Hot Idea Update

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Fossils in Martian Meteorite: Real or Imagined?

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In August, 1996, David McKay and his colleagues at the Johnson Space Center, Stanford University, and McGill University reported evidence for fossil life in a meteorite from Mars. Since then, scientists from around the world have been testing this idea, which in science generally means they are trying to prove the idea wrong. If an idea stands up to such scrutiny, it is on pretty solid ground. The latest round of testing comes from John Bradley (MVA, Inc. and Georgia Tech), Ralph Harvey (Case Western Reserve), and Harry Y. McSween (Univ. of Tennessee). They suggest in a short report in Nature that most of the tiny, tubular, segmented objects that resemble tiny fossils ("nanofossils") described by McKay and his associates are actually thin fractures parallel to atomic planes in minerals in the martian meteorite. The features have been modified, Bradley and coworkers say, by the way samples are prepared for study, producing the apparent segmentations. Dave McKay and his collaborators agree that some structures in the rock are mineral features, but say others are not, and that the sample preparation techniques they used do not produce pronounced segmentation. It appears that a nanofossil is in the eye of the beholder.

References:

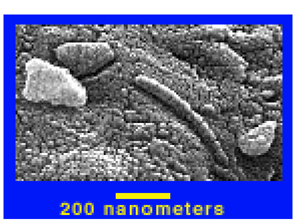
Bradley, J. P., Harvey, R. P., and McSween, H. Y., Jr., 1997, No "nanofossils" in martian meteorite. *Nature*, v. 390, p. 454.

McKay, D. S., Gibson, E., Jr., Thomas-Keprta, K., and Vali, H., 1997, Reply. *Nature*, v. 390, p. 455.

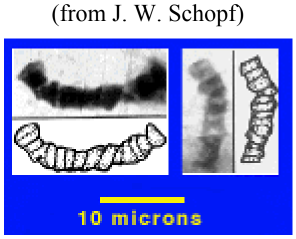
The Original Observations

The original paper by Dave McKay and his cohorts cited several lines of evidence that hinted at past life in martian meteorite ALH84001, as summarized in the first edition of **PSRD**. One of them dealt with observations of fossil-like objects in the rock. Though much smaller, the wormy structures resemble ancient microfossils found on Earth. Because of their small size, they are called "nanofossils."

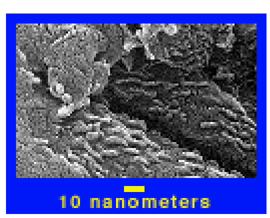
in ALH84001



in Earth rocks
(from J. W. Schopf)



in ALH84001



Click each image to enlarge it.

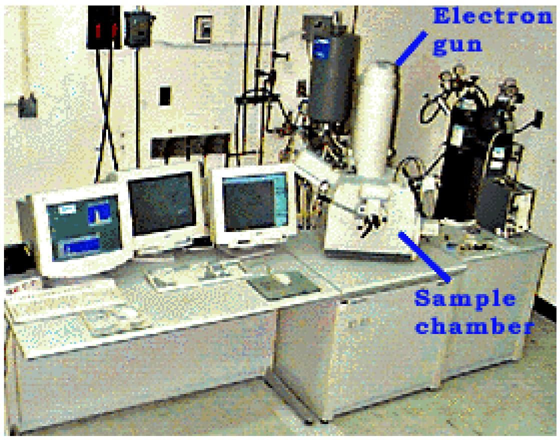
The photo on the **left**, which has appeared in numerous publications, shows a small, tubular, segmented object in ALH84001. Note the resemblance to microfossils found in ancient rocks on Earth (**center**), although the terrestrial fossils are much larger. In some cases, many of the fossil-like objects in ALH84001 are found in one place, as shown in the photo on the **right**. The curious alignment bothered some scientists, making them wonder if the structures might be related to the crystal structure of the underlying rocky material.

Crystal structures or fossils?

The main argument at first centered on the small sizes of the nanofossils. Some scientists wondered if an organism could actually be that small and still function. Others argued that such small organisms are found in the fossil record on Earth, though some questioned those observations. The viability of such small creatures is still debated, including by Bradley and his colleagues in their communication to Nature, though McKay and friends cite occurrences of bacteria as small as 70 nanometers.

The prime tool for examining rocks at high magnification is the electron microscope. There are two basic types. One is called a scanning electron microscope (SEM), which sprays a highly-focused beam of electrons in a grid pattern on the sample, which can be a little chunk of a rock or a polished piece. An SEM is shown in the photograph below.

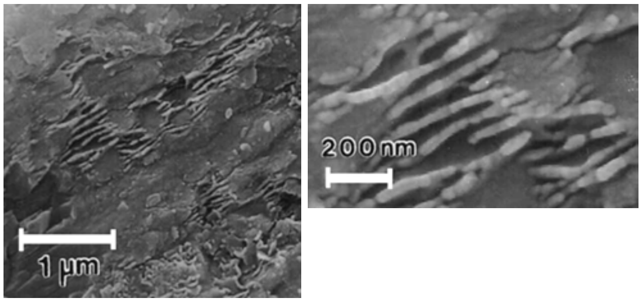
Samples are placed in the sample chamber, which is then evacuated by powerful vacuum pumps. The tall column labeled "electron gun" is also evacuated. It produces electrons near the top and accelerates them down toward the sample. Electromagnets focus the beam to a very fine point (about 1 nanometer in diameter), while other magnets cause it to move in a grid pattern. The monitors allow scientists to view the images produced by detectors that see electrons that bounce off the sample or others (called secondary electrons) that are produced in it. The monitor on the far left provides informtion about the chemical composition of the mineral in the sample.



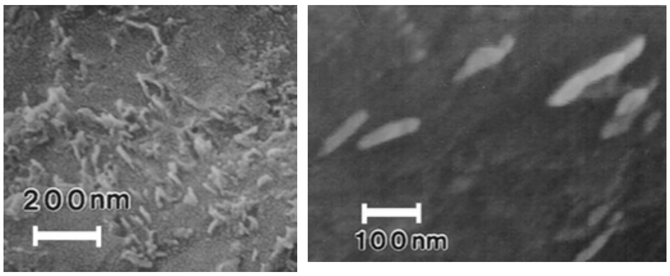
The other type is called a transmission electron microscope (TEM), which transmits electrons through very thin (less than one micrometer) slices of rock. TEMs can also move the electron beam in a grid pattern to produce an image like a picture.

An interesting problem in looking at rocks with electron microscopes is that the instruments are so good that you can see features you might not expect to see. Crystallographic features not visible in conventional light microscopes are evident, and some types of fractures can appear curved or worm like. Even more confusing, because the samples need to be coated with some kind of conducting material to carry off the electrical charge deposited by the electrons, scientists have to worry about introducing artifacts when they apply the coating to their samples. Small crystallographic features and artifacts from sample preparation are what Bradley and coworkers argue are the so-called nanofossils observed by McKay and his team.

Pyroxene Crystal Surface
Click on an image to enlarge it.



Carbonate Crystal Surface
Click on an image to enlarge it.



Scanning electron microscope images obtained on samples of ALH84001 in John Bradley's lab. Photos on the right are higher magnification pictures of regions in photos on the left. The top pair show the surface of a pyroxene crystal; the bottom pair show a carbonate crystal.

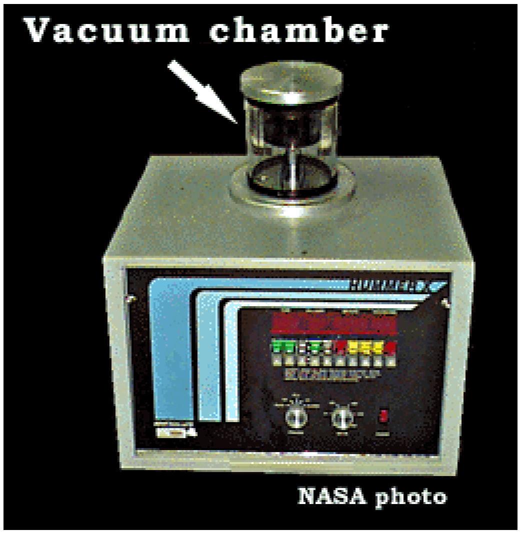
Bradley and his team suggest that the nanofossils in ALH84001 are not fossils at all, but are instead small-scale features of crystals (which Bradley calls "cleavage lamellae") of pyroxene and carbonate in the rock. Basically, these are parallel planes in mineral crystals that leave steps on broken surfaces. Many of the elongated microscopic features in the rock are lined up on the surfaces of crystals and seem to emerge from inside the grains. Bradley says that this is evidence for a crystallographic origin, not fossils deposited on the surface. Some of these features are even curved like the nanofossils reported by McKay.

In their reply to Bradley and coworkers, McKay and company agree that there are numerous crystallographic features on crystal surfaces in ALH84001, and they illustrate this with some photographs like those above. They also argue that some features may have been caused by weathering, producing clay minerals. No matter how the linear features formed, McKay and associates agree that such features are not of biological origin.

On the other hand, the McKay group points out that there are other curved and more isolated structures besides those shown by Bradley, and it is those structures that the group claims are biological. They also argue that the structures they call nanofossils are much larger, up to 750 nanometers (0.75 micrometers) long, than those shown by Bradley (see the photographs above). John Bradley counters in a communication to PSRD that many of the elongate structures in their images are just as long, and also point out that some of the previous evidence cited by McKay and colleagues, such as the herd of nanomaggots, are the same size as most of the crystallographic features observed. McKay notes that objects like those in the nanomaggot herd are more ovoid than elongate, and thus less likely to be mineralogic features.

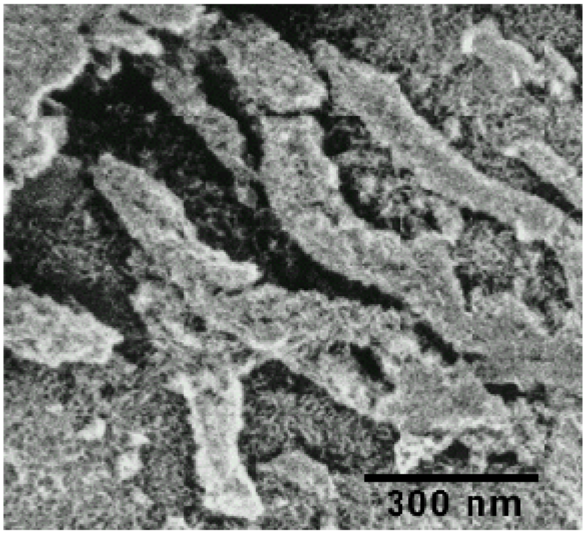
Pesty Problems with Sample Preparation

This is a typical apparatus used for depositing conducting coatings on samples. Samples are placed in the glass bell jar (vacuum chamber) and the jar is pumped down to a low pressure. Rods of carbon or wires of metal such as gold, are heated by electric currents so hot that they begin to evaporate. The vapor lands everywhere, some forming a thin coating on the sample.

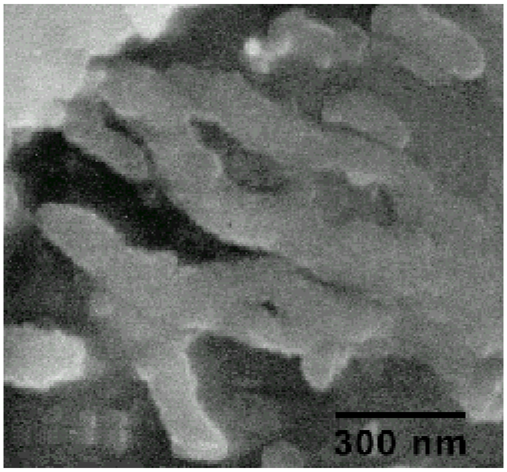


Everyone who works with electron microscopes worries about introducing artifacts during sample preparation, and the smaller the feature you examine, the more troublesome the problem becomes. The samples are coated with a conducting substance such as carbon, gold, and palladium. These coatings are ultrathin, typically between 2 and 20 nanometers thick. As thin as that is, it is significant compared with the scale of the features suspected to be nanofossils. McKay and coworkers show an interesting example of this effect.

uncoated



coated

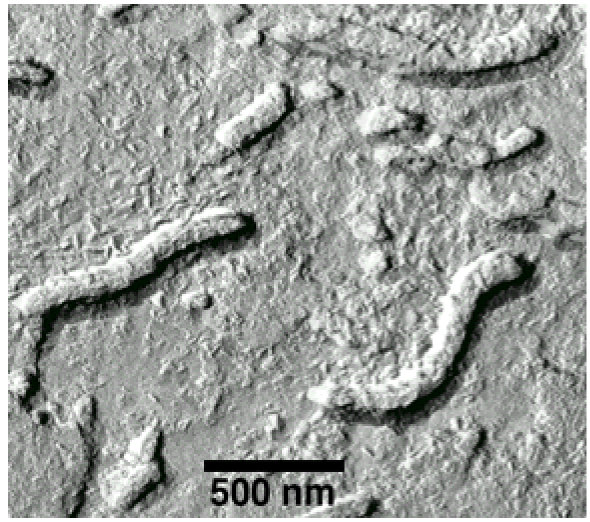


The **left** image, shown by McKay and coworkers in their paper, shows the surface of an uncoated carbonate area in ALH84001. (Surfaces can be examined without coating by using low electron voltages, but the images are not as sharp so the samples are usually coated.) In between the elongated objects the surface is wispy and composed of many tiny grains.

The photograph on the **right** shows the same surface as the left, now coated with a layer of carbon 10 nanometers thick. The elongated objects are unchanged, though easier to see, but the wispy material is no longer visible and the surface looks smooth.

This shows that coating samples can hide some features. Another problem is that coating might lead to creating features that were not present in the rock. This is what Bradley and his colleagues suggest has happened to produce the apparently segmented objects in ALH84001. They argue that thick coatings of gold or a mixture of gold and palladium cause the formation of segmented surfaces, and the thicker the coating, the more pronounced the segments. Thus, they argue that the obvious segmented nature of the feature shown in the first photograph in this article is not a real feature of the rock, but formed when the sample was coated.

McKay and associates disagree with this interpretation as they have observed segmented structures on samples prepared in several different ways. For example, the photograph on the **right** shows elongated, S-shaped objects with segments, though the segments are not as clear as they are in photos in McKay's original paper. This sample was prepared by making a replicate of the surface by placing a fluid, plastic substance on an uncoated, freshly broken surface of ALH84001, which they believe preserved the original features in the sample. This plastic was removed after it had hardened, then examined in a transmission electron microscope. The objects have a segmented structure, perhaps representing divisions inside the cells, which McKay and colleagues claim is good evidence that the objects are real fossils.



John Bradley suggested to PSRD that even the replication technique may introduce artifacts. The technique is well established, but is usually used to replicate objects on the micrometer scale or larger. The problem with replication at the nanometer scale is that the structure of the replicating material itself contributes to the textures you observe. In addition, when the material is removed from the sample, it might form stretch marks or cracks, perhaps producing a bogus segmented structure. Bradley concludes that the most effective way to identify features in rocks as nanofossils is to use transmission electron microscopy, which allows you to see interior cell walls and other diagnostic features.

An Unsolved Problem

It appears that one person's nanofossil is another person's artifact. In spite of this apparent complete disagreement, however, this latest debate has helped clarify some issues. For example, it is agreed that some of the features in ALH84001 that vaguely resemble nanofossils are actually structural features of the minerals, weathering products, or both. It shows that sample preparation is worth an even more thorough look, so that we can know which features might be artifacts and which are probably not.

Undoubtedly, the continued debate will lead to new tests of all the evidence for life in ALH84001. The debate over nanofossils is part of a larger debate on the temperature of formation of the carbonates in the meteorite, which is argued even more vigorously than is the reality of the nanofossils! Other **PSRD** articles that have dealt with the temperature of origin of the carbonates are listed below. Whatever the outcome of all the arguments and detailed study of the martian meteorites, it will show us how to search for life in samples returned from the surface of Mars, which is planned tentatively for the year 2005.

Additional Resources

David S. McKay and others, 1996, Search for Past Life on Mars: Possible Relic Biogenic Activity in Martian Meteortie ALH84001, *Science*, vol. 273, p. 924-930.

G. Jeffrey Taylor, "Life on Mars? The Evidence and the Debate." *PSR Discoveries*. **Oct 1996**. <http://www.psrd.hawaii.edu/Oct96/LifeonMars.html>

G. Jeffrey Taylor, "Life on Mars -- The Debate Continues." *PSR Discoveries*. **March 1997**. <http://www.psrd.hawaii.edu/Mar97/LifeonMarsUpdate.html>

E. R. D. Scott, "Shocked Carbonates may Spell N-o L-i-f-e in Martian Meteorite ALH84001." *PSR Discoveries*. **May 1997**. <http://www.psrd.hawaii.edu/May97/ShockedCarb.html>

G. Jeffrey Taylor, "Low-temperature Origin of Carbonates Consistent with Life in ALH84001." *PSR Discoveries*. **May 1997**. <http://www.psrd.hawaii.edu/May97/LowTempCarb.html>

Mars links, including past and future mission descriptions from the National Space Science Data Center (NSSDC).