Ancient Life on Mars?

A meteorite has yielded evidence—but not proof—of ancient life on Mars. The claim has excited skeptical fascination among scientists but has made no converts so far

Earth-invading aliens will haunt television screens this fall when the networks air knockoffs of the popular "X-Files" science fiction series. But scientists won't have to turn on the tube for their own drama featuring putative visitors from another world. Their show kicked off in a blaze of publicity on 7 August, with the early release of a paper from this issue of *Science*. It will be played out over the coming months in scientific meetings and journals as researchers debate the meaning of the findings, which appear on page 924. There, a diverse group of nine researchers from five institutions led by geologist David McKay of NASA's Johnson Space Center (JSC) in Houston argue that the best explanation for three different minerals, an organic residue, and bacteria-like structures found together in a meteorite that was blasted from the surface of Mars is ancient life on the Red Planet.

NASA

MONICA GRADY, BMNH, LONDON

Tiny, tiny Martians? In a Martian meteorite, patches of carbonate some 50 micrometers across (*right*) harbor putative fossils like this half-micrometer "tube-like structural form."

"We are not claiming that we have found life on Mars," cautions McKay. "And we're not claiming that we have found the smoking gun, the absolute proof, of past life on Mars. We're just saying we have found a lot of pointers in that direction." He adds that no one line of evidence requires their dramatic conclusion that minute bacteria flourished on Mars billions of years ago, when planetary scientists believe it was a wetter and more hospitable place. But when the evidence is taken together, "we consider that to be the most reasonable interpretation," he says. "We welcome other people looking at [the meteorite] and making other interpretations."

The few researchers familiar with the evidence before the paper was released (*Science* lifted the embargo on the paper when news of the findings leaked out) didn't need any prompting to suggest other interpretations. "I think it's very unlikely they have remnants of biological activity," says William Schopf of the University of California, Los Angeles, who has spent his career separating microfossils of early life on Earth from impostors. Nonetheless, "this is a first step; additional work needs to be done" to search the meteorite for more persuasive clues.

Others are just a bit more upbeat. "I'm not convinced," says interplanetary dust particle specialist Donald Brownlee of the University of Washington, "but I think they have made a credible case that these things could be microfossils. It's unprecedented. It's one of the most important things in science, if it's true. [Exobiology] is intellectually interesting, but without any data, it's just speculation; I think there's some data now."

The data nearly eluded researchers. Found in Antarctica in 1984, the 1.9-kilogram, softball-size meteorite that McKay, geochemist Everett Gibson of JSC, electron microscopist Kathy Thomas-Keprta of Lockheed Martin in Houston, and their colleagues studied didn't get any special scrutiny for 10 years. Meteoriticists already knew that some meteorites are actually chunks of the moon and Mars, blasted into space by large impacts (*Science*, 14 August 1987, p. 721). But the minerals in ALH84001, as it was designated, didn't look Martian at first. Only in 1994, after David Mittlefehldt of Lockheed Martin in Houston pointed out subtle similarities to known Martian meteorites, was ALH84001 admitted to the select club, which now has just 12 members.

Since then researchers have put together its life story. Radiometric dating shows that ALH84001 congealed from magma to become part of the original Martian crust 4.5 billion years ago, just 100 million years after the planet formed, making it the oldest rock known from any planet. Still early in Martian history, a meteorite impact shattered the rock, leaving fractures where minerals—including the putative traces of life—formed perhaps 3.6 billion years ago. Much later, another impact launched the rock into space. Radioactive nuclei created by deep-space radiation show that it wandered there for 16 million years before blazing through Earth's atmosphere and crashing into the Antarctic ice cap. It lay buried for 13,000 years until scientists found it on wind-scoured ice in the Allan Hills region of Antarctica.

Even after ALH84001 had been identified as Martian, it stood out. Using sophisticated laser techniques to lift and separate intact organic molecules from rock surfaces, analytical chemists Simon Clemett and Richard Zare of Stanford University and their colleagues last year found relatively abundant polycyclic aromatic hydrocarbons (PAHs) on fracture surfaces inside the meteorite. PAHs are large, complex organic molecules that are commonplace in some interplanetary dust particles, interstellar dust, and many organic-rich meteorites from the asteroid belt—the residue, it is thought, of non-biological reactions among simpler carbon compounds. To McKay and his colleagues, however, their presence in a meteorite from Mars raises the possibility of a different origin—the breakdown of organisms that once lived in the ancient rock.

That assumes that the PAHs are indigenous to the meteorite rather than Earthly contaminants. The compounds, after all, are ubiquitous on Earth, formed not only by the degradation of living things but also by power plants and automobile engines. And meteoriticists have been misled by contamination before. In the 1960s, a few researchers reported that a meteorite had yielded organic matter that appeared to have been biologically produced, along with microscopic "organized elements" presumed to be fossils. After heated polemics, it all turned out to be Earthly contamination, including degraded ragweed pollen masquerading as alien life forms.

But Clemett and his colleagues seem to have convinced most researchers that this meteorite's PAHs are not contaminants. The checks include the lack of PAHs in other Antarctic meteorites and in ALH84001's own outer rind, where it melted during atmospheric entry. The dearth of PAHs there suggests they didn't leak in from an outside source. "No one wants to repeat that episode" of the 1960s, says McKay. "We've been very careful about the data; we're confident about them."

Finding Puts Mars Exploration on Front Burner

It is rare enough for a scientific discovery with no practical applications to draw an enthusiastic response from politicians, but it is almost unheard-of for House Speaker Newt Gingrich (R–GA) and U.S. Vice President Albert Gore to agree on the need for more government spending. The startling claim that a meteorite, consisting of a chunk of Mars rock, bears evidence of ancient life has provoked just such a reaction, however: Both political leaders told NASA Administrator Daniel Goldin separately in recent days that they are willing to find more money to beef up the agency's Mars exploration effort. If that happens, the first hints of extraterrestrial life could jump-start the struggling U.S. space science program.

NASA is already starting to re-evaluate its plans for Mars exploration. Jurgen Rahe, head of NASA's solar system exploration division, says researchers planned to convene this week at NASA headquarters in Washington, D.C., to come up with a draft plan and price tag for a revamped Mars program. High on the list of topics is whether to speed up an attempt to return samples from the planet's surface by several years. That session will feed into a high-level reassessment: On 7 August, President Bill Clinton announced that Gore will organize a White House meeting before the end of the year to map out a bipartisan course for the U.S. space program and focus on the issues raised by the new findings. "I am determined that the American space program will put its full intellectual power and technological prowess behind the search for further evidence of life on Mars," he said.

Goldin told reporters on 7 August that scientists, not engineers or politicians, will shape whatever emerges from these deliberations. "We will be driven by the science process, and not by a rush to go to Mars," he promised. But the prospect of politicians unleashing a flood of new money makes some scientists uneasy. "We don't want to move too fast," says Joseph Burns, a Cornell engineer and astronomer who recently chaired the National Research Council's (NRC) committee on planetary and lunar science exploration. "We can't rush it just to get something up there." The worry is that good science could get lost in the shuffle.

In the past 2 years, space science as a whole has labored under serious budget constraints. NASA's $2 billion space science program would drop to a $1.8 billion effort under Clinton's 1997 budget request, and the decline would continue for at least 5 years under his long-term plan to eliminate the deficit (*Science*, 22 March, p. 1660). In spite of those constraints, NASA had been planning to spend about $100 million a year over the next decade to launch a series of Mars-bound spacecraft every 2 years starting this November, culminating in a 2005 flight that would return soil and rock samples to Earth. Unlike the $1 billion instrument-packed behemoths that flew in the past, the new generation consists of small spacecraft, costing about $150 million apiece, that rely on miniaturized technology. Some will feature tiny rovers crawling around a mother ship on Mars' surface, while others will circle above, mapping the planet.

This plan for stripped-down probes has won grudging approval from planetary scientists. But a report by the NRC committee chaired by Burns—which was coincidentally released on 6 August, the same day that the news about possible life on the planet broke—notes that there remain serious concerns with the Mars program. First, the cost and weight caps that had been imposed by Goldin will limit the range of the surface rovers and the data they can gather—a point that the NRC study calls "a major shortcoming" in NASA's blueprint. The panel also raises concerns about whether the Mars-bound instruments have been adequately tested, and criticizes NASA for focusing on building smaller spacecraft rather than on miniaturizing instruments as well. That could "seriously undermine" the scientific results of the missions, the NRC study finds.

If the new findings loosen the purse strings, both the rover and instrumentation problems could be eased, says Rahe. Representative Jerry Lewis (R–CA), who chairs the House panel that oversees NASA funding, says he supports increasing the agency's budget to accommodate more aggressive exploration. But Goldin warned that the pressure to reduce the deficit could force NASA ultimately to cut other programs to expand Mars efforts.

Even if new funds do emerge, there are likely to be disagreements over just how much the Mars program should be speeded up. A central part of the discussion at this week's meeting, says Rahe, was to be the pros and cons of moving up the sample return mission. While some NASA officials say a 1998 launch is conceivable, Rahe says that would require a huge and fast infusion of money, given the mission's $500 million price tag. A more likely scenario is that NASA will propose it for 2001, according to several researchers. "You need precursor missions to know where to go," says Burns. "You can't just go up and grab something and come back."

But despite those cautionary words, it is clear that the controversial Mars findings are already breathing new life into solar system exploration.

–**Andrew Lawler**

Meteoriticist John Kerridge of the University of California, Los Angeles, agrees "they've done a reasonably good job" of showing that "at least some of the PAHs are indigenous to the meteorite." But even then there are plenty of explanations for their presence that don't require life, he says. "Decomposition could certainly produce polycyclic aromatic hydrocarbons, but there are dozens of other mechanisms for making PAHs." They could have formed from simpler compounds on Mars that never evolved chemically to living organisms, he notes.

McKay agrees but offers other, independent lines of evidence to strengthen the case. One consists of the mix of microscopic mineral deposits that his group and others have mapped within fractures in ALH84001. The most abundant mineral, carbonate, forms "globules" about 50 micrometers across, which McKay and his colleagues liken to carbonate globules that others have reported forming in the laboratory and in a freshwater pond as bacteria alter the environment. In addition, they note that the larger globules have manganese-containing cores and concentric rings of iron carbonate and iron sulfides. That structure implies that the chemical environment changed as the globules were deposited, perhaps because of bacterial metabolism.

"None of this [can] distinguish between biology and chemistry," cautions Kenneth Nealson of the University of Wisconsin at Milwaukee. Nealson, whose work on bacterial carbonate precipitation is cited by McKay and colleagues, notes that warm fluids circulating through the Martian crust might have deposited the same sequence of minerals without any help from organisms. Indeed, a group led by meteorite specialist Jim Papike at the University of New Mexico analyzed grains of pyrite—iron disulfide—in the same fractures, looking for the skewed ratio of sulfur isotopes that is a signature of biological activity on Earth. They came up empty. "I don't think the McKay group should be bent out of shape" by this negative result, says Papike, "but it doesn't help them either."

But two other minerals that the group found on the carbonate globules tip the balance toward a biological explanation, McKay and his colleagues say: the iron oxide called magnetite and an iron monosulfide called pyrrhotite, both of which form particles less than 100 nanometers in diameter. The highly magnetic magnetite, for example, bears a strong resemblance to the "magnetofossils" left in terrestrial sediments by bacteria that made the mineral to guide them along Earth's magnetic field lines, says co-author and biomineralogist Hojatollah Vali of McGill University.

The sheer diversity of minerals is supporting evidence, says Vali, since the magnetite and pyrrhotite are found in regions of carbonate where acid seems to have pitted the surface. "I couldn't find any acidic conditions under which you can precipitate iron sulfide and magnetite together, whereas in biogenic systems we have many such cases," he says. Joseph Kirschvink of the California Institute of Technology agrees that the combination "definitely is peculiar," making a Martian biogenic source "not unreasonable at all."

In their most provocative claim, the authors suggest that they can actually see traces of the culprits, in the form of the "ovoids" revealed by a state-of-the-art, high-resolution scanning electron microscope. "Our favored interpretation is that these are in fact microfossils from Mars," says McKay. "That is an interpretation; we have no independent evidence."

At 20 to 100 nanometers in length, the objects are 100 times smaller than the smallest microfossils of ancient bacteria ever found on Earth, Schopf points out. McKay and colleagues cite a paper by geologist Robert Folk of the University of Texas, Austin, reporting fossilized "nanobacteria" in some young terrestrial rocks, but, in Folk's words, "everybody is pretty skeptical" that his objects are fossils. The Martian look-alikes face even greater skepticism. "The little blobs [in ALH84001] didn't convince me," says Nealson. They aren't pollen, as in the 1960s episode, but "I think you can form little blobs on rocks with all kinds of chemical precipitates."

What's lacking is evidence other than shape that these forms were once living. But McKay and colleagues are looking hard. Since the *Science* paper was completed, they have gone on to find a variety of generally elongated structures, which one observer compares to so many miniature Chee-tos. At least one of the fossils is long and apparently segmented, reminiscent of some microfossils from Earth's Precambrian era. Now Clemett and his colleagues are beginning to look for amino acids, which could be better markers of past life than PAHs. The JSC group will also try to slice open a putative microfossil to see if it has a cell wall. All Earthly bacteria have cell walls, and fossilized cell walls might retain traces of organic matter. Schopf would also like to see examples of the supposed bacteria frozen in the act of reproducing—a standard he applies to proposed terrestrial microfossils.

Don't expect this drama to be wrapped up in the next TV season. The sort of supporting evidence that would convince Schopf and other critics could be slow in coming. As Schopf quoted Cornell exobiologist Carl Sagan: "Extraordinary claims require extraordinary evidence."

–Richard A. Kerr

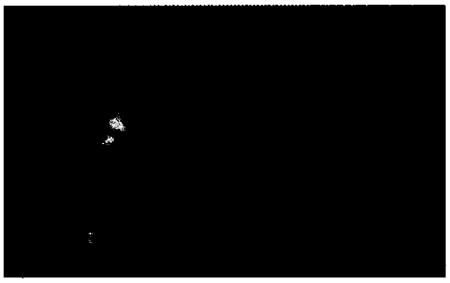
Additional information including images can be found at the NASA web site (http://cu-ames.arc.nasa.gov/marslife/index.html) and the Science *homepage (http://www.sciencemag.org).*

NATIONAL SCIENCE FOUNDATION

Panel Backs S&T Centers Program

A once-controversial $60 million program at the National Science Foundation (NSF) to support university-based centers studying multidisciplinary topics is worth preserving at its current level, says an outside panel. In a report released last week,* a joint committee of the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine finds that the 7-year–old experiment in funding "medium-size" science is producing mostly top-notch research, and it recommends that the current batch of 24 Science and Technology Centers (STCs) should be allowed to recompete for new funding. "NSF has done well by these centers," says panel chairman William Brinkman, vice president of physical sciences research at Lucent Technologies in New Jersey.

The report reflects consensus on a program begun in 1989 by then-NSF Director Erich Bloch to fund projects too risky or broad for single labs to tackle. Critics argued at the time that it would let mediocre researchers escape peer review and reduce the amount of grant money available to individual scientists, who make up the core of NSF's $2.4 billion research portfolio (*Science*, 4 January 1991, p. 19). The program never grew to the size that Bloch envisioned, however: Rather than supporting up to 100 centers, NSF eventually held two competitions and funded 25 centers on topics ranging from molecular biotechnology to high-pressure studies and astrophysical research in Antarctica. The first class of 11 centers have passed two interim reviews as part of an 11-year agreement; 13 others are now undergoing their second review (one voluntarily closed after 4 years).



M. GEUSZ/CBT

Lighting the way. A firefly gene linked to human *c-fos* promoter illuminates the skin of a transgenic mouse developed at the NSF Center for Biological Timing.

NSF requested the academy report to help it chart the future of the program, which represents roughly 2% of NSF's overall budget. In November, NSF senior managers will offer recommendations to NSF's governing body, the National Science Board.

The panel, set up by the academies' Committee on Science, Engineering, and Public Policy, found "that most STCs are producing high-quality world-class research that would not have been possible without a center structure and presence." The "center approach," the report says, is "a valuable and necessary tool in NSF's portfolio of support mechanisms." At the same time, the panel also found that some centers experienced scientific and administrative leadership problems. And it noted that one unnamed center went overboard in supporting K–12 education and outreach in response to "mixed signals" from NSF.

The panel recommends that NSF continue the current level of funding for the program and that its budget be kept distinct from the rest of NSF's research portfolio. It also says future competitions should continue to be open to all disciplines and be run out of a separate office rather than by each of NSF's seven directorates. The centers' "paramount goals," it says, should be "research and the undergraduate and graduate education linked to it."

"I'm happy about it [the report]," says Gene Block, director of the NSF Center for Biological Timing at the University of Virginia in Charlottesville. Block notes that the STC money has supplemented single-investigator grants by funding technical development projects and fostering collaboration on circadian-clock genes in plants and animals. "We really are believers in both types of support," Block says. NSF's David Schindel of the Office of Science and Technology Infrastructure agrees that the report is "very clearly positive," but adds that kind words don't guarantee the program's future in these harsh budgetary times. "Even if [the science board] feels very positively about the centers, there are competing priorities," Schindel says.

–Jocelyn Kaiser

An Assessment of the National Science Foundation's Science and Technology Centers Program, National Academy Press.