Life on Mars: Tempest in a Teapot? A First-hand Account[1]

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You must not fool yourself—and you are the easiest person [for you] to fool.

Feynman's First Principle (Richard Feynman, CalTech Commencement Address, 1974)

Hints of Martian Life?

The news was trumpeted in banner headlines: "PAST LIFE FOUND ON MARS!" Asked by the National Aeronautics and Space Administration (NASA) to give the public a first-blush scientific appraisal of this extraordinary claim, I was on hand at the Washington, D.C., news conference that announced the find in August 1996. But my involvement began earlier.

At the request of NASA administrators, in January 1995 I journeyed to the Johnson Spacecraft Center (JSC) in Houston, Texas, to render a verdict on what geologist-mineralogists there believed might be microfossils in a chunk of meteorite thought to have come from Mars. Designated judge of their breakthrough discovery, I was sworn to secrecy by the JSC scientists lest their find hit the newspapers before they had the facts.

What caused the fuss was tiny orange-colored pancake-shaped globules of carbonate mineral, 2 to 200 μm across and ringed by thin black and white rinds. Flushed with excitement, the researchers contended that never before had ringed discs like these been seen in a meteorite, and since this one was said to have come from Mars—which in the distant past may have harbored life—and since the objects were made of the same mineral and some were about the same size as shells

[1] Read 24 May 1997.

of a particular type of protozoan (foraminiferans, “forams” for short), they thought they might have chanced on a mélange of Martian fossils.

Because of my discovery of the most ancient (nearly 3.5-billion-year-old) fossils known on Earth (Schopf, 1993), I had been brought in to shore up the paleontologic guess of geologists schooled in rocks and minerals, but not in biology.

Their guess was wrong. The discs certainly were not remnants of protozoans. A number of the objects were simple foramlike discs, but many of the others merged one into another in a totally nonbiologic way. Their overall size-range also did not fit biology and they lacked any of the telltale features—pores, tubules, wall layers, spines, chambers, internal structures—that earmark tiny protozoan shells. Moreover, the “lifelike” traits they did possess (carbonate composition, discoidal shape, ringed rims) could be explained by ordinary inorganic processes.

Carbonate minerals are, of course, laid down by life—by protozoans, clams, snails, corals, even certain seaweeds. But carbonates also form by purely inorganic means and are known from many meteorites, not just the one containing the putative fossils, where their nonbiologic genesis is beyond question. The discoidal shape of the carbonate globules didn’t seem to require biology either. Formed when mineral-bearing solutions percolated through a thin crack in the rock, the pancakes are flat on top and bottom because the solidifying carbonate ran out of space above and below. And they are more or less circular and merge one into another because as minerals drop out of solution they crystallize around all sides of a grain first formed (the “center of nucleation”), in this case making a disc or, if the grains are closely packed, discs that merge. Their rimming rings, I thought, came from the same process. When the makeup of a crystallizing solution changes, so do the minerals laid down. The thinly layered black and white rims showed that chemical conditions changed as the pancakes formed, not that the discs were formed by protozoans.

I raised these points with the JSC scientists. They seemed to agree. The matter, I thought, was closed. But I urged them to continue the hunt. I believed then as I do now that the search for hints of life in Martian meteorites is a promising way to attack a truly fascinating question. It *is* important to know whether life once existed (or still does) on Mars.

(Still, I was taken aback when, more than a year later, at the August 1996 news conference, the same little pancakes were again proffered as evidence of Martian life, this time of bacteria rather than “protozoans.” The facts hadn’t changed, only the meaning attached to them.)

NASA Stages a Press Conference

Several weeks before the August news conference I received a phone call from NASA headquarters informing me that the JSC scientists I had visited earlier had completed studies they claimed held evidence of ancient life on Mars. A technical article reporting their results was soon to appear in *Science*, a highly respected journal reserved for the hottest of hot discoveries. NASA felt obliged to inform the public, and planned to do so at a pre-publication press conference. But because some at headquarters thought the evidence "a bit iffy" they wanted an outside expert to evaluate the findings publicly when they were announced to the world. Would I, please, perform this task?

I was reluctant. I had plenty on my plate already and feared this was one more in a string of spurious claims for "life in meteorites" that dates to the early 1960s. Still, I hadn't read the article, hadn't seen the evidence. And the scientists making the claim were colleagues. I agreed to "think about it."

A copy of the soon-to-be-published report arrived the next day. I studied it. Carefully. Three times. I was not impressed. Though some of the report was backed by solid scientific data, support for other parts was wanting. Crucial questions had not been asked. Works published earlier and critically relevant to the authors' discussion had been ignored. Alternative, to me more plausible, ways to explain the findings were given short shrift. The manuscript's concluding claim of "evidence for primitive life on early Mars" seemed overblown, ill-conceived.

I called NASA, and, quoting Carl Sagan's catchphrase that "extraordinary claims require extraordinary evidence," told the official I'd been dealing with that for this claim the evidence was not even close. I suggested names of three other scientists to serve in my stead.

A few days later NASA called back. NASA director Dan Goldin had personally pegged me for the job, partly, I gather, because he's a Sagan fan (and was said to have been pleased by the quote), but I think mostly because he knows it's in NASA's best interest to get the story straight.

Any claim for life on Mars—whether of organisms small or large, past or present—is bound to stir controversy. This one would be no exception. The "iffy" evidence was certain to raise eyebrows and, since NASA's budget hearings were looming, even the timing of the announcement might be regarded as suspicious. My guess is that Mr. Goldin—a truly able administrator and brilliant politician (appointed by Republican Bush, a star of Democrat Clinton's team)—figured a preemptive strike was in order. To protect NASA's reputation and at the same time stifle the easily predicted army of naysayers, he decided to assign a hard-nosed outsider to evaluate the claim. Who better than one calling for it to be backed by "extraordinary evidence"?

Before the call relaying Mr. Goldin's personal request, I thought I was in the clear. This was a task I did not want. But Goldin is the NASA boss—the "faster, cheaper, better" guy, an appointee of two presidents. Who was I to turn him down?! I agreed.

Prelude to the Feeding Frenzy. The news conference wasn't scheduled for another two and a half weeks. I tried to put it out of my mind, but by the next weekend I'd become increasingly concerned. My skepticism was bound to raise some hackles. I spent a couple of days listing my arguments on vu-graphs (see-through charts like those NASA often uses), and early the following Tuesday faxed copies to Houston. It was only fair to warn the JSC group of what I planned to say (and I also wanted to make certain I had not misunderstood the technical details of their article—I was sure they'd straighten me out).

My hope for dialogue came to naught. Neither they nor I had time. About an hour and a half after I sent the fax I received yet another call from Washington: "Bill, get on the 1:30 afternoon flight. The press conference has been moved up."

I arrived at Dulles Airport late that night and at NASA headquarters the next morning. I was squired to a basement room in which I found the JSC team rehearsing its lines. They were prepared. Thoroughly. They even had a high-tech cartoon-video to tell the story of the flight of the meteorite from Mars through space to us. And though the room lacked a VCR to show the video, they didn't miss a beat. When they came to that part of their run-though, one of the team said: "My video talkover lasts two minutes, forty-seven seconds." The one next to him laughed: "Mine's only two minutes, nineteen."

(VCR-blind, the first gave his rendition practically the same as he gave it later to the reporters upstairs. The two-nineteen version changed not at all. These folks were pros!)

Finally my turn came in the practice session. They had videos. I had vu-graphs. They'd practiced. I hadn't. They were NASA. I, an outsider. Still, I gave my spiel. By that time there was a pride of NASAites overlooking our run-through, Dan Goldin among them.

I finished.

Utter silence.

Then a woman on the headquarters staff rose and berated the troops: "Schopf has just demolished you. Can't you guys be more *positive?!*" (I don't know who this person was—was never introduced, never caught her name—but you can see her on the CNN tape of the press conference introducing Administrator Goldin.)

The JSC crew was in a quandary. Like me, they knew their story was circumstantial. There was no “smoking gun.” But it was important for them to look good, to please the boss. The pressure was great. They seemed torn.

At the practice session I tried to be reasonable, even gentle. I did, too, at the later news conference, a performance for which I’ve been much praised—but also chastised (by no less than a Nobel laureate!), for being too soft. Still, it seems to me that the “Mars Meteorite Research Team” (as they were now calling themselves, bolstered by input from scientists at McGill, Georgia, and Stanford Universities) tackled a difficult interdisciplinary problem. An instant answer, pro or con, was not in the cards.

Breaking the news to the world. Not only had I not practiced for the news conference, I had not been warned what to expect. Maybe no one knew. The only thing I had to go on was memories of the late 1960s, when I and five other scientists (officially, the Lunar Sample Preliminary Examination Team) were tasked to do the first studies of Moon samples gathered on the Apollo 11 and 12 missions. While the Apollo crews rested in quarantine in another part of the building, we sorted, studied, and described the rocks. To test whether they harbored virulent Moon-germs (dubbed “Gorgo” by us), we even monitored the effects of lunar dust fed to Japanese quail, germ-free mice, and various plants (some of which grew better than on Earth soil). Interactions with the media were friendly, interviews were one-on-one or at most involved a few pool reporters from magazines, newspapers, radio, or television.

The Mars news conference could not have been more different. Instead of a few reporters there were five hundred. Instead of note pads there were scores of video cameras. There was so much electronic gear in the auditorium that the sound system overloaded and the conference had to be delayed to take care of high-pitched feedback whining through the hall.

On the stage I was seated alongside the chief of the Stanford group that identified organic compounds in the meteorite. Just before the conference was to begin he waved to a friend among the gaggle of journalists. Within only a few seconds he, and I next to him, were besieged by a churning sea of microphone-thrusting reporters, all determined to shove to the front of the pack. A media feeding frenzy!

Things quieted down and we waited for another twenty minutes as coverage switched to the south lawn of the White House, where President Clinton read a carefully crafted statement on the significance of the science about to be revealed. For the next two and a half hours

CNN carried our press conference to the world. Mr. Goldin led off, followed by the well-choreographed presentations of the Research Team. My remarks came last, followed by a lengthy session of questions from the Washington press corps and journalists assembled at NASA installations across the country, and answers from those of us on the dais.

The team's presentations were measured and sensible, their arguments plausible. By the time they finished, virtually all of the hundreds of journalists on hand seemed willing to believe. Introduced as the designated "skeptic" to "begin the debate," I had no doubt my words would prove unwelcome—I was uncomfortable, alone, like Daniel in the lion's den. But the evidence was (and still is) inconclusive, and it fell to me to point that out. Some claim the glass is half full. To others it's half empty. But no one who knows the facts would claim it's overflowing—not then, not now, not even the Research Team. Here I review why it seems to me their evidence falls short.[2]

Meteorites from Mars

Mars as an abode for life. The notion of life existing on Mars—now or in the past—is not implausible. In some ways the planet is like a smaller version of Earth, a rocky body half the size with one-third the gravity, but with a day only 37 minutes longer and seasonal swings (in a 669-day year) much like our own. But in other ways Mars markedly differs—it's frigid and arid with a thin, mostly (95 percent) carbon dioxide atmosphere only one-tenth the pressure of Earth's. At Carl Sagan Station, where NASA's Pathfinder landed in July 1997, temperatures range during the Martian summer from that of a freezing winter day in southern Canada to the coldest on Earth.

Yet not always was Mars so cold and dry, a fact key to the past-life-on-Mars story since the Martian meteorite dates from early in Mars's history when rivers flowed, the atmosphere was thicker, and life may have gained a foothold. A second key is that the story centers on minute forms of life, bacteria, simple single-celled microbes that play a far larger role in the evolutionary Tree of Life and are much more resilient than previously thought. They exist on Earth in a striking range of

[2] In addition to sources cited in the text, data considered here are from Romanek et al. (1994), Anders (1996), Clemett and Zare (1996), Gibson et al. (1996), McKay et al. (1996a, 1996b), Shearer and Papike (1996), Kerr (1997), and Valley et al. (1997); reviews by McSween (1994), Achenbach (1997), Goldsmith (1997), Jakosky (1997), Scott (1997), and Yarus (1997); and references cited therein.

settings—scalding deep-sea vents, sulfurous acid springs, cracks and crevices in rocks deep in the crust, on and within ice sheets and permanently frozen Arctic tundras, even in mineral-encrusted fissures in the rocks of Mars-like ice-cold deserts.

If bacteria can survive, even thrive, here, why not also on Mars?

ALH84001. The claim for ancient life on Mars comes from a potato-sized, 1.9 kg-meteorite, ALH84001—named for where and when it was found (Allan Hills ice field, Antarctica, in 1984) together with its sample number (001)—that was plucked out of the ice during the annual expedition of the U.S. National Science Foundation's Antarctic Search for Meteorites program.

The rock, dating from about 4.5 billion years ago, formed early in Mars's history at a depth of a few kilometers. Though sketchy, its subsequent history has been pieced together. Like early Earth, ancient Mars was bombarded by rocky chunks swept from orbit as it circled the Sun. According to the scenario favored by the Mars Research Team, these impacts cracked and fractured ALH84001, and since this was early in the planet's history, 3.6 billion years ago, when Mars was warmer and wetter, groundwater seeped through the fissures and filled them with carbonate mineral. But the age of the carbonate fracture-fillings is open to question, by some evidence dating from only 1.3 rather than 3.6 billion years, and an alternate version has the carbonate emplaced much later when the impact that careened ALH84001 off the Martian surface infused the veins with hot CO_2-charged fluids.

About sixteen million years ago an asteroid struck Mars with terrific force, gouging a huge crater and ejecting pieces of the planet's surface with enough power to escape its gravitational pull. ALH84001 was one of those pieces. It hurtled through space for millions of years, until, attracted to Earth, it fell to Antarctica thirteen thousand years ago.

Though thousands of meteorites are known, ALH84001 is one of only a dozen or so identified as Martian. A mix of the isotopes of oxygen ($^{16}O/^{17}O/^{18}O$) in minerals of these meteorites shows they are not Earth rocks and not from the Moon, and because they share the same chemistry all are thought to come from the same source. Like the others, ALH84001 is an igneous rock, so it and the others must have formed on a body large enough to have partly melted—a planet-sized body, and with Earth and the Moon ruled out only Mars, Venus, and Mercury are left. The link chaining the group to Mars is provided by one of ALH84001's siblings (meteorite EETA79001), which contains tiny pockets filled with gases that match those measured in Mars's atmosphere by NASA's 1976 Viking landers. The gas mix is distinctly Mars-like and differs from any known elsewhere.

Rocks trickle in from Mars. Most meteorites are debris left over from the formation of the solar system. But about two dozen have been identified as chunks dislodged from planetary neighbors, half from Mars, half from the Moon. Six of the dozen Mars meteorites were discovered in Antarctic ice fields, so of the eight thousand meteorites recovered from Antarctica roughly one of every thousand is a piece of Mars.

Though ordinary travel-times from Mars to Earth are millions of years, under some conditions they can be very much less. Using computers, Gladman and Burns (1996) at Cornell University simulated the histories of more than two thousand objects that careened off Mars's surface, and found that a small fraction could have arrived in no time flat. According to their calculations, "fast transfers (taking less than a year) from Mars to Earth must have occurred numerous times during the Earth's past. . . . If Martian microorganisms can survive a year in space, many may have already arrived."

The Cornell scientists were concerned with *live* organisms whereas the Mars Research Team's evidence is of life long dead. If live microbes could get here, their fossils might too!

Search for the Smoking Gun

The claim for ancient life on Mars is backed by three types of evidence, all found in the carbonate-filled fractures of ALH84001:

1. Tiny pancake-shaped globules—orange-colored carbonate discs and their dark (iron sulfide and oxide) rims—made up of minerals that on Earth can be formed by bacteria
2. Organic molecules like those produced by breakdown and geologic aging of fossilized organic matter
3. Minute jellybean-shaped and threadlike bodies that resemble fossil microbes

At the NASA press conference, Administrator Goldin proclaimed the findings "compelling." In one sense they certainly are, for like clues in a good detective story they are captivating, even gripping. But the findings are far from "irresistible, overwhelming," as the term is also used, and of the three lines of evidence only one—the possible fossils—is a potential smoking gun.

Martian minerals. Consider first the mineral evidence. On Earth, bacteria sometimes play a role in forming carbonate, sulfide, and oxide minerals like those in ALH84001. Yet the same minerals are common products of geology, wholly inorganic in origin, and are present in other meteorites where their nonbiologic source is beyond dispute. The minerals hold clues to the history of the Mars rock but are themselves not firm evidence of life.

Nothing about the carbonate pancakes pegs them as products of biology. Resurrected from their earlier designation as possible "Martian protozoans," their link to bacteria is equally unproven. The sulfides also lack a biologic signature, and the mix of sulfur isotopes they contain would on Earth tag them as inorganic rather than bacterial (Shearer and Papike, 1996). And though the iron oxides (minute crystals of magnetite, Fe_3O_4) have been dubbed "magnetofossils" in the popular press and some scientific articles, they are fossils in name only. Crystals like those in ALH84001 are present in certain strains of microbes, which use them as tiny compasses if they are the right size (40 to 120 nm), have their magnetic poles pointing in the same direction, and are linked in long ensheathed chains that boost the magnetic signal. The iron oxides in the Martian meteorite come in other sizes as well and are randomly oriented, never bound in chainlike aggregates. They are indistinguishable from nonbiologically formed particles of magnetite.

A piece of the puzzle not yet in place is the temperature at which the minerals formed, crucial because life's chemistry breaks down if temperatures are too high. The current world's record of 113°C is held by microbes isolated from deep-sea fumaroles, and key molecules of life disintegrate above about 125°C. The Research Team argues that the chemistry of the vein-filling carbonate shows it formed at temperatures low enough (less than 80°C) for life to exist. But other workers using different indicators arrive at much higher estimates—150°, 250°, 300°, even more than 650°C—temperatures too hot for life. A high temperature would rule life out, whereas a low one would show only that microbes could have existed, not prove they did.

New results can be expected from ongoing studies of the mineralogy of ALH84001 and other Martian meteorites. But unless the minerals are somehow shown definitely to be biological, they cannot answer the question of life on Mars.

Organic molecules possibly from Mars. One of the most intriguing findings of the Research Team is the identification in ALH84001 of organic compounds known as polycyclic aromatic hydrocarbons (PAHs). Though this points in a promising direction for future exploration of the Red Planet, the presence of PAHs, like that of the minerals, is not proof of Martian life.

It seems odd to think that "organic" molecules could be other than signposts of life. But "organic" and "biological" do not have the same meaning. Organic compounds are composed of carbon and hydrogen (combined often with oxygen and/or nitrogen) and can be made either by biological or by nonbiological processes. The confusion comes because the same four elements, CHON, make up biological molecules, biochemicals formed by living systems. All biochemicals are organic but not all organic chemicals are biological. PAHs are organic because they are made of carbon and hydrogen. But because they are not made in living cells they are not biochemicals, not molecules formed by life.

Organic matter buried and pressure-cooked in rocks undergoes a series of chemical changes that leads slowly to a honeycomb-like structure of ring-shaped molecules composed of pure carbon (graphite, or if the pressure is especially intense, diamond). PAHs, ring compounds made of carbon and small amounts of hydrogen, are a way-station along this path. The same path is traveled by all organic compounds regardless of their starting makeup, regardless of their (biological or nonbiological) source.

PAHs are abundant in the organic matter of fossil plants and animals, common in automobile exhaust and factory smoke (generated from burning of fossil fuels), present even in the vapors rising from a grilled steak. Though PAHs are not biochemicals, not themselves formed by life, on Earth they come from breakdown of once-living matter.

Yet PAHs are made easily by simple chemical reactions in the total *absence* of life so they are common also in meteorites, especially those rich in nonbiological organic matter, and abundant on surfaces of dust grains and graphite particles that speed through interstellar space. Like PAHs in other meteorites, those in ALH84001 may be entirely nonbiologic.

There is yet another problem. Ever since the NASA press conference there has been debate whether the PAHs found in ALH84001 actually belong to the Martian rock. There are good reasons to believe they were in the rock when it crashed to Earth, but it's not easy to be sure because PAHs from atmospheric pollution and probably also Antarctic coals are present in the snow and ice at Allan Hills, and those in the meteorite are on surfaces of cracks, where they may have been deposited from seeping meltwater. But regardless of how this debate turns out, it cannot answer the question of past life on Mars since there is no clear-cut way to tell whether the PAHs found are or are not of biologic origin.

Still, if they are truly from Mars the PAHs could pave the way to important findings. NASA plans to hunt for life in Mars samples to be returned to Earth in 2008. Only hard-line enthusiasts think the dust and stones will harbor anything alive—unlike its more clement past, Mars now is an awful place to live, its surface drenched in lethal UV rays and so dry and frigid there's no water for life to use. So NASA has pinned its hopes on detecting microscopic fossils, a needle-in-a-haystack hunt. The first task will be to find the haystack. Organic compounds like PAHs may provide the means. On Earth, organic matter and life go hand-in-hand. The same should hold for Mars if life ever existed there. NASA's best bet is to ferret out and bring back rocks rich in coaly carbon and search them for tiny fossils.

Fossil microbes on Mars? Ancient life on Mars. The minerals can't prove it. The PAHs can't either. The "fossils" could—but they don't, and there are good reasons to question whether they are in any way related to life.

"A picture is worth a thousand words." Shown in newspapers, magazines, and on television around the world, "Mars fossils" have captured the public's fancy. Their lifelike shapes are palpable, far easier to understand than arcane chemistry.

Unlike the press, the Mars Meteorite Research Team has handled the supposed fossils with kid gloves. Their seven-page article (McKay et al., 1996a) includes only four sentences on the objects, which suggest almost in passing that as "features resembling terrestrial microorganisms . . . or microfossils [they are] compatible with the existence of past life on Mars." The objects they illustrate are exceedingly small, 20 to 30 nm across (Fig. 1), and though their jellybean-like form resembles rod-shaped bacteria they are much too minute for the comparison to hold.

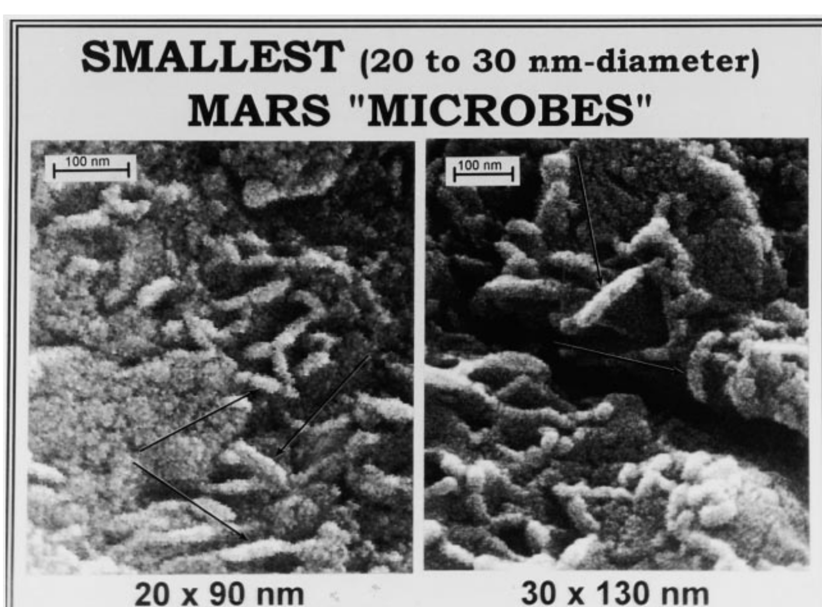

Figure 1. Jellybean-shaped objects (at arrows) pictured in the Mars Meteorite Research Team's article (McKay et al., 1996a)

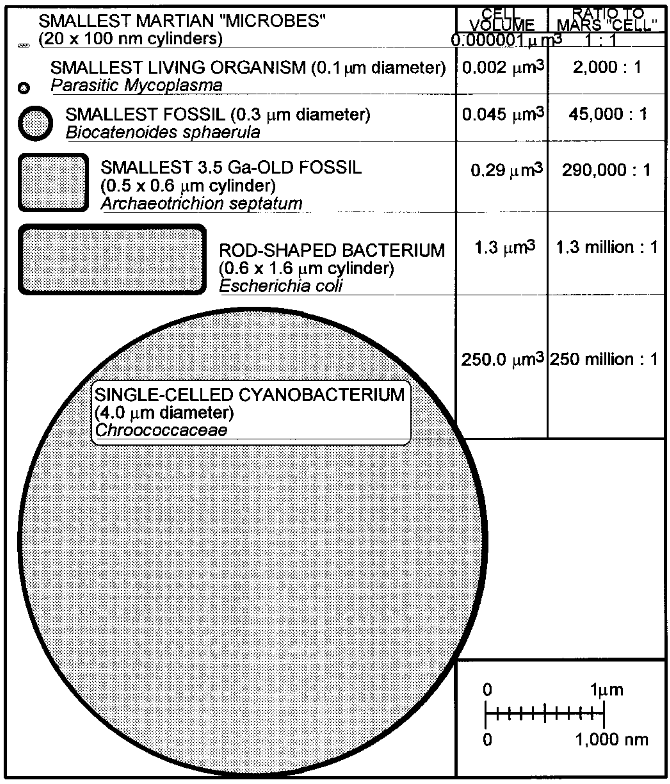

Figure 2. Comparison of the sizes of living and fossil organisms with the Mars "fossils" reported by McKay et al. (1996a)

More than a million times smaller than a run-of-the-mill bacterial cell (Fig. 2), they are actually more like ribosomes, 20 nm-size protein-making bodies present in cells in prodigious numbers—about twenty thousand in a typical bacterium, more than a hundred thousand in a human cell. The "Mars fossils" are the size of minute particles *within* bacteria, not bacteria themselves!

Other than shape, size is the only hard fact yet revealed about the fossil-like objects, potentially telling because there is a limit to how small cells can be. The tiniest microbes on Earth, bacteria of the genus *Mycoplasma* that live as parasites in cells of other organisms, usually mammals, show the limits of life. The most minute are about 0.1 μm (100 nm), contain only a fraction of the genes of a typical bacterium, and are encapsulated by a thin membrane rather than a sturdy cell wall (Fig. 3). Only one-billionth as massive as a single protozoan, they are able to function because they are bathed in the nutrient-rich cytoplasm of the host cells they inhabit.

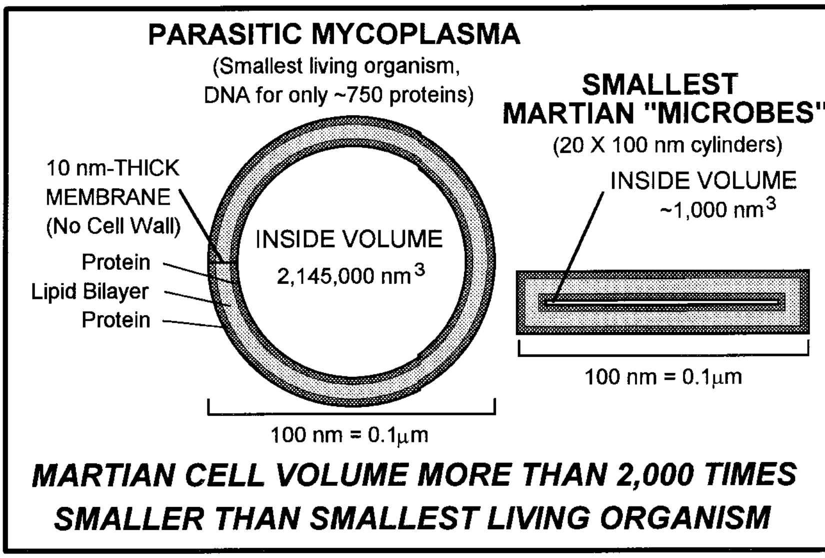

Figure 3. Comparison of the smallest known cellular organism (a parasitic mycoplasma) with the putative fossils reported by McKay et al. (1996a)

If the "Mars fossils" actually were once alive they must have been composed of cell-like compartments that cordoned off their living chemistry from the surroundings. But because their 20-to-30-nm breadth is thinner even than the simplest bacterial cell wall they would have been like mycoplasmas, bounded by a membranous structure rather than a thick-walled casing. Judging from biological membranes, which take up 6 to 10 nm, the living cavity would have been minuscule. No information has been published about what encases the "fossils" (or even whether they have true cells) so the space available to house living processes can only be estimated. But it is certain to be much less than that of the tiniest mycoplasma, evidently by about two thousand times (Fig. 3). In other words, for the "Mars microbes" to grow and reproduce even like rudimentary mycoplasmas, each of their biochemicals would have to do the work of some two thousand earthly counterpart molecules.

Something is amiss. How could such tiny microbes live? They're said to be rock dwellers, not parasites, not bathed in life-supporting nutrients. Claimed to be "primitive," they have a biochemistry whose efficiency is difficult to fathom (especially in comparison with that of a mycoplasma, which is actually a highly evolved version of that derived from a larger, originally free-living ancestor). And if the "fossils" are actually billions of years old and too tiny to have cell walls, why aren't they weathered, flattened, crushed, wrinkled, and shredded like ancient fossils on Earth?

At the NASA news conference, pictures were unveiled of other "fossils" not mentioned in the McKay et al. (1996a) article. Two types were shown, curved simple cylinders (Fig. 4) and a stringlike specimen cracked into segments (Fig. 5). Though similar in general shape to true fossils, the volumes of these objects are hundreds of thousands of times smaller (Figs. 4, 5). And no data have been presented to show whether these or the jellybean-shaped structures (Fig. 3) are composed of organic matter rather than mineral; whether they are hollow and cellular rather than solid and crystalline; or why they are exposed in bas-relief on fractured surfaces rather than being embedded in rock as Earth fossils are. Their overall size range, variability, and distribution in ALH84001 have yet to be reported, and it hasn't even been demonstrated that they are unquestionably part of the meteorite rather than contaminants or stringy substances splashed on the rock fragment when it was examined.

According to one recent report, the segmented stringlike object (Fig. 5)—now world-famous as the icon of Martian life—is the only such specimen ever found, detected once and as recently as November

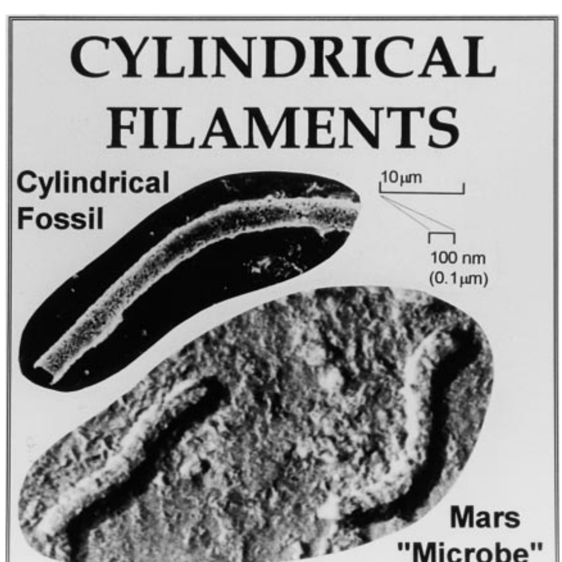

Figure 4. A *bona fide* fossil (*Eomycetopsis* from the 850-million-year-old Bitter Springs Formation of central Australia; scale = 10 μm) compared with the cylindrical "Mars microbes" unveiled at the August 1996 press conference (scale = 100 nm = 0.1 μm)

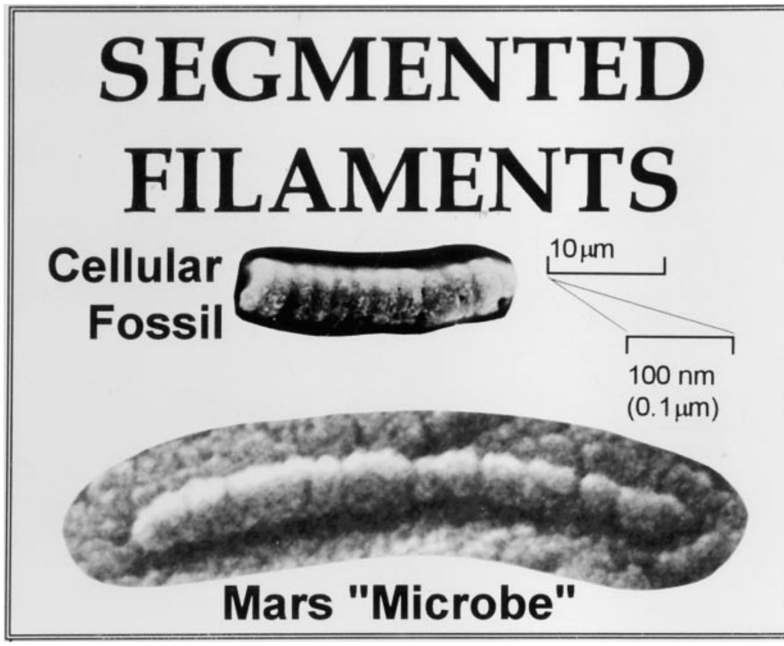

Figure 5. A cellular fossil cyanobacterium (from the 850-million-year-old Bitter Springs Formation of central Australia; scale = 10 µm) compared with the single known segmented (cracked) Martian stringlike specimen (scale = 100 nm = 0.1 µm)

1997 never relocated (Achenbach, 1997, p. 13). And according to an even more recent report, "the putative microfossils are nothing more than narrow ledges of mineral protruding from the underlying rock, that . . . masquerade as fossil bacteria" (Kerr, 1997, p. 1706). Even the Research Team seems to have backed off from its earlier claims, in their words warning that "the morphology of the possible fossil forms . . . is certainly not definitive, and more data are needed" (McKay et al., 1996b, p. 2124).

Could bizarre Mars fossils be identified? Because bacteria can live almost anywhere and are the most ancient forms of life on Earth, it seems sensible to search Mars rocks for bacteriumlike fossils and signs of their living processes. But what if Martian "bacteria" were not at all like those on Earth? Could fossil cells truly bizarre in earthly terms be identified as remains of life?

This type of question is not new to paleobiologists, especially those hunting life's remnants in ancient (Precambrian) rocks. The answer is yes, even for tiny organisms long extinct that bear no obvious relation to life today.

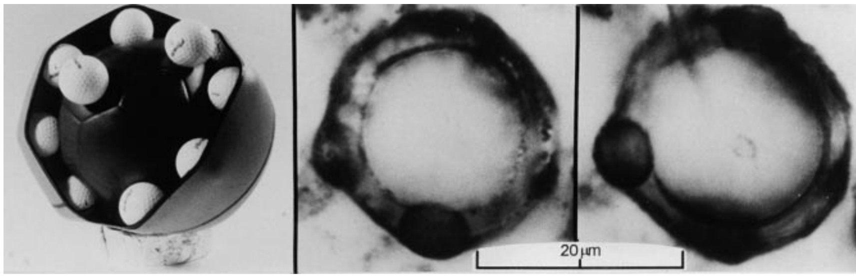

Figure 6. A model (left) of the bizarre 2.1-billion-year-old microfossil *Eosphaera tyleri* (center and right)

Two examples illustrate the point. Imagine a minute microbe having the form of a soccer ball covered by a layer of golf balls encapsulated by a basketball. Nothing so bizarre exists today. But cells like this floated in shallow seas more than two billion years ago (Fig. 6). They were named *Eosphaera* ("dawn sphere") and known to be planktonic because of their spread in the fossil-bearing rock (the Gunflint Formation of southern Canada). We can only guess that the soccer ball core is a central cell, the golf balls reproductive bodies, the basketball a protective shroud. But we know for certain that *Eosphaera* was once alive—it's made of organic matter (now coaly), has cells and wall layers, is known from many specimens (some complete, others decayed, distorted, torn, flattened), has a biological size-range, is part of a complex biological community, was fossilized by processes well understood.

A form even more otherworldly is shown in Figure 7—a chocolate-covered peanut connected by a slender stem to a miniature umbrella. Bizarre indeed! But organisms of this form, too, have been found in the Gunflint rocks (Fig. 8) and named *Kakabekia umbellata* (for the Kakabeka Waterfall, where the first of its type were found, and its umbrella-like crown). How *Kakabekia* fits in the Tree of Life is completely unknown, but enough specimens have been found to guess its life cycle (the crown expands from parasol to large umbrella as peanutlike spores are spawned to reproduce the stock).

Life varies over time, place to place, no doubt planet to planet. But if the right questions are asked and enough data amassed, even fossils strange to us can be identified as remnants of life long past.

Lessons From the Hunt

Headlines win. Perhaps the most obvious lesson learned from this latest chapter in the search for life on Mars is one all too familiar: Initially, at least, headlines and soundbites win while facts and reason lose.

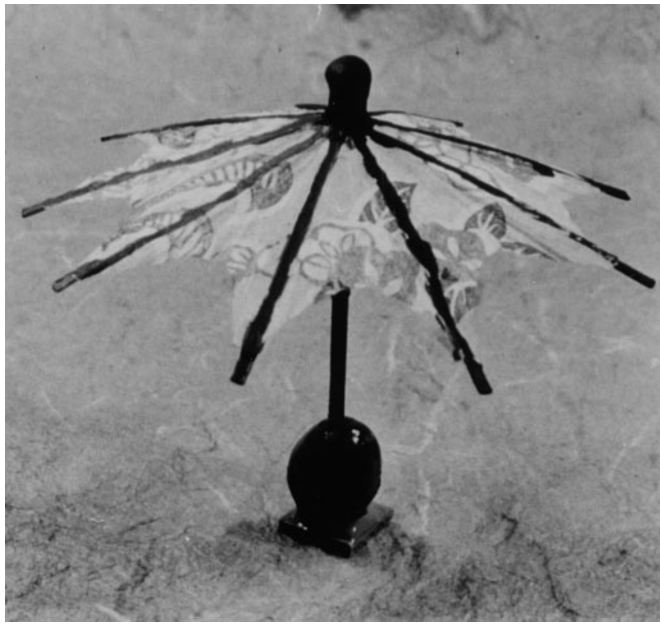

Figure 7. A model of the 2.1-billion-year-old fossil shown in Figure 8

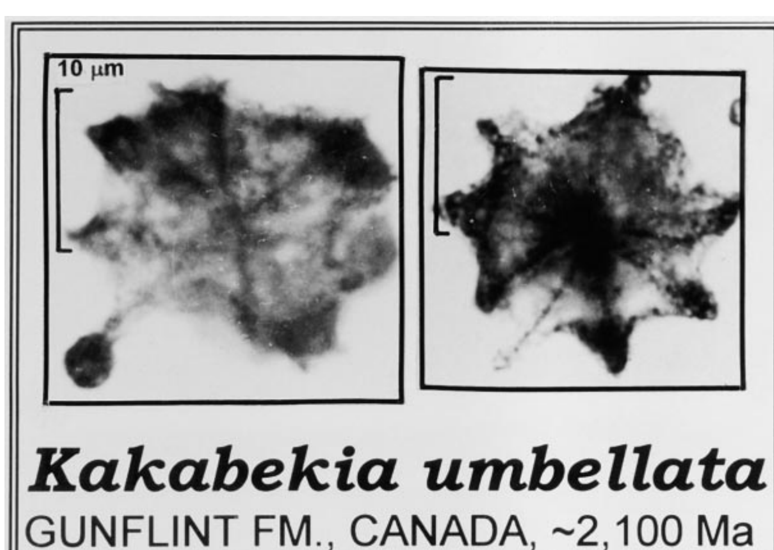

Figure 8. Specimens of a bizarre Precambrian fossil (*Kakabekia umbellata*) not obviously related to microbes living today

Most Americans (more than 60 percent by one poll) agree that "NASA has proved primitive life was present on Mars."

In the face of iffy evidence and a multitude of unanswered questions, why do so many take this view? Some simply want to believe, others are impressed by NASA's track-record and think its backing foolproof. Even among scientists, few are expert in the disparate fields needed to assess the report. Yet hopes certainly have been stirred in the public at large—sold as "good science," if the claim collapses it will give a black eye not only to NASA but to science as well.

The humanness of scientists. A second lesson is that scientists are no more immune from workplace pressures than anyone else, as illustrated by two different readings of the recent history.

According to one, NASA geologist-mineralogists chanced on a suite of minerals they thought possibly biologic in an ancient Martian meteorite. Spurred by these hints, they researched meticulously for two and a half years and added supporting evidence from the Stanford PAHs-group and McGill and University of Georgia specialists. Judicious scientists, they released the findings only after their soon-to-be-published manuscript passed peer review, and then only at the behest of NASA headquarters, which felt duty-bound to inform the public. The published account was meant as a preliminary report, not the final word, and the claim was of evidence "compatible" with past life on Mars, not that they had proved it present. But "compatible . . . possible . . . perhaps . . . maybe" make mushy soundbites and don't sell newspapers. The Research Team was done in by an overzealous press corps.

An alternate scenario has it that the researchers came to be so caught up in the find that normal caution was cast aside. Evidence at odds with the hoped-for outcome was marginalized (such as that of life-searing high temperature and the unbelievably small size of the putative fossils) or even shoehorned to fit the story (such as the "protozoans" recast as bacterial detritus). To seal the case, eye-catching pictures of fossil-like objects were unveiled to the public without peer review or the backing of solid studies. The announcement of still-preliminary results was premature, but with NASA's congressional budget hearings on the horizon the scientists acquiesced to higher-ups who wanted NASA in the headlines. President Clinton's introductory remarks and the press conference itself were part of an elaborate PR blitz that began a week earlier than scheduled not so much because the news had leaked (as it surely had, at least from White House consultant Dick Morris to his ladylove at the Jefferson Hotel), as to avoid being upstaged by presidential candidate Bob Dole's impending announcement of a running mate.

Parts of each version may be right.

Science is not a guessing game. A third, and probably the most important, take-home lesson is that science is self-correcting. There are fine lines between what is known, guessed, and hoped-for, and because science is done by real people these lines are sometimes crossed. But science is not a guessing game. The goal is to know. “Possibly . . . perhaps . . . maybe” are not firm answers, and feel-good solutions do not count. Either life once existed on Mars or it didn’t. Either ALH84001 contains telling evidence or it doesn’t. Eventually, hard facts will sort it out.

It is right to demand that extraordinary claims be backed by extraordinary evidence. But in the hunt for life on other planets another Sagan catchphrase applies as well: “Absence of evidence is not evidence of absence.” If there was once or is now life on Mars or elsewhere in the accessible reaches of space, science must ferret it out!

Acknowledgments

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