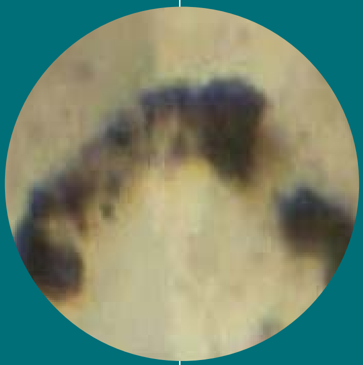
In the past year scientists have been forced to reconsider how they identify life in the most ancient rocks on earth—and elsewhere in the solar system



ISUA, GREENLAND (*opposite page*), is home to rocks harboring well-accepted evidence that living cells existed on earth more than 3.7 billion years ago, only several million years after the planet itself formed. But other extremely old finds in Greenland and Australia—including microscopic squiggles thought to be fossil cells (*above*)—have recently been challenged.

# Questioning the Oldest Signs of Life

By Sarah Simpson

Prehistoric creatures left seemingly endless proof of their existence fossilized in age-old rocks. Monstrous thighbones of lumbering dinosaurs that drowned in flooded rivers now lie encased in sandy mudstone. Jagged fronds of tropical ferns once growing in muddy swamps are pressed between jet-black layers of coal. Squiggly worm burrows, excavated within a slimy seabed, lace steel-gray limestone. These signs of life are unmistakably distinct from their stony tombs. But the more ancient the creature, the more obscure its grave.

Before life began walking, slithering or putting down roots, nothing much more than solitary microscopic cells populated the globe. Virtually all traces of those that lived before about 2.5 billion years ago—a period known as the Archean eon—have since become nearly indistinguishable from the rocks that entomb them. Millions of brutal years of burial and resurfacing, akin to repeated pressure cooking, permitted very few fossilized cells to survive in rocks accessible at the earth's surface today. Often geologists must instead rely on other signs of life, or biosignatures—including rather subtle ones, such as smudges of carbon with skewed chemical compositions unique to biology.

A decade ago high-powered microscopes enabled geologists to detect apparent fossils in earthly rocks an astonishing 3.465 billion years old—as close as tangible fossils may ever take us to the time when simple inorganic molecules first self-replicated and began selectively interacting with their environment, defining life's earliest moments. By 1996 new techniques for measuring slight variations in the chemical makeup of carbon samples seemed to solidify previous hints that life existed at least 365 million years earlier. That same year the stunning announcement that a meteorite found in Antarctica was carrying 3.9-billion-year-old biosignatures from Mars further energized scientists, who grew more confident in their ability to detect past life from faint traces in rocks.

But the uncontested glory did not last. Evidence from the Martian meteorite came under fire almost immediately, and only one life sign from Mars still clamors for acceptance [*see box on page 76*]. In early 2002 confidence over the widely accepted views on earthly evidence experienced a similar meltdown. A flurry of research has cast serious doubt on interpretations of the earth's two oldest geologic records of life, in Greenland and Australia. Some new evaluations of the geology suggest that the rocks formed in environments where life never could have thrived. Others question whether lifeless chemistry might have been able to mimic the special traces of carbon or even the shapes of microscopic fossils—rendering these clues useless as biosignatures.

The revisionist analyses are fueling an ongoing debate over how anyone can ever be sure of correctly identifying primitive life on earth—or elsewhere in the solar system. "If we can't get it right on earth, we can't get it right on Mars," says paleontologist Bruce Runnegar of the University of California at Los Angeles. That's a point that space scientists are sure to keep in mind when evaluating Martian rocks slated to be inspected by two NASA rovers early next year.

## Overview/*Early Life*

- Many traces of the earth's most ancient microscopic life—so-called biosignatures—are subtle and encased in rocks. Apparent biosignatures become most convincing as signs of life when geologists can confirm that the host rocks formed in a biologically friendly environment, such as a shallow sea.
- Several biosignatures can be mimicked by nonbiological chemical reactions that occur at high temperatures and pressures—reactions often experienced by deeply buried rocks or those that harden from a molten state.
- The ambiguity surrounding the origins of apparent biosignatures demonstrates that accurate interpretations of the geology are key to any search for signs of very ancient life, be it here on earth, on Mars or beyond.

## To Hell and Back

THE MOST ANCIENT—and easily the most controversial—evidence of life on the Blue Planet turned up seven years ago on a tiny nubbin of land at the southwest corner of Greenland's cold and barren island of Akilia. The island, which squats 30 kilometers south of the capital, Nuuk, extends a mere two kilometers across at widest reach; a hiker can traverse the ground in question in five minutes. There, underneath thick patches of arctic moss and lichens, all-important bands of milky, quartz-rich rock gleam among the darker volcanic slabs surrounding them. Using radioactive elements found only in volcanic minerals, scientists have dated one nearby slab to a whopping 3.83 billion years ago, ranking it among the oldest rocks preserved on the earth's surface today. And based on the position of the gleaming white rock (which contains no datable minerals), many geologists say that the white material is even older.

Akilia's stark landscape gives the impression that its rocks have looked this way ever since their primordial origins. But the earth is a dynamic place. These outcrops—like most from the Archean eon—have suffered one of the most torturous geologic processes that the earth has to offer: metamorphism. For 85 percent of the planet's lifetime, these rocks were buried, twisted, folded or pumped full of fluids; they were plunged to hellish depths nearly 70 kilometers underground and baked at 700 degrees Celsius before returning to the surface during at least two different episodes of uplift. If any of

J. WILLIAM SCHOPF *University of California, Los Angeles* (*page 70*); JAMES L. AMOS *Corbis* (*preceding page*)

WHITE STRIPES in this rocky outcrop at the southern tip of Greenland's tiny island of Akilia hide flecks of carbon that were initially hailed as a signature of life older than 3.8 billion years.

CHRISTOPHER M. FEDO *George Washington University*

these rocks are the relics of the floor of an ocean once teeming with microscopic creatures, it could well be impossible to find traces of those organisms still intact.

Yet in 1996 geochemist Stephen J. Mojzsis, now at the University of Colorado at Boulder, glimpsed a suggestion of life inside that tortured white stone. Through the probing eye of a scanning electron microscope, he discerned black specks of graphite, a pure-carbon mineral that sometimes forms when organic matter is heated. He also noted that tough crystals of apatite encasing the graphite probably sheltered it from the harshest metamorphic transformations.

But what convinced Mojzsis were the uniquely skewed ratios of isotopes in the two dozen specks he analyzed in more detail. Each was diagnostically enriched in the lightest and most common isotope of carbon: carbon 12. Living organisms are frugal. So when they use carbon dioxide to fuel their activities, they exploit the light carbon isotope more efficiently than they do carbon 13, which is notably heavier because of an extra neutron in each atom's nucleus. This preference leaves them with a surplus of carbon 12 atoms—roughly 2 to 3 percent more than exists in carbon dioxide dissolved in the ocean.

This light carbon signature had been gaining support as an uncontestable marker of life for almost 60 years as researchers published thousands of similar measurements from younger rocks. Therefore, when Mojzsis's graphite samples clustered around 3.7 percent, it made perfect sense for him to declare them compelling evidence for the oldest known life on earth. This conclusion had an additional implication—that life got its start in a hostile period when devastating meteorite impacts were boiling off the oceans and turning the earth's atmosphere into a scorching mist of vaporized rock for millennia on end. Indeed, many scientists hailed Mojzsis's discovery as the key that would unlock a virtually unknown era of earth history, says geologist Christopher M. Fedo, now at George Washington University.

A year later, in 1997, Fedo accompanied Mojzsis and several other geologists to Akilia. Fedo recalls that at first it felt "like visiting hallowed ground." But almost immediately the two young researchers began seeing different pictures of the past—and different explanations for what the light carbon signal really means. From the makeup and structural relation of the rocks, Mojzsis and his colleagues had inferred that the graphite-bearing rock originated in a biologically friendly environment: an ocean basin where sand and other particles, including the cells of marine organisms, formed layers of quartz-rich sedimentary rock. On seeing the rocks for himself, Fedo, who had just spent a year mapping Archean rocks in Zimbabwe, became extremely skeptical. He knew that igneous rocks—those solidified from hot magma—can look sedimentary, and vice versa, once they have lost or gained key minerals during metamorphism. "If we're going to understand life, we'd better understand geology," Fedo says.

Subsequently, Fedo and geochronologist Martin J. Whitehouse of the Swedish Museum of Natural History in Stockholm returned to Akilia to make their own maps and chemical analyses. Their verdict, which they published last spring, was that the quartz-rich rocks that Mojzsis and others were calling old sediments were actually the progeny of igneous rocks that had endured a particular metamorphic process known to create graphite from nonbiological sources of carbon. Fedo and Whitehouse insisted that the graphite's light carbon signature might have to be explained by some process unrelated to biology. It is wrong, Fedo asserts, to believe that inorganic reactions cannot mimic light carbon signatures just because they haven't been proved to do that so far.

## Geology Is Everything

ENORMOUSLY COMPLICATED geology is the reason that Mojzsis, Fedo and a slew of other investigators disagree about Akilia. It is also the reason that field geologist Minik T. Rosing of the University of Copenhagen's Geological Museum calls Akilia "utterly uninteresting." No combination of geologists can agree on the history of the rocks, he says, and so "we might never be able to resolve the problem." And that's from a Greenland native who has spent more than 20 years studying the icy island's geology.

But many investigators have not let go of settling the debate at Akilia. Indeed, Akilia is near the top of Bruce Runnegar's agenda as the new director of NASA's Astrobiology Institute, a consortium of 15 research teams across the U.S. dedicated to pursuing evidence for the origin and evolution of life on earth and beyond with an annual budget approaching $20 million. "Within a year or so we plan to take the people who really know the rocks and get some sort of consensus on what we're sampling in the field so that everybody knows what everybody else is talking about," he says.

Yet Rosing and other researchers—including paleontologist J. William Schopf of U.C.L.A.—point out that even if scientists can agree that the rocks at Akilia are former sediments, they still won't be able to prove where or when the carbon originated. They insist that light carbon, and indeed graphite, in such highly metamorphosed rocks can only suggest the possibility of life. By itself, it cannot constitute proof. When sediments are pressure-cooked, fluids might carry in carbon from other, younger sources. Also, the carbon bonds of any organic matter within them start to break and can be reset, even if the carbon is sheltered by tougher crystals of apatite. “There really is no good way, in my opinion, to go from [the measured] value back to what the original values were,” Schopf says. “There’s a big difference between knowing it and having a hint.”

Akilia’s limelight has diverted attention from a much more convincing hint of early life that exists about 180 kilometers northeast of that island, in a part of Greenland called Isua. There Rosing recently detected the light carbon biosignature in rocks that he argues experienced a mere migraine compared with Akilia’s hellish past. This pocket of relatively gentle metamorphism was not easy to find. Isua’s four-kilometer-wide belt of Archean rocks stretches 35 kilometers along the western edge of the bluish-gray monolith of the Greenland ice cap. The distinctive shimmer of the rocks and their marble-size crystals of red garnet, black

# Biosignatures at a Glance

BEFORE PLANTS AND ANIMALS AROSE, single-celled microbes populated the earth. Scientists gather physical signs of these primitive organisms by combing ancient rocks for subtle traces of their existence, called biosignatures. But such finds can be questioned as evidence for life if their presence can be plausibly explained by nonbiological processes—as in the disputes described below. *—S.S.*

## LIGHT CARBON

DEFINITION: Carbon having a higher ratio of carbon 12 to carbon 13 than occurs in nonbiological materials; the higher ratio reflects organisms’ preference for using carbon 12 as they convert carbon dioxide into cellular material.

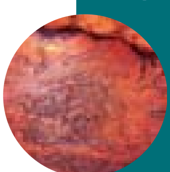
OLDEST DISCOVERY: Tiny specks of carbon found in Akilia, Greenland, in rocks more than 3.8 billion years old. Recent research contradicts assertions that the host rocks came from an environment that could have supported life. The debate leaves carbon (*black dots, left*) in rocks that formed more than 3.7 billion years ago in Isua, Greenland, as the oldest uncontested relic of life on earth.

## LIGHT SULFUR

DEFINITION: Sulfur having a higher ratio of sulfur 32 to sulfur 34 than does sulfur that has not been processed by the microscopic organisms that use this element as a source of energy.

OLDEST DISCOVERY: Flecks of the iron-sulfide mineral pyrite within 3.5-billion-year-old rocks from northwestern Australia. Some researchers question whether the spiky gray crystals (*right*) that harbor the pyrite truly formed in an environment that could have sustained life. Records of this biosignature become unambiguous by about 2.5 billion years ago.

## STROMATOLITES



DEFINITION: Layered, domelike formations constructed by colonies of microbes.

OLDEST DISCOVERY: Fossilized mounds discovered in northwestern Australia and dating to about 3.5 billion years ago; these are the oldest known macroscopic representatives of life on earth (*left*). Most other stromatolites of this age are disputed as evidence for life because their simpler structures strongly resemble mineral layers that can be produced nonbiologically.

## MOLECULAR FOSSILS

DEFINITION: Complex organic molecules resembling those in living cells today.

OLDEST DISCOVERY: Hydrocarbons found in Australian rocks some 2.7 billion years old. These molecules, derived from fossilized cell membranes, are the oldest undisputed evidence for eukaryotic cells (those containing a true nucleus) and for oxygen-producing cyanobacteria, possibly even the lineage that led to *Eoentophysalis* (*right*) 700 million years later.

## MICROFOSSILS

DEFINITION: Remains of once living cells.

OLDEST DISCOVERY: Microscopic, carbon-rich squiggles (*left*) found in 3.5-billion-year-old rocks in northwestern Australia. These finds were originally interpreted as remnants of ancient microbes, but recent work suggests lifeless chemistry could have created them. Younger microfossils, including a two-billion-year-old cyanobacterium from Canada, are widely accepted.

## BIOLOGICAL MINERALS

DEFINITION: Mineral grains produced by living cells.

OLDEST DISCOVERY: Unique forms of the magnetic mineral magnetite (*right*)—nearly identical to those known to occur in certain modern bacteria on earth—found in the Martian meteorite ALH84001. The Martian minerals are thought to be 3.9 billion years old; similar magnetite crystals have been detected in Australian rocks nearly two billion years old. Both finds remain in question.

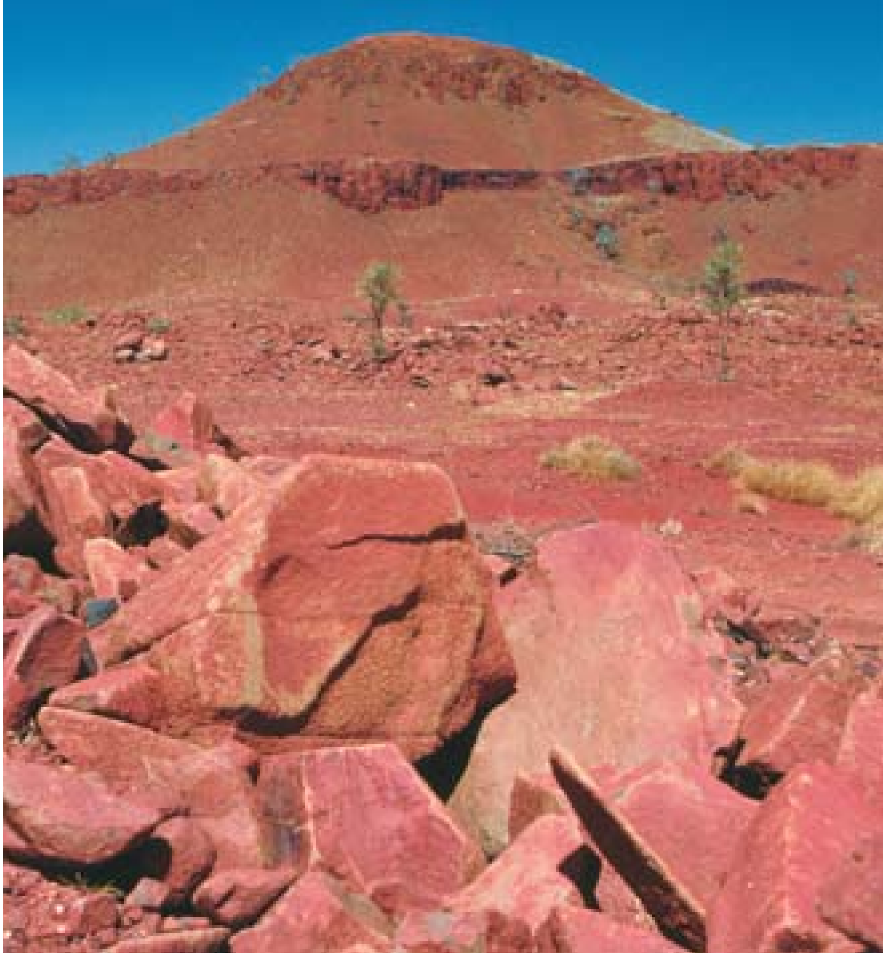
hornblende and sage-green diopside in most places attest to metamorphic tortures nearly as intense as those experienced at Akilia.

"I didn't go there to look for life, and I've always been skeptical about it," says Rosing, who initially visited Isua to understand how hot fluids transform the rocks. Since his first research visit in 1980, he has traipsed repeatedly among caribou, white polar hare and ptarmigan in this remote area—accessible only by helicopter—for one to three months at a shot. This intensive examination eventually enabled him to set aside rocks that were igneous or otherwise too complicated to harbor clear signs of life. Then, in 1999, he described a promising outcrop of old sediments at Isua's western edge that other geologists agree must be older than 3.7 billion years, making them potentially as old as Akilia's. And that's where he found the light carbon biosignature.

The relatively undisturbed geology in this part of Isua revealed important details about the sedimentary environment that were simply impossible to decipher at Akilia. The light carbon was tied up in layers of clay, which would have trapped organic particles when they settled to the bottom of an ocean. The carbon is also abundant in the rocks, and it persists through a thick pile of ancient sediments that represents as much as a million or more years of slow deposition. Every day, every night, for all that time, carbon with exactly the same composition of that in present-day microorganisms rained down to the bottom of a deep ocean, Rosing explains.

So far no one has seriously challenged his basic interpretations, and he has been working to characterize the microbes that might have produced light carbon. "That's what everyone thinks is the best bet for evidence of biology in Greenland," Runnegar says.

But even the best evidence in Greenland offers only a solitary sign of life. Surely a multiplicity of clues from a single site would be even more convincing. That was precisely the strength of Schopf's landmark interpretation of rocks on the other side of the world, one that went uncontested for nearly a decade.



MARS-LIKE LANDSCAPE of northwestern Australia's Pilbara region is the source of 3.5-billion-year-old microscopic structures that some interpret as fossilized strings of ancient cells.

## Surf or Sizzle?

OF ALL POTENTIAL biosignatures, what pleases scientists most is a bona fide fossil of an organism's body, even if it is only one or two cells in size. In this category, Australia's timeless landscape holds most of the records. Uncontestable microfossils—including those of oxygen-producing cyanobacteria—exist in rocks about two billion years old. And convincing examples of so-called molecular fossils—relics of complex organic molecules that were once fatty constituents of cell membranes—turned up three years ago in rocks 2.7 billion years old. But neither of these exciting finds pushed back the fossil evidence as far as the pioneering work of Schopf, who, after devoting three decades of study to ancient microscopic fossils, launched a new wave of early-life research in 1993.

As in Greenland, the oldest signs of life in the land Down Under are exposed in a remote, desolate area—an ancient landscape about 1,200 kilometers north of Australia's west coast port of Perth. If it weren't for the wallabies hopping among silica-tipped spines of spinifex grass or the occasional roadhouse marking the spot where one dirt track meets another, the dusty, low hills of northwestern Australia might be mistaken for Mars. Near Marble Bar, a tiny watering hole in this sublime sea of red, geologists long ago described the Apex chert—the final home of Schopf's tiny, famous fossils—as a mixture of sand and small pebbles once churned by waves along a shallow seaway flanked by volcanoes. The chert (which, like the graphite-bearing rocks of Greenland, cannot be dated directly) is conveniently sandwiched between two lava flows, which have been dated precisely at 3.46 billion and 3.47 billion years old. Of the half a dozen claims of Archean microfossils—including ones from four locations in South Africa—this age made Schopf's the oldest. Further analysis would reveal that his cache, if truly biological, was also the most diverse, with 11 new species of microorganisms identified.

According to Schopf, the chert contained telltale smudges of graphite that he

OPPOSITE PAGE: MINIK T. ROSING *Geological Museum, University of Copenhagen* (*light carbon*), TIM LYONS *University of Missouri* (*stromatolites*), J. WILLIAM SCHOPF *U.C.L.A.* (*microfossils*), ROGER BUICK *University of Washington* (*light sulfur*), H. J. HOFMANN *McGill University* (*molecular fossils*), KATHIE L. THOMAS-KEPRTA *Lockheed Martin* (*biological minerals*); THIS PAGE: PENNY TWEEDIE *Corbis* calls threadlike strands of once living cells. His biological interpretation of these smudges was backed by the chert's distinct enrichment in light carbon and the nearby presence of fossilized stromatolites, mineralized mounds of bacterial mats that serve as the only sign of Archean life visible to the naked eye. Based on this trio of evidence, everything from textbooks to television, even the *Guinness Book of World Records*, touted this landmark finding as the earth's oldest fossil evidence for life.

But early last year Schopf's celebrated vision of the cradle of life was upended by a reinterpretation of the local geology—and of the fossils themselves. In March micropaleontologist Martin D. Brasier of the University of Oxford and seven of his colleagues published the first robust reanalysis of Schopf's 1993 conclusions. Among several challenges, Brasier asserted that the chert harboring the presumed fossils was not deposited on the sunny floor of a shallow sea but rather deep within the dark subsurface plumbing of seafloor hot springs. This distinction is critical because Schopf had proposed that many of his fossils may have been light-loving cyanobacteria. Even more damaging, however, was Brasier's suggestion that many of the microscopic structures that evoke life for Schopf may be nothing more than lifeless artifacts.

Today Schopf admits that it was a mistake to rely on the geologic mapping of others in the construction of his original story, conceding, albeit reluctantly, that his famed fossils may not have been photosynthesizers. Instead they may have been the forebears of heat-loving bacteria that color the steamy geyser pools in Yellowstone National Park and populate submarine volcanoes. Schopf has recently reevaluated the carbon smudges using a technique known as Raman imagery, which employed scattered light to probe their internal three-dimensional structures. The results indicate that many of the structures in question look like cell walls.

Still, Brasier asserts that the light carbon enrichments may well be able to form through lifeless chemical reactions—much as Fedo and others have argued could have occurred at Akilia. Little definitive research has been done in this area, but a handful of experiments do suggest that the right combination of metals and other chemicals—like those abundant in seafloor hot springs—might ignite reactions that could mimic biology's preference for the light isotope of carbon. And although Brasier does admit that some of the carbon could represent scattered remains of microbes, he insists that "you must falsify [nonbiological] origins for these materials before you accept biological ones."

The same policy must be applied, Brasier and others would argue, to another biosignature—light sulfur—preserved within 3.47-billion-year-old Australian rocks that sit a two-hour, back-breaking car ride northeast of the controversial Apex chert. Sulfur-rich rocks from the ironically named North Pole district contain a surplus of sulfur 32 (relative to heavier sulfur 34) that is characteristic of waste materials produced by bacteria known to use sulfur as an energy source. Light sulfur signatures, like those of carbon, unambiguously record life over much of the earth's history. But in these very old rocks in western Australia,

## Martian Magnets

METEORITE ALH84001 hit Antarctica 13,000 years ago.

PULLING CONVINCING SIGNS OF LIFE out of a single space rock isn't easy. But one of the last surviving claims that biosignatures endured meteorite ALH84001's trip from Mars has weathered a recent barrage of criticism.

For the past seven years microscopist Kathie L. Thomas-Keprta of Lockheed Martin in Houston and her colleagues have kept alive the idea that minuscule grains of the mineral magnetite within the potato-size meteorite—bits widely accepted to have formed on Mars some 3.9 billion years ago—are indistinguishable from the tiny magnets made by some aquatic bacteria on earth.

Skeptical researchers have pointed out that, as is true of certain putative biosignatures on earth, a lifeless chemical process could have created the lifelike material, in this case a heat-induced transformation of iron-rich minerals during a collision the rock suffered while still on Mars. But such an impact would have created magnetite with impurities (such as magnesium and manganese), Thomas-Keprta notes, and the grains she calls biosignatures are 100 percent pure—a finding she and her colleagues recently confirmed with new three-dimensional tomography scans of the Martian magnetite.

In addition to the lack of chemical impurities, about 25 percent of the magnetite in ALH84001 shares at least five other distinct characteristics with magnetite made by the bacterial strain MV-1 here on earth. The Martian and MV-1 magnetite grains are in the same size range, lack significant structural defects and share an unusual elongated crystal shape that strengthens the mineral's magnetic properties, for instance. If any single criterion is absent from a Martian grain, it is excluded from further consideration as a possible biosignature. The test is so stringent that nearly one third of the bacterial crystals would fail to pass the test, Thomas-Keprta points out.

MARS

The new evidence makes her almost certain that the tiny magnets are true signs of past life on Mars, but many other scientists remain unconvinced. Even Thomas-Keprta says she won't be satisfied with finding only one likely trace. "Defining a biosignature is almost as difficult as defining life itself," she admits. In the next year she and her colleagues will begin to scour the meteorite for a particular iron sulfide mineral that bacteria on earth are known to produce. *—S.S.*

SETI LEAGUE, USED BY PERMISSION *www.setileague.org* (*top*); NASA AND THE HUBBLE HERITAGE TEAM (*bottom*)

MITSUAKI IWAGO *Minden Pictures*

STROMATOLITES, towering structures built by colonies of microorganisms, live today in such places as Shark Bay, about midway along the western coast of Australia. Ancient versions dating to about 3.5 billion years ago are among the few putative signs of life that old that are still largely unchallenged.

the controversy is the same: Did the rocks form in low-temperature environments inhabited by bacteria or in higher-temperature locales where nonbiological reactions could have mimicked the bacterial isotope patterns? Australian geologist Roger Buick of the University of Washington and his collaborators argue the former, stating that sulfur-bearing crystals formed in an evaporating lagoon. But not everyone, most notably Runnegar, agrees with this interpretation of the region's geology.

Despite the controversies, Schopf maintains his basic position. He counters that although an individual biosignature can be cast in an uncertain light, the uncertainty does not render the evidence useless. A suite of biosignatures from a single location—even if disputable when viewed individually—packs a powerful punch. He is fond of saying, "If it looks like life, has the ecology of life, has the isotopes of life and fits with all other evidence of life, then most likely it's life."

## Earth and Beyond

STILL, IN THE END, the interpretations of the oldest rocks in both Greenland and Australia are unavoidably complicated by the possibilities of both biological and nonbiological origins. Lest you worry that scientists are losing their ability to recognize early life, though, remember that the brouhaha over Akilia and Apex are just about being the very oldest signs of life. That's important but not the be-all and end-all. Rocks at Isua and South Africa's Transvaal Basin are just a tad younger and, some would argue, much less controversial. Although many scientists quibble over the details, the great antiquity of life is generally accepted.

Perhaps the most important conclusion that has crystallized from these arguments is this: whether you are investigating ancient rocks on earth or potato-size meteorites from other planets, don't count on a single smoking gun to be your proof of life. That conclusion has serious implications for further hunts for early life on earth and for how future evidence from Mars is interpreted. Brasier cautions that without having "the criteria for the detection of early life clear in our minds *before* we have a robotic or manned mission to Mars ... we will end up having profitless debates that may simply demoralize the scientific community."

NASA scientists share that concern, which is why they are determined to decipher the geology of Mars before tackling a search for past life. "When you consider the fact that field geologists have been crawling over the earth for 200 years and are still having problems [agreeing on reliable biosignatures], we're way far away from being able to do a credible search for biosignatures on Mars," says planetary scientist Steven W. Squyres of Cornell University.

Since 1997 Squyres has been working as chief scientist for NASA's upcoming Mars landing missions, which will scour the planet's surface for hints that its past environment might have been biologically friendly. Two remote-controlled, robotic geologists, called the Mars Exploration Rovers, are scheduled for launch in late May and June and should begin their fieldwork on the Red Planet in January 2004. The landing sites, to be announced sometime this month, will target spots where orbiting spacecraft have discovered tantalizing hints that liquid water—a requirement for all known forms of life—once existed.

As experiences from Greenland and Australia illustrate, it is difficult to find readable records here on earth because the constant motion of tectonic plates have so chewed them up over the past four billion years. But because such a global process may never have existed on Mars, researchers predict that its surface has remained intact—except for a few meteorite impacts—during that same period. Squyres notes the irony: "If life did come to being on Mars, evidence for it might be much easier to find." SA

*Sarah Simpson is a contributing editor at* Scientific American.

### MORE TO EXPLORE


**Evidence for Life on Earth before 3,800 Million Years Ago.** Stephen J. Mojzsis et al. in *Nature,* Vol. 384, pages 55–59; November 7, 1996.

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**Questioning the Evidence for Earth's Oldest Fossils.** Martin D. Brasier et al. in *Nature,* Vol. 416, pages 76–81; March 7, 2002.

**Metasomatic Origin of Quartz-Pyroxene Rock, Akilia, Greenland, and Implications for Earth's Earliest Life.** Christopher M. Fedo and Martin J. Whitehouse in *Science,* Vol. 296, pages 1448–1452; May 24, 2002.

**Magnetofossils from Ancient Mars: A Robust Biosignature in the Martian Meteorite ALH84001.** Kathie L. Thomas-Keprta et al. in *Applied and Environmental Microbiology,* Vol. 68, No. 8, pages 3663–3672; August 2002.