing more than grains of magnetite. They have analyzed ALH84001 with transmission electron microscopy for a year and seen nary a nanofossil—but have found many linear "whiskers" of magnetite that strongly resemble the "nanofossils" in size and shape, says Harvey. The JSC group, using scanning electron microscopy (SEM) and a different sample preparation technique, has found no whiskers, admits Kathie L. Thomas-Keprta of Lockheed Martin in Houston—raising the possibility that a whisker seen in SEM looks like a "nanobacterium."

And this is one question that may be answered in the coming months: Thomas-Keprta announced that she has developed a technique for plucking a single "nanobacterium" from the rock and slicing it open. Such a look inside one of structures should settle whether it is merely magnetite or not.

Turmoil over temperature

A plethora of papers at the meeting examined another troubling issue: the temperature at which the carbonate rosettes formed. That is relevant because McKay's team suggests that although the rosettes weren't produced by microbial metabolism, the bacteria altered the chemical environment in such a way as to induce carbonate formation. And assuming martian microbes had the same heat tolerance as earthly ones, that process must have happened at temperatures below about 115°C. Cosmochemists thought it would be straightforward to learn the formation temperature, because it affects both isotopic ratios and chemical composition.

Before the meeting, however, estimates of the formation temperature of ALH84001's carbonate were all over the map. McKay and colleagues cited a low-temperature estimate made in 1994 by one of their co-authors, Christopher Romanek of the Savannah River Ecology Lab in Aiken, South Carolina. He measured the ratio of oxygen-18 to oxygen-16 of the meteorite's total carbonate. At higher temperatures, the carbonate would have picked up less oxygen-18; Romanek concluded from the higher ratios he measured that it formed below 80°C. But in July 1996, just before the *Science* paper was published, Harvey and McSween studied the abundance of magnesium, iron, and calcium in the carbonates—and concluded that they formed above 650°C.

Now, new chemical and isotopic data presented at the LPSC and in recent papers challenge the assumption behind both results. Both groups had assumed that fluids carrying dissolved elements from the meteorite's dominant mineral, orthopyroxene, had undergone thorough chemical exchange with the carbonates; in other words, that the carbonate was in chemical and isotopic equilibrium with the rest of the meteorite. New evidence showed that it wasn't—and opened the way to a new set of conflicting temperature estimates.

On the low-temperature side is isotope geochemist Valley. "We've not found evidence for equilibrium in this sample," he told the meeting. "There is instead rampant disequilibrium." By blasting atoms from the carbonate with a 30-micrometer-wide beam of ions and running the ionized atoms through a mass spectrometer, Valley found a range of oxygen-isotope compositions of 11.5 to 20 parts per thousand, as he and his colleagues reported in the 14 March issue of *Science* (p. 1633). If the carbonates had been in equilibrium with surrounding rock, they would have had the same isotopic composition wherever they were analyzed. That means that they formed either at low temperatures or too quickly to reach equilibrium. Valley favors low temperatures because the delicate alternation of magnesium-rich and iron-rich carbonates across the rosettes seemed unlikely to have formed rapidly. A companion paper by Kirschvink and others (p. 1629) found that two mineral grains retained magnetic field orientations and therefore also suggested fairly low temperatures.

At the meeting, members of a team led by Laurie Leshin of the University of California, Los Angeles, reported that when they analyzed their own sample of ALH84001, they found an even wider range of oxygen-isotope compositions. In addition, isotopic variations correlated with variations in calcium composition, something Valley couldn't see because his rice grain–size sample didn't contain the full range of carbonate compositions.

That correlation over a wide range of compositions suggests a very different interpretation to Leshin—a high-temperature origin. "We have a couple of possibilities for environments" under which the carbonates could have formed, she said, and both make life quite unlikely. In one, mineral-laden water flowing through the rock deposited the carbonates, and their composition varied as the temperature swung by up to 250°C. In the other, pockets of trapped fluid—mostly carbon dioxide, an unlikely place for life—deposited carbonate whose composition varied as deposition depleted the fluid.

This latter scenario dovetails with an earlier talk by Edward Scott, Akira Yamaguchi, and Alexander Krot of the University of Hawaii. Based on inspection of the micrometer-scale distribution and composition of mineral grains in the meteorite, they suggested that the shock of an impact—which all agree ALH84001 felt more than once in its existence—melted small parts of the rock and injected the resulting fluid into impact-induced cracks. Within seconds, the melt would have crystallized into the carbonate seen today without the least bit of life being involved.

This display of dueling isotopes and temperatures left the LPSC audience torn, and few partisans were persuaded to change sides. Asked what he made of the burgeoning isotopic debate, Harvey replied: "I'm confused, in a very happy way," given that the more data, the better. To help end the confusion, researchers also plan to analyze isotopes of carbon that might constrain temperatures further. If LPSC attendees learned one thing from the give-and-take of the meeting, it was that it will take a broad web of evidence—chemical, mineralogical, and microscopic—to yield a decisive yea or nay on whether ALH84001 holds signs of past life. NASA is now preparing to divvy up the meteorite to more researchers to open the way to the broad-based attack that might finally yield a verdict.

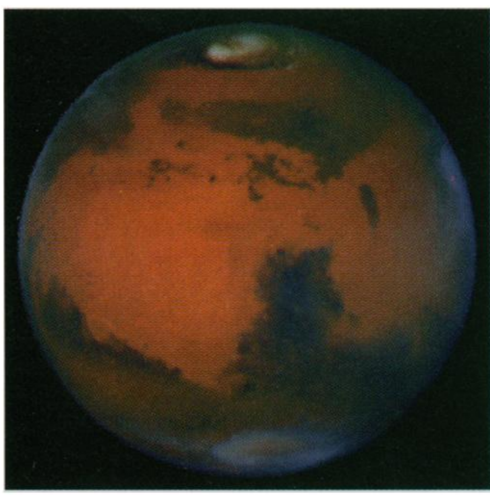
–Richard A. Kerr

Additional Reading

For extended abstracts of the 37 LPSC talks on martian meteorite ALH84001, see URL http://cass.jsc.nasa.gov/lpi/meteorites/lpscabs.html

MARS IMAGES

One fine day on Mars. The Hubble Space Telescope took its sharpest image ever of the planet Mars last month. Astronomer David Crisp of the Jet Propulsion Laboratory in Pasadena, California, and his colleagues acquired the Hubble image on 10 March in part to scout out what the Pathfinder spacecraft will find when it lands on Mars on 4 July. A martian dust storm could play havoc with the Pathfinder lander and the small rover it will place on the surface, both of which depend on full sunlight falling on their solar power panels. As northern hemisphere spring begins on Mars, however, the Hubble's Wide-Field Planetary Camera-2 revealed nary a dust storm in sight. White clouds made of water-ice shroud the giant impact basin Hellas near the bottom of the image as well as several great volcanoes on the right. Meanwhile, NASA officials have given the go-ahead to two robotic missions to the Red Planet in 2001; the robots will do some science but will also scout out conditions, such as radiation levels, of vital interest to any future human visitors. **–R.A.K.**



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