Analyses of a martian meteorite sparked a search for geological markers that record the existence of life from long ago—and perhaps from far away—but mounting failures point up the difficulties

Reversals Reveal Pitfalls in Spotting Ancient and E.T. Life

Today, life seems easy enough to recognize. Much of it is green and grows, some of it walks or slithers, and even that mold on the bathroom wall all too obviously reproduces. But a few billion years hence, what could be said about today's life? What lingering traces—a smudged imprint in rock, an oddly composed bit of organic matter, or distinctively imbalanced isotopes—might show that life existed eons before?

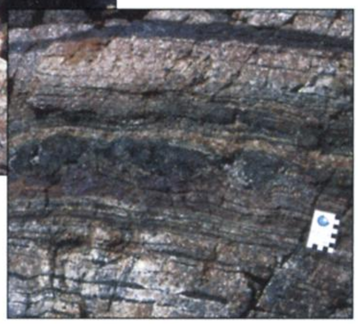
For almost 2 centuries, paleontologists wrestling with that sort of question have pushed the earliest known life back in time, first using bone and shell, then wormy squiggles in the mud and vanishingly small fossils. And in the past few years, egged on by a claim for traces of life in a 4.5-billion-year-old rock from Mars, researchers have explored new kinds of biomarkers—molecules and isotopes—in very ancient rocks. But interpreting both new and old kinds of markers has proven more complicated than many had hoped, and the results have sparked several heated debates.

In this issue of *Science*, for example, two geologists challenge a startling claim for the first signs of life on Earth: that the skewed isotopic composition of bits of graphite in rock from an island off Greenland shows that life existed 3.85 billion years or more ago, when huge, globe-sterilizing impacts were still battering the planet. The debate highlights the growing realization that as analyses become ever more high-tech, relying on tinier samples and subtler traces, it becomes more important to understand the environment in which a presumed biomarker formed. "Know the rock" is the new catchphrase.

As a result, many of the arguments over early-life claims center on geology. Researchers in paleontology and the burgeoning field of astrobiology are learning, or relearning, the lessons of geological context. Those lessons are essential not only in analyzing carbon and other isotopes but also in searching for microfossils and worm tracks on Earth and in seeking subtle biosignatures in the martian meteorite. "We had a very optimistic view of how easy it was going to be to recognize the signs of life," says meteoriticist Harry McSween of the University of Tennessee, Knoxville. "We have a lot of work to do."

A big claim from a small beginning

The latest controversy concerns a claim for the oldest signs of life on Earth. In 1996, geochemist Stephen Mojzsis, now at the University of Colorado, Boulder, and his colleagues analyzed bits of graphitic carbon from a patch of rock from the small island of Akilia, southwest of Greenland. Previous studies had suggested that the rock is a sedimentary banded iron formation (BIF) and at least 3.85 billion years old. Using an ion microprobe, Mojzsis found that 20-micrometer spots of graphite encased in micrograins of this formation were strongly depleted in carbon-13, the heavier stable isotope of carbon.



Bands of contention. The lighter stripes in this rock are either sediments with signs of earliest life or inscrutable volcanics.

At the time, that looked like a promising biosignature. Life, in particular relatively sophisticated photosynthesizing organisms, preferentially incorporates the lighter isotopes of carbon. And BIFs are composed of particles that settled to the bottom of the sea, where organic matter might collect; that carbon might have survived in the form of the graphite bits. Mojzsis and his colleagues concluded that they had "strong evidence for life" by 3.85 billion years ago—400 million years earlier than previously thought.

Such a provocative claim prompted renewed interest in the backyard-size chunk of Akilia rock. Geologist Christopher Fedo of George Washington University in Washington, D.C., and geochronologist Martin Whitehouse of the Swedish Museum of Natural History in Stockholm remapped the geology of the 2-kilometer-long island and analyzed the elemental composition of the rock in question. On page 1448, they argue that the Akilia BIF is no BIF at all. "The green bands look identical to green rocks that surround it," says Fedo. "The trace-element composition of these things looks nothing like a BIF." Instead, they see a magnesium-rich volcanic rock repeatedly kneaded by tectonic forces and injected by quartz-rich fluids to form the banding. "The layering is clearly not sedimentary," Fedo says.

Mojzsis disagrees. The Akilia outcrop isn't a classic BIF, he says, but it is a quartz-rich sedimentary rock injected by magnesium-rich magma to form the banding. Most of Fedo and Whitehouse's elemental analyses are of the intruded rock and therefore irrelevant, he says, and the rest are consistent with the quartz-rich rock—which harbors the isotopically light carbon—being sedimentary.

Despite that defense, researchers familiar with Greenland geology now tend to reject a sedimentary origin for the Akilia rock. "Fedo and Whitehouse provide strong evidence that ... none of the layering can be considered sedimentary," says geochemist Balz Kamber of the University of Queensland in Brisbane. That "suggests that the isotopically light carbon cannot be proven to be biogenic." Field geologist Minik Rosing of the Geological Museum of the University of Copenhagen says he finds Fedo and Whitehouse's arguments "very convincing."

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More contested life signs

A more tangible milestone in the record of life on Earth is the earliest known microfossil, ascribed to 3.5-billion-year-old blue-green algae in rock from Australia; their discovery was announced by paleontologist William Schopf of the University of California, Los Angeles, in 1993. But in March, micropaleontologist Martin Brasier of the University of Oxford and colleagues challenged that finding, too.

Instead of being a piece of a sunny, shallow sea floor, the siliceous rock bearing the fossils formed in the dark roots of a sea-floor hot spring, said Brasier. The microscopic squiggles therefore are not the remains of photosynthesizing blue-green algae but lifeless jumbles of organic matter, Brasier argues. Schopf admits that he got the geological context wrong, but he insists that the rock preserves some kind of hot-spring microbe, just not blue-green algae. Brasier doesn't have "the experience looking at Precambrian microfossils," says Schopf.

Two views. A microfossil (*right*) becomes a blob with more depth of focus.

Yet another landmark, the oldest sign of animals, came under attack in February (*Science*, 15 February, p. 1209). Squiggly grooves supposedly cut in mud by burrowing worms 1.1 billion years ago—half a billion years before the previous record—were redated to 1.6 billion years old. That strained credulity—especially because some researchers had begun to think that the squiggles resembled mud cracks more than worm tracks.

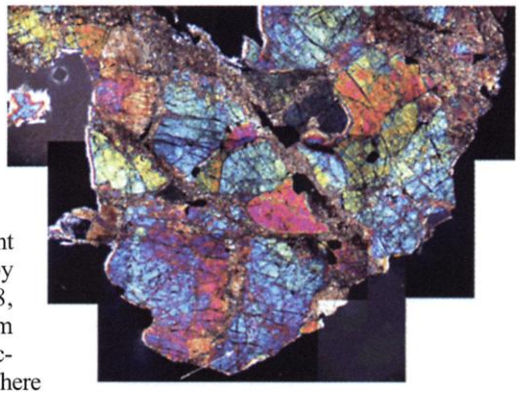
While these milestones are being questioned, another promising technique for spotting ancient life turns out to be "more complicated" than previously thought, as the technique's originator says. By a Herculean analytical effort, geochemists Brian Beard and Clark Johnson of the University of Wisconsin, Madison, had managed to measure the tiny enrichment of the light isotope of iron caused by bacteria (*Science*, 4 December 1998, p. 1807); inorganic processes didn't seem able to do it. But it turns out that this fractionation isn't a definitive sign of life. "There are a lot of chemical processes that can fractionate iron isotopes," says geochemist Ariel Anbar of the University of Rochester in New York state. "The trick will be using some more context to pull out a biosignature."

Mars, again

Perhaps the biggest disappointment in the search for biomarkers has come from astrobiology's most famous exhibit: martian meteorite ALH84001. At its premiere in 1996, this chunk of rock was said to contain four kinds of apparent biosignatures: organic matter, carbonate minerals, magnetite grains, and actual bacterial microfossils. After 5 years of study, only nanometer-scale grains of magnetite—indistinguishable from those made by some bacteria—remained (*Science*, 22 December 2000, p. 2242). Now even the magnetite is under heavy fire.

At the March Lunar and Planetary Science Conference in Houston, soil mineralogist D. C. Golden of Hernandez Engineering and NASA's Johnson Space Center (JSC) in Houston and his colleagues reported that they had used heat to break down iron-rich carbonates and create magnetite grains that bear a striking resemblance to those of ALH84001. According to Golden, they even bear the distinctive faceting previously known only in biogenic magnetites. But geologist David McKay of JSC, leader of the group that originally proposed the ALH84001 biosignatures, didn't "see anything that would change our minds. Clearly, more work needs to be done in this area."

Soon enough, McKay got his wish. In the 14 May issue of the *Proceedings of the National Academy of Sciences*, meteoriticist Edward Scott and microscopist David Barber of the University of Greenwich, U.K., reported that a dissection of ALH84001 at the nanometer scale, using transmission electron microscopy, shows magnetite growing and filling voids with the same crystallographic orientation as that of the surrounding carbonate. This suggests to them that the shock of a meteorite impact vaporized pockets of ALH84001's iron-rich carbonates. Then, the iron was redeposited as magnetite, which tracked the structural orientation of the remaining carbonate. "Biogenic sources should not be invoked for any magnetites," they write.



Creative crash? An impact on Mars formed the gray bands—and, possibly, lifelike magnetite—in this slice of martian meteorite.

Such setbacks are reminding researchers that life usually doesn't leave a unique trace; in many cases, what organisms do, inorganic chemistry can too. "It's not enough to say, 'Here's a biomarker that organisms produce,'" says meteoriticist Ralph Harvey of Case Western Reserve University in Cleveland. "You have to say, 'Here's why it can't be produced other ways.' That's a much bigger burden."

And it requires a major commitment to detailed, interdisciplinary geological study, adds geologist Roger Buick of the University of Washington, Seattle. It's all too easy to "fly into a place knowing very little about the geological context, grab one sample, perform [a] particular scientific trick on it, and write a presto paper," he says. But the recent rash of contested claims shows that over time, the scientific method is doing its job. "People who do have the geologic skills to reinvestigate some of these claims are doing what should have been done at the beginning," says Buick. "I'm pleased it's happening."

The burden of understanding geological context will weigh most heavily on astrobiologists. "If the specialists cannot agree on the quality of evidence from terrestrial [Akilia] rocks," asks Queensland's Kamber, "what hope is there to agree on evidence from tiny meteoritic fragments or returned samples?"

But there is some hope, researchers agree, as evidenced in recent earthly successes. Copenhagen's Rosing has found Greenland rock 3.7 billion to 3.8 billion years old—from just after the bombardment—with isotopically light carbon that everyone seems to agree really did start out as a sediment. And individual complex molecules unique to terrestrial eukaryotic microorganisms have been found preserved in 2.5-billion-year-old rock, 300 million years before the first suspected eukaryotic fossils (*Science*, 25 June 1999, p. 2112). With the impetus from ALH84001 and a commitment to the interdisciplinary investigation of geologic context, biosignatures could work, researchers say. "I don't believe any of the evidence from the martian meteorite," says geochemist George Cody of the Carnegie Institution of Washington's Geophysical Laboratory in Washington, D.C., "but it's been the biggest boon for space science. It got us thinking." **–RICHARD A. KERR**

CREDITS: (TOP TO BOTTOM) M. BRASIER *ET AL.*, *NATURE* **416**, 73 (2002); ED SCOTT AND CYRENA GOODRICH/UNIVERSITY OF HAWAII