Hot Idea posted October 18, 1996

Life on Mars?

Written by G. Jeffrey Taylor
Hawai'i Institute of Geophysics and Planetology

People have long wondered if life could have existed or even still exits on Mars. The Viking landers in 1976 searched for signs of life in the red soil, but found no clear-cut evidence. Future missions are planned to search other terrains on Mars, such as areas where water must have flowed in rivers and formed lakes that eventually dried up. But the search has already started. A group of investigators at the Johnson Space Center and Stanford University has revealed evidence from an intense, careful study of a meteorite from Mars that tiny bacteria-like creatures may have lived in cracks in the rock.

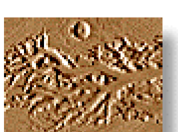
In this first issue of **PSR Discoveries**, we describe evidence the researchers have assembled, and present some of the nonbiological alternatives other scientists have proposed. We intend to follow the debate as it unfolds during the coming months or, perhaps, years.

Begin your discovery here. Investigate the type of evidence of most interest to you or simply go through the list in order.

Hot Idea Contents

Meteorite from the Ancient Crust of Mars. ALH 84001 originated as a slowly-cooled igneous rock in the Martian crust, was excavated by an impact, altered by fluids, and finally sent to Earth by another impact.

The Evidence and the Debate. The NASA-Stanford group cites four lines of evidence for fossil life in ALH 84001, all of which are found associated with unusual globules of carbonate minerals: (1) formation before arrival on Earth; (2) concentrations of organic chemicals; (3) tiny grains of iron oxide and iron sulfide; and (4) tubular, fossil-like objects. Alternative interpretations appear in pop-up windows which you open with a click of a button (a JavaScript enhancement).



Ancient Hospitable Mars. Before about 3 billion years ago, Mars may have had a more clement climate than now, perhaps allowing life to develop.

The Researchers.

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

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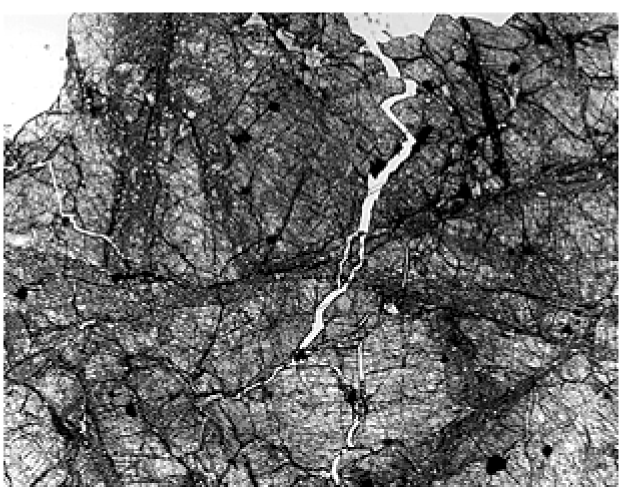
Life on Mars?
Meteorite From the Ancient Crust of Mars

by G. Jeffrey Taylor

Photograph of a specimen of Allan Hills (ALH) 84001, a 1.9 kilogram (4.2 pound) meteorite found in Antarctica. The little cube in the picture is 1 cm across.

Like most meteorites, it was partly covered with smooth, dark, glassy material, called the fusion crust, which formed when the rock blazed through the Earth's atmosphere.

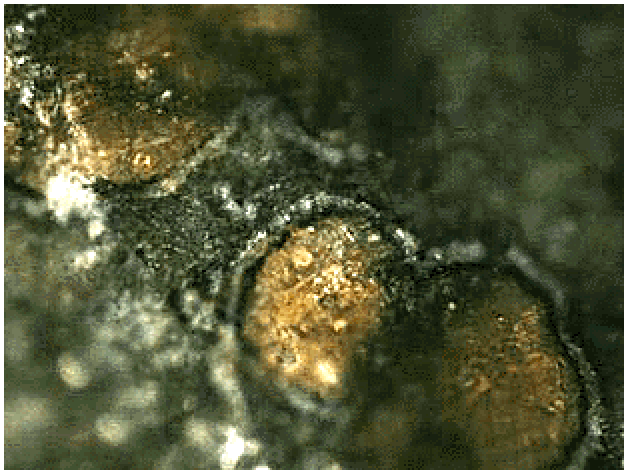
It was found in 1984 during the annual meteorite search in Antarctica. According to geologist Roberta Score, former laboratory manager in the meteorite curatorial facility and the explorer who actually found the meteorite, the rock looked greenish inside as it lay on the Antarctic ice. In the laboratory, however, it looks gray. (NASA photo.)



View of a thin slice of ALH 84001 in a microscope reveals large crystals (up to 6 mm long) of orthopyroxene (a silicate mineral containing iron and magnesium) and a small grain near the top of the photo of plagioclase feldspar (sodium-calcium alumino-silicate), rendered glassy by shock waves.

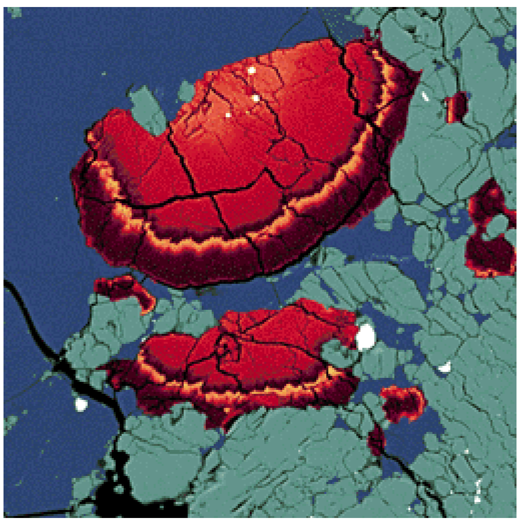
Orthopyroxene makes up about 95% of the rock, and the large size of the crystals suggests that the rock crystallized in a slowly-cooling magma body inside the Martian crust.

The crystals contain numerous cracks and are separated by crushed zones of much smaller crystals. These zones probably formed when high-pressure shock waves, generated by an impact, crushed portions of the large crystals. Crushed zones and other cracks in the rock contain the carbonate globules that have the features ascribed to biological processes. (Photo courtesy of David Mittlefehldt, Lockheed Engineering and Science Company.)

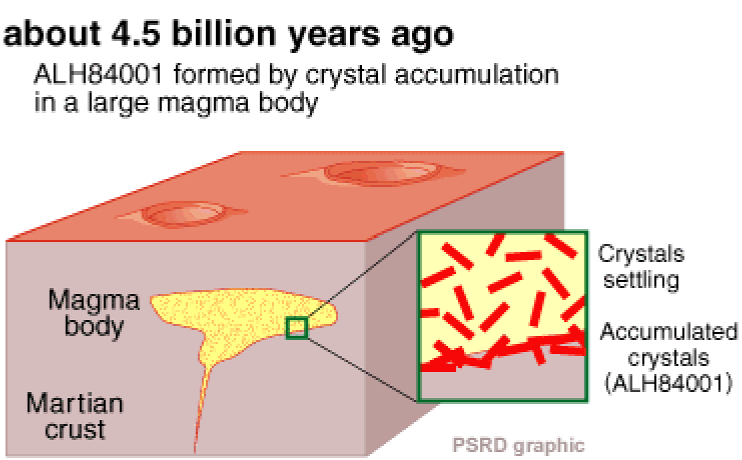


The meteorite is decorated with globules of carbonate minerals that seem to occur along cracks in the rock. These globules have a somewhat orange color and are small, only 0.1 millimeter across.

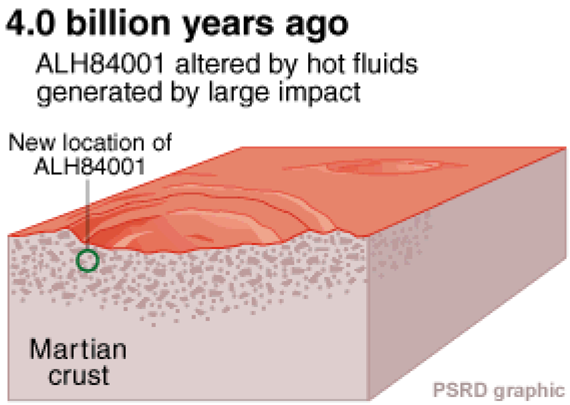
As discussed in The Evidence and the Debate, a big discussion centers on the origin of the globules, especially whether they formed from very hot fluids (more than 650 degrees Celsius) or cooler ones (between 0 and 80 degrees Celsius) . Life would not have survived high temperatures. (NASA photo.)



When viewed in an electron microscope, it is obvious that the carbonate globules are complicated. This photograph is a colorized image of the intensity of electrons bounced back from a polished surface of a sample of ALH 84001. The colors represent different minerals. Green is orthopyroxene (the silicate with iron and magnesium), blue is glassy plagioclase feldspar, and the various shades of red and orange are carbonate minerals with a range in chemical composition. (Photo courtesy of Ralph Harvey, Case Western Reserve University.)

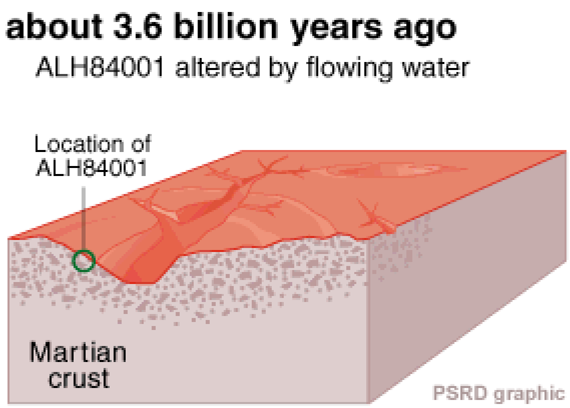


Studies of ALH 84001 have revealed the basic outline of the rock's history. It formed about 4.5 billion years ago in a relatively large magma body inside the crust of Mars. Its high abundance of one mineral (orthopyroxene) indicates that this mineral must have accumulated in the magma, probably near the bottom of the magma body, eventually forming the original igneous rock with large crystals of orthopyroxene. (Graphics by Brooks Bays, PSR Discoveries graphic artist.)



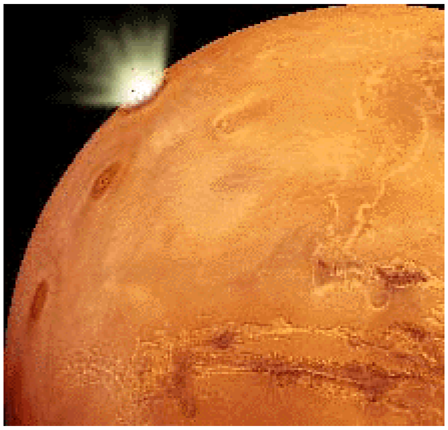
An impact blasted ALH 84001 4.0 billion years ago, ripping it from its deep location and probably placing it nearer to the surface in a pile of debris. The shock waves deformed the pyroxene crystals and converted the feldspar to glass. This event also heated the rock, allowing Ar gas to escape and resetting the potassium-argon clock, which allows scientists to determine the age of the impact.

On the basis of the elemental compositions of the carbonate minerals, Ralph Harvey (Case Western Reserve University) and Harry Y. McSween (University of Tennessee) have proposed that the rock was 650-700 degrees Celsius after the impact and hot fluids rich in carbon dioxide circulated through the crater, depositing the carbonate globules along cracks. (Graphics by Brooks Bays, PSR Discoveries graphic artist.)



In contrast to Harvey and McSween, most investigators, such as Allan Treiman of the Lunar and Planetary Institute and others at the Johnson Space Center in Houston and the Open University in England, believe that mineral compositions and the abundances of the isotopes of carbon and oxygen in the globules imply that the carbonates were deposited by relatively cool (no more than 80 degrees Celsius) flowing water enriched in carbon dioxide, after the rock had been deformed by impact.

Determining the age of the carbonate globules is extremely difficult. Estimates range from 1.4 to 3.6 billion years. The age is not known accurately enough to link the formation of the carbonates to the 4.0 impact event, to the relatively wet era on Mars between 3 and 4 billion years ago, or to any time before it was blasted off Mars and sent our way. (Graphics by Brooks Bays, PSR Discoveries graphic artist.)



Scientists in Switzerland, Japan, and the U.S. (Arizona, and California) have measured the time ALH 84001 was exposed to cosmic rays in space. This actually dates the time the meteoroid containing the rock was smaller than a few meters across; the interiors of larger objects are shielded from radiation. This time is between 16 and 17 million years ago, and may indicate when it was lifted off Mars by an impact as depicted in this artist's rendition. It could have been liberated earlier, however, as a large object, and the 16 to 17 million years simply dates a recent breakup of the object as it wandered in space. (Graphics by Brooks Bays, PSR Discoveries graphic artist.)

It is easy to determine how long a meteorite has been on Earth if it was seen to fall. Fortunately, we can also determine the residence time of other meteorites by determining the extent to which radioactive isotopes (produced by cosmic rays) have decayed. Useful isotopes for this purpose are carbon-14 and aluminum-26.

Measurements done on ALH 84001 by scientists in Arizona show that the meteorite fell about 13,000 years ago. It was eventually spotted in 1984 by Roberta Score, and identified as a Martian meteorite in 1994 by one of Roberta's colleagues, Dave Mittlefehldt.

Now ALH 84001 is the focus of intense scientific scrutiny because of the possibility that the carbonate globules were formed in part by biological activity of ancient Martian life forms.

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PSRD Discoveries

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Life on Mars?
The Evidence and the Debate

by G. Jeffrey Taylor

Researchers at the Johnson Space Center and Stanford University have outlined four main lines of evidence that point to biological activity in Allan Hills (ALH) 84001 and, hence, that life once existed on Mars. They have carefully pointed out alternatives to each piece of the story, but they argue that taken as a whole, the best explanation for ALL the features associated with the orange carbonate globules in ALH 84001 is that tiny organisms lived on the surfaces of cracks.

Other scientists have devised even more alternatives than David McKay and his colleagues had considered, and a spirited debate is beginning. **PSR Discoveries** presents the evidence assembled by McKay and coworkers, along with the alternatives that have been discussed so far. Whatever the outcome of the debate, it seems certain that it will spark a great deal of research and we will end up knowing more about the geologic, and possibly biologic, history of Mars.

The Evidence and the Debate Contents

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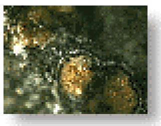
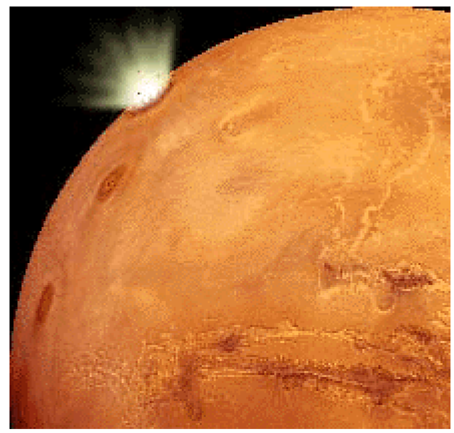
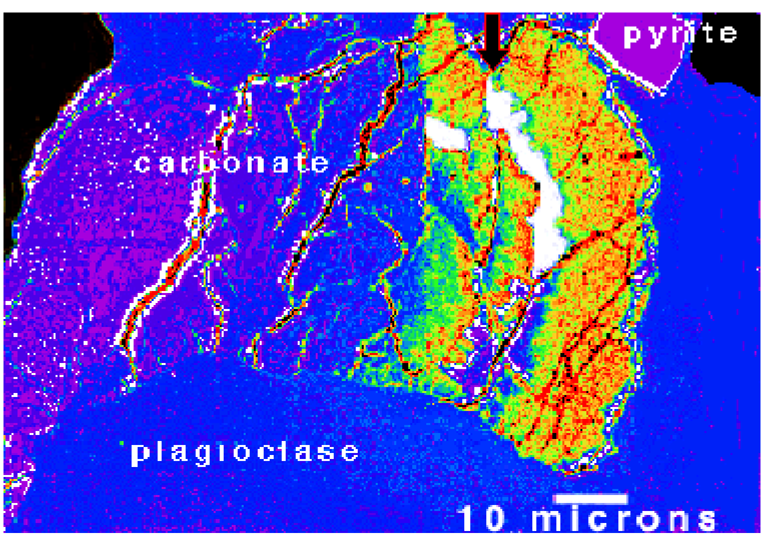


Carbonate Globules Formed on Mars

by G. Jeffrey Taylor

There is little doubt that a group of meteorites come from Mars. The evidence is described clearly in a report on the web site of the meteorite curators at the Johnson Space Center (see link on our title page). The ratios of the isotopes of oxygen indicate that ALH 84001 is also a member of that group, though it is much older than the others (over 4 billion years vs 1.3 billion years or less). The meteorite also contains trapped gases like those in the Martian atmosphere. It seems highly likely that ALH 84001 comes from Mars, and there is not much debate about this point. This is an artist's rendition of the impact that liberated ALH 84001 from the martian surface. (Graphic by Brooks Bays, PSR Discoveries graphic artist.)





There is also little dispute that the carbonate nodules formed before the meteorite arrived on Earth 13,000 years ago. As seen in this photograph, which has been colorize to highlight compositional distinctions, the prominent chemical zoning pattern is offset in some carbonate globules, undoubtedly because of an impact event that took place before arrival on Earth. An arrow points to the offset, shown prominently by the white bands. The formation age of the carbonates also indicates a pre-terrestrial origin for them. Although the age of the globules is highly uncertain, there is no question that they formed at least a billion years ago, long before the meteorite landed in Antarctica. (Image based on photograph by David Mittlefehldt.)

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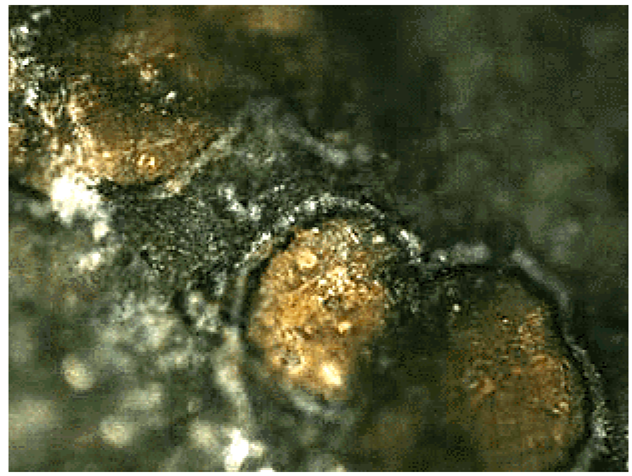
Carbonate Globules Formed From Liquid Water

by G. Jeffrey Taylor



Survival of life like that on Earth requires hospitable conditions, most notably water. Data on the isotopic compositions of oxygen in the carbonate globules indicate that the carbonates formed between 0 and 80 degrees Celsius, appropriate for life to flourish. (NASA photo)

Alternative View of Temperature

Link to Alternative View for browsers not yet supporting JavaScript.

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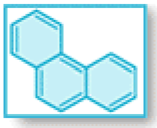
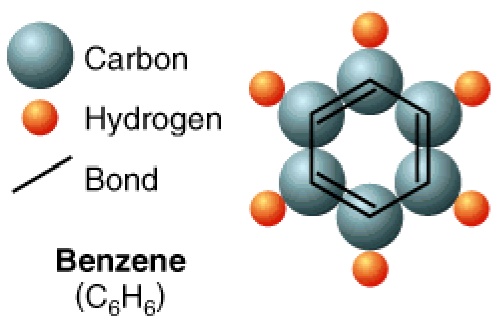
October, 1996

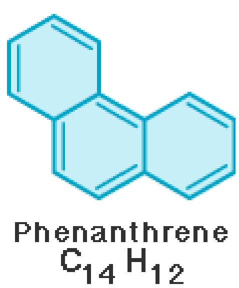
by G. Jeffrey Taylor



Polycyclic Aromatic Hydrocarbons



Organisms are made of complicated hydrocarbons (compounds made mostly of hydrogen and carbon), so their presence should be marked by high concentrations of hydrocarbons produced when the organisms decayed. One group of hydrocarbons produced by decomposition of ancient organisms on Earth are called polycyclic aromatic hydrocarbons. These are certainly aromatic: they stink! The simplest one is benzene, depicted here. The corners of the hexagonal structure are occupied by carbon atoms, and a hydrogen atom is bonded to each carbon. The structure of benzene is usually drawn as a hexagon with a circle in the center. The circle represents six electrons in the molecule that are not associated with specific carbon atoms, but are spread out above and below the plane containing the carbon atoms. (Graphic by Brooks Bays, PSR Discoveries graphic artist.)



More complicated aromatic hydrocarbons consist of benzene molecules linked together, such as phenanthrene, shown here. When two or more benzenes are joined the compounds are called "polycyclic aromatic hydrocarbons," or PAHs for short. A number of PAHs were detected in ALH 84001. Researchers at Stanford University, working with colleagues at the Johnson Space Center, have shown that the PAHs in ALH 84001 are not contaminants from the laboratory or Antarctica. PAHs are produced by decay of organic materials; for example, PAHs are abundant in coal deposits. Their presence in ALH 84001 suggest to the Stanford-NASA team that organisms were present. The researchers acknowledge that PAHs are also present in carbon-rich meteorites and in interplanetary and interstellar dust, in which PAHs formed by nonbiological chemical processes, but show that the PAHs in ALH 84001 are different from those in other meteorites, except for a type called "CM carbonaceous chondrites." CM chondrites contain clay-like minerals, organic compounds, magnetite, and iron sulfides. Astronomical observations of asteroids suggest that many asteroids may be like CM carbonaceous chondrites. (Graphic by Brooks Bays, PSR Discoveries graphic artist.)

Alternative Views of Nonbiological Hydrocarbons

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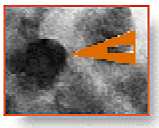
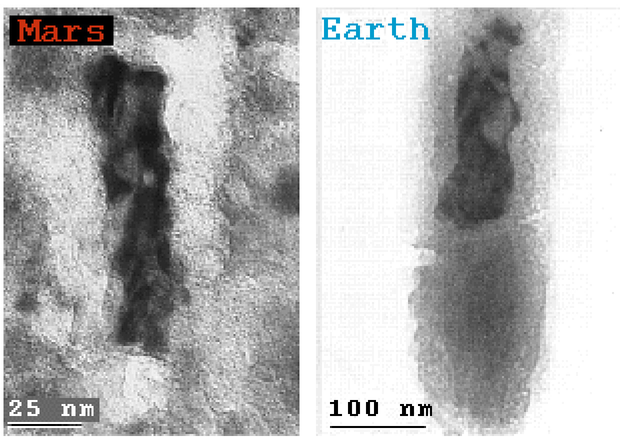
October, 1996

by G. Jeffrey Taylor



Tiny Grains of Magnetite and Iron



McKay and co-workers have identified very small grains of magnetite (iron oxide) and two types of iron sulfide. These have similar sizes and shapes as magnetite and iron sulfide grains formed by bacteria on Earth. This photo shows an iron sulfide grain from the Martian meteorite (left) and a similar grain in a terrestrial bacteria living in the cell of a plant root. (Photo adapted from *Science*.)

Alternative View of Mineral Formation

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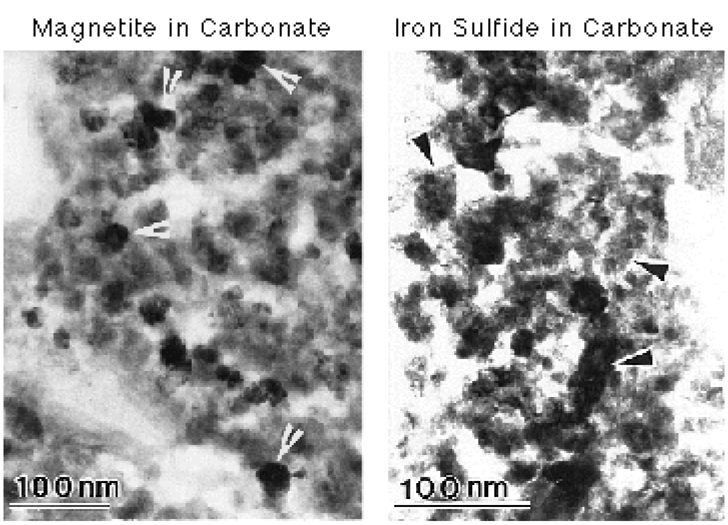
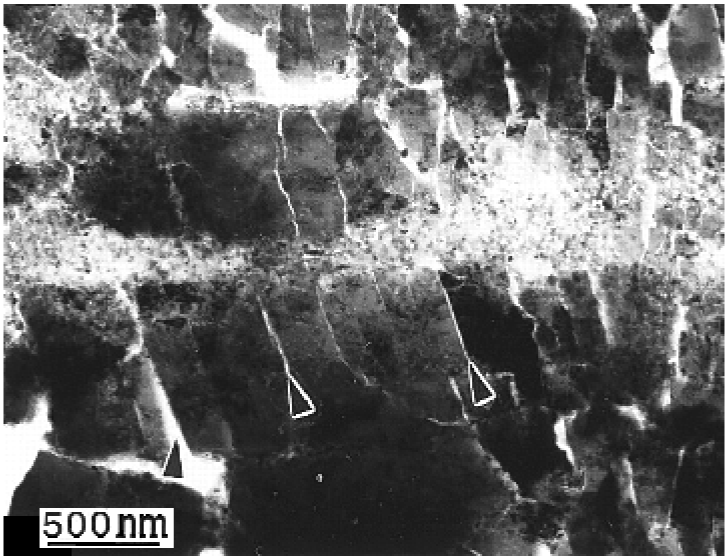


Whether the shapes can be produced by non-biological processes or not, McKay and colleagues argue that the types of minerals present and evidence for some of the carbonate dissolving suggests that biological activity was involved. This photograph shows the distribution of small magnetite (left) and sulfide grains in a carbonate matrix. (Photo adapted from *Science*.)



This photograph shows a light band cutting across a carbonate grain. McKay and co-workers suggest that this band was formed by partial dissolution of carbonate. It is in these areas that the magnetite and iron sulfides shown above are found. According to the research team, dissolution of the carbonate required that the water be acidic, but formation of magnetite and iron sulfide from water would have required alkaline (far from the acidity needed to dissolve carbonate), unless bacteria or other microorganisms were involved. The lack of a simple non-biological way to produce the minerals existing together leads them to conclude that magnetite and sulfide formed as the result of biological processes. (Photo adapted from *Science*.)

Alternative View of Mineral Dissolution

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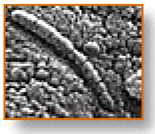
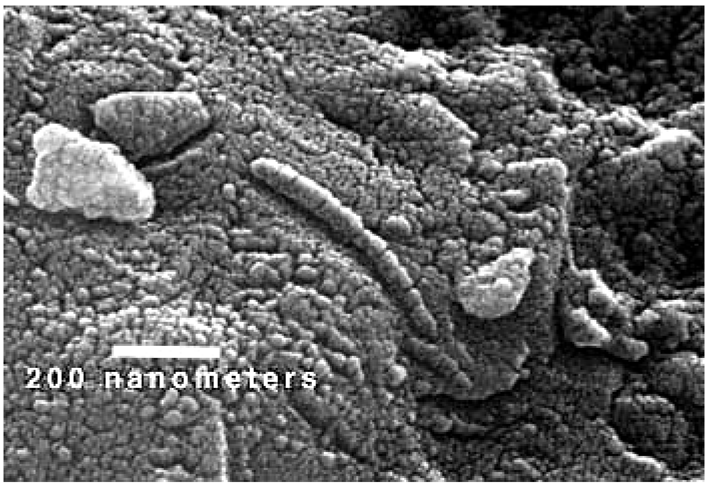
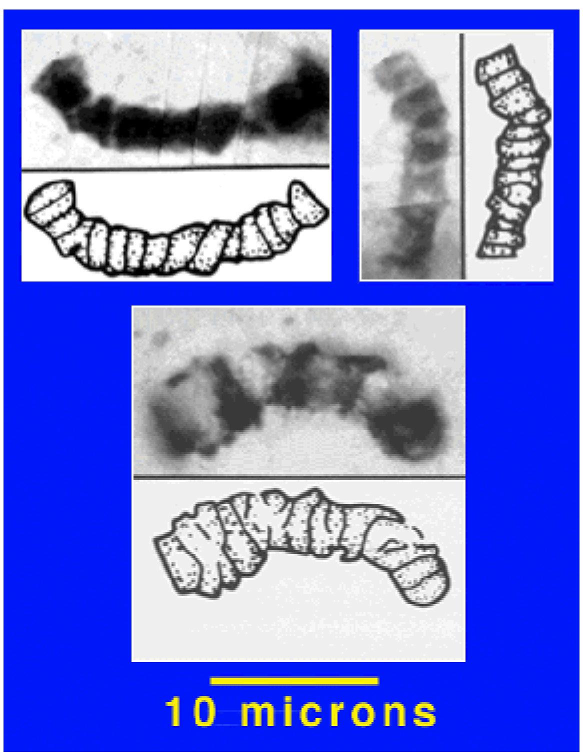


Microfossils

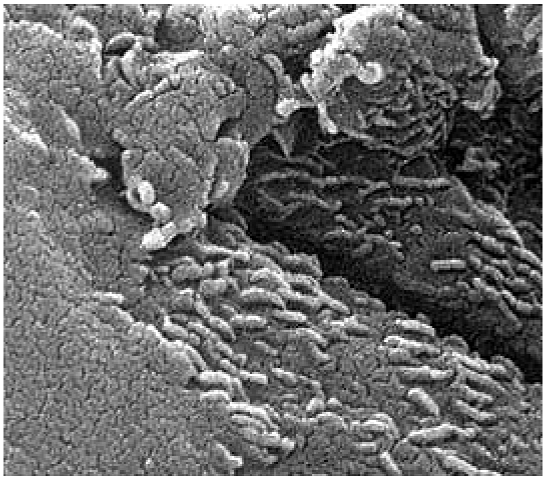
by G. Jeffrey Taylor



The most stunning evidence for most of us is the presence of tiny, tube-shaped objects that resemble terrestrial microfossils. The one shown here, photographed with an electron microscope, is about 20 nanometers wide (that's only 0.00002 millimeters) and has segments suggestive of filamentous cyanobacteria. Cyanobacteria used to be called blue green algae. They occur as single-cellular or multicellular (filamentous) forms. Bacteria and cyanobacteria are called prokaryotes, which are organisms whose cells do not have a nucleus. Instead, they have a single strand of DNA, strung in a closed loop. (NASA photo.)



These very tiny fossils were discovered in Western Australia by J. William Schopf (University of California, Los Angeles). A photograph of each specimen appears with an interpretive drawing of the structure. The resemblance to the structures in ALH 84001 is quite striking, though those from the Earth are much larger: the scale bar on the photo is in micrometers, rather than nanometers. (Photo courtesy of J. William Schopf.)



This image shows a large number of microscopic fossil-like objects on ALH 84001 resembling a herd of nanomaggots. Each one is about 10 nanometers long. (NASA Photo.)

Alternative View of Shapes

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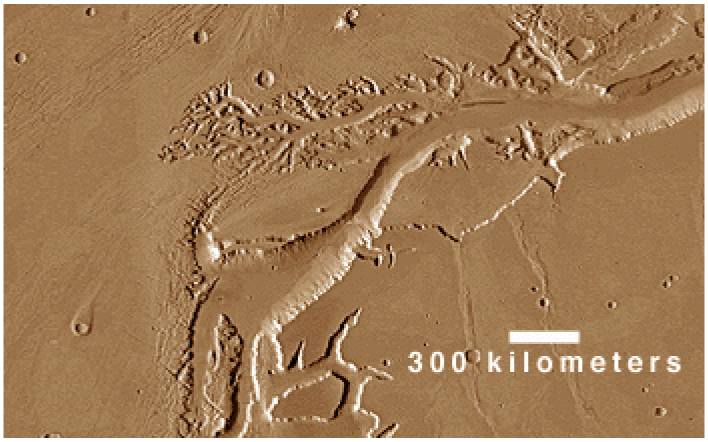
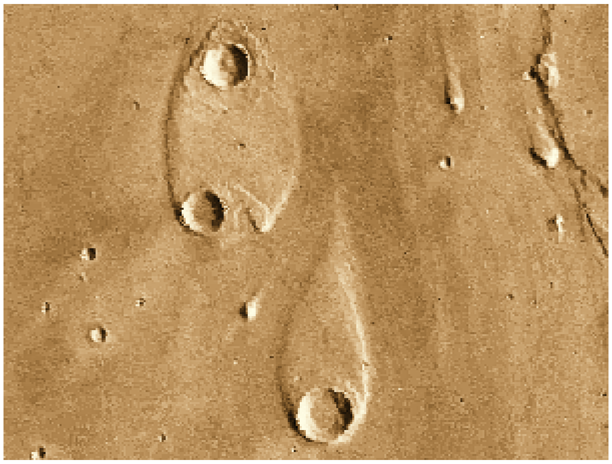
Life on Mars?
Ancient Hospitable Mars by G. Jeffrey Taylor

All known forms of life on Earth require the presence of liquid water. Mars is an attractive planet to search for extraterrestrial life because its surface contains clear evidence that water flowed across it. There are large channels and valley networks, both of which seem to require large amounts of flowing water. The meteorites from Mars contain hydrated minerals, indicative that water was present in their magmas, hence available to be transferred to the atomsphere to produce a far wetter climate than possessed by present-day Mars. How much warmer and wetter the atomsphere was is not known with certainty, but there certainly was abundant flowing water, especially early in Martian history.

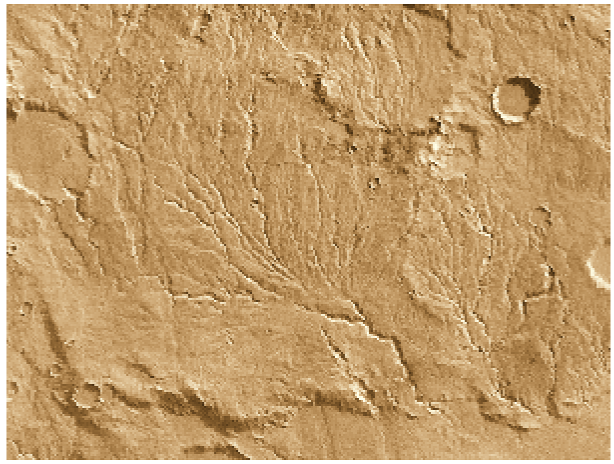


Large channels like this one in Kasei Vallis indicate that water once flowed in prodigious amounts on Mars. However, this does not imply that it had to be incredibly rainy on Mars. In fact, it may not be possible to form such huge floods by rainfall alone. The water more likely emerged from the ground when ice melted rapidly, perhaps because of magmas moving through the crust. The water would end up spurting from the ground, sweeping downhill and eroding the landscape. (23°N, 65°W, NASA photo.)



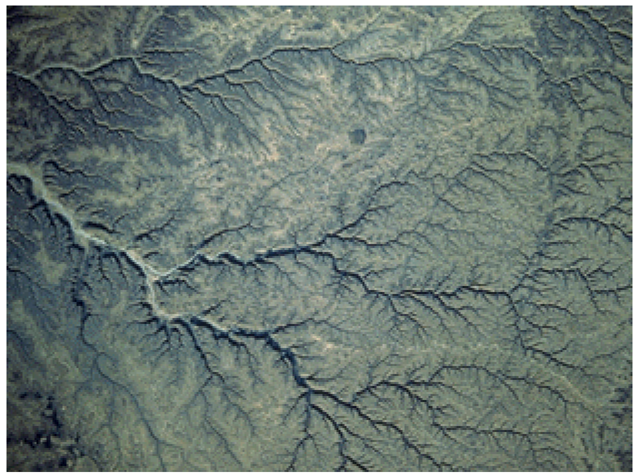
This photograph of an area near the mouth of Ares Vallis in Chryse Planitia shows the power of the surging water. Flood waters flowing from the bottom to the top of the image were diverted by two craters 8-10 kilometers in diameter. Two streamlined islands were formed. (20°N, 31°W, NASA photo.)

Valley networks also indicate the presence of liquid water on the surface of Mars. Some may have been formed by groundwater flowing onto the surface, but others resemble typical branching drainage networks on Earth. However, this and other networks on Mars lack the small-scale streams feeding into larger ones. This may indicate that rainfall was not the only process at work to provide the water to carve the valleys. (42^{o}S, 92^{o}W, NASA photo.)

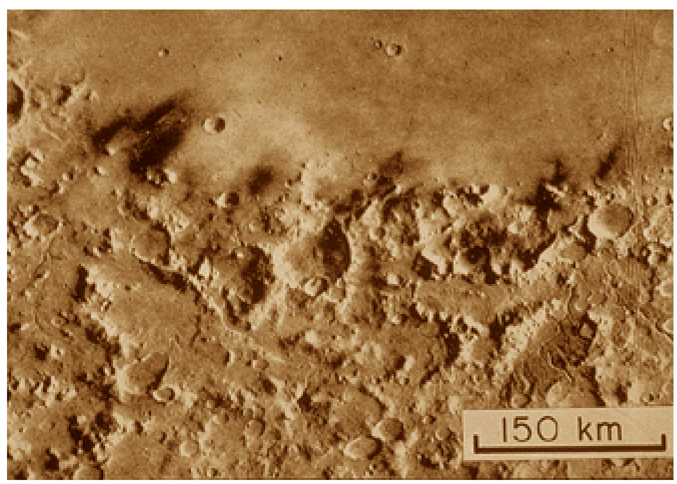


This branching, or dendritic, drainage network in South Yemen was photographed by the Space Shuttle. Note that it is more intricate than the network on Mars, with many smaller streams flowing into larger ones.

Calculations suggest that the amount of water required to form channels and valley networks on Mars could have been a few percent of the volume of Earth's oceans, although some estimates place the amount at much less than one percent. On Mars as on Earth, there would have been seas and land masses, not a global ocean.The presence of water on Mars, at times flowing in great rivers and standing in lakes (which were probably frozen on top), makes it promising to search for life on this desert-like, reddish planet. (NASA photo.)



Most of the prominent valley networks occur in the ancient highlands of Mars. This region is characterized by numerous large craters that have been strongly eroded. Since most large craters formed before about 3.8 billion years ago (an age inferred from studies of large craters on the Moon and from lunar samples), erosion rates must have been quite high, certainly much higher than they have been since that time. ALH 84001 is an old rock, formed in the ancient highlands and was involved in a large cratering event 4.0 billion years ago. Conditions in the ancient highlands would have made it likely that the rock was exposed to water, either on the surface or flowing through cracks beneath the ground. (NASA photo.)



Return to Life on Mars?.

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Life on Mars?
The Researchers

List of authors of the *Science* article:

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

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  Johnson Space Center
- Everett K. Gibson, Jr.
  Johnson Space Center
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