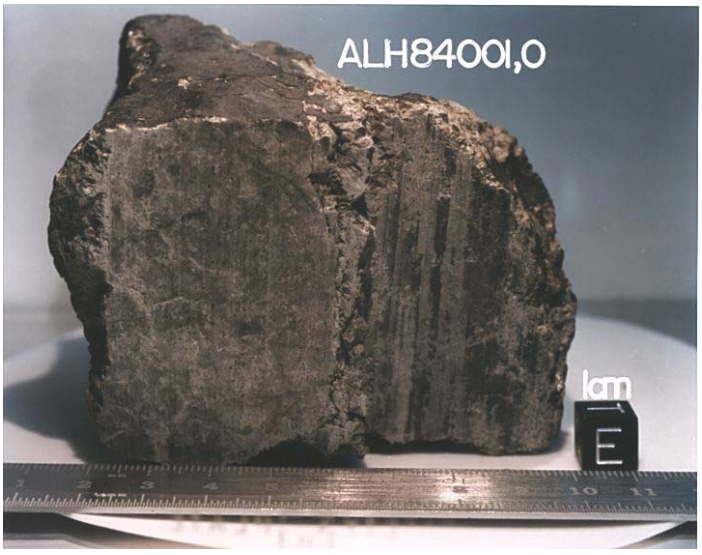
Evidence of past life in Mars in ALH84001

Introduction

Almost ten years ago, based on information supplied by NASA experts, the August 7th, 1996 front page headline of the New York Times announced that *"Clues in Meteorite Seem to Show Signs of Life on Mars Long Ago"*. It was followed by a statement from the very President Bill Clinton, calling this *"potentially, one of the most important scientific discoveries in history"*. Consequently, a general level of great excitement was immediately disseminated, from the top scientific elite down to the broad ordinary public baseline.

Nowadays, the entire world is still waiting for such big news to be true. What actually happened? Was the announcement just fireworks in order to distract mass attention, or really there was some evidence that made honest scientists to go wrong unwillingly? Was it worth having risked the prestigious reputation of NASA and the careers of the involved professionals based on ambiguous evidence?

This essay will begin with a succinct description of the remarkable features actually contained in the meteorite in question, technically known as ALH84001, followed by the presentation of derived arguments to buttress either the extraordinary case of relic life on Mars, or just the coincidence of usual abiotic processes – nothing extraordinary at all. Finally, an unbiased discussion will try to shred some light about the properness of the original claim, as well as its present validity.



Credit: NASA

Figure 1
The Mars meteorite ALH84001
Probably, the most intensively studied 2-kg rock in mankind history.

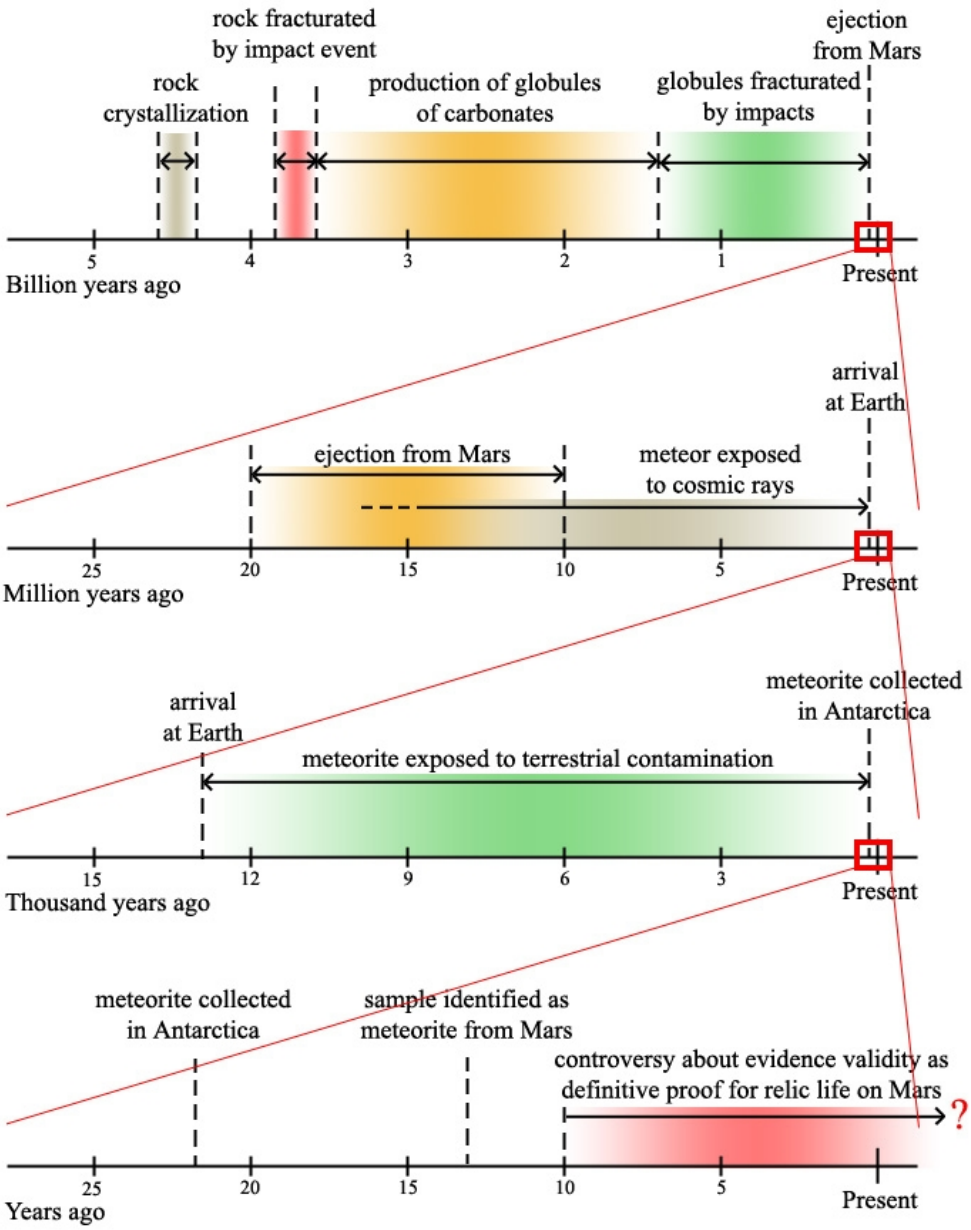
The facts (almost) everyone agreed with

Five particular features have been conclusively proved as facts from in depth scientific examination of the 2-kg meteorite ALH84001 (Figure 1). They are:

a) Origin and evolution

ALH84001 has been confirmed to be from Mars (Romanek 1994) because the chemical composition of trace amounts of gas trapped inside is a nearly perfect match to the composition of the Martian atmosphere found by the *Viking Landers*.

The history of the meteorite has been obtained from precise radioisotopic dating processes (Gibson et al. 1997) becoming outlined as follows:



ALH84001's history highlights are (i) the original rock was a 4.5 billion-year-old igneous rock from the earliest Martian crust, (ii) after the rock been reheated, globules of carbonates were produced while still on the red planet, (iii) a massive asteroidal impact both sealed the rock by fusion and blasted it off, (iv) it had a residence time in space for about 16 million years, and (v) it has been on Earth only 13,000 years.

b) Presence of carbonate precipitates

Along its fractures, ALH84001 contains globules of mineral *calcite* – calcium carbonate – from 20 to 250 microns in diameter (Gibson et al. 1997). Apparently, they were deposited from a fluid saturated with CO_2 that percolated through the cracks after the silicates were formed (Knoll 1998).

c) Presence of mineral magnetite

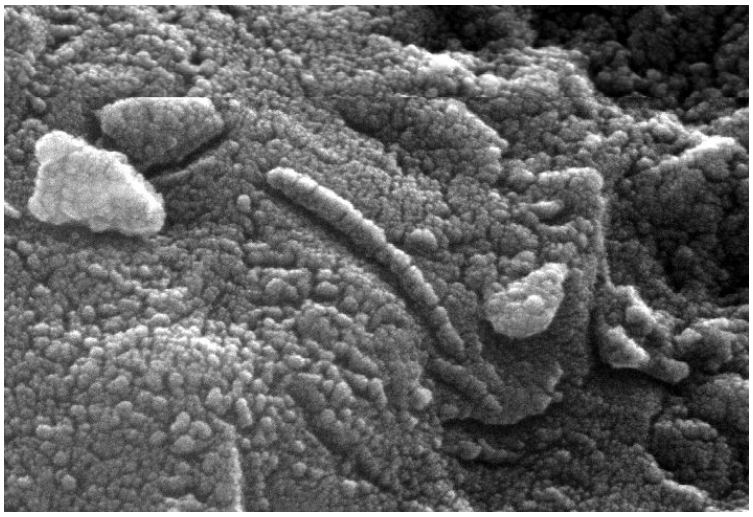
ALH84001 contains very tiny grains of *magnetite* – a mineral made of oxygen and iron, thus sensitive to magnetic fields – in the carbonate globules (McKay et al. 1996).

d) Presence of complex organic molecules

Indigenous carbon-bearing molecules such as *polycyclic aromatic hydrocarbons* (PAHs) and *amino acids* – the chemical building blocks of proteins – are observed near the carbonate globules (McKay et al. 1996; Bada et al. 1998).

e) Content of tubelike structures

Electron microscopy images show that in around the carbonate grains there are large numbers of elongated, tubelike structures – about 20 nm wide and 100 nm long – (McKay et al. 1996) that resemble fossilized microorganisms (Figure 2).



Credit: NASA

Figure 2
A highly amplified image of ALH84001 showing the "nanostructures".

Inferred arguments that have split the waters

Based on its *known origin and evolution*, each one of the remaining four particular facts found in ALH84001 were claimed by McKay et al. (1996) as evidence supporting the case of relic life on Mars. However, any plausible pro argument has also found its correspondent counter argument. The following table summarizes the case:

evidence	***PRO biotic origin argument***	***CON biotic origin argument***
Presence of carbonate precipitates	Carbonate globules have been formed at a time while most likely there still existed liquid water on Mars. In Earth, carbonate globules are usually caused due to biologic activity if formed at low temperatures (below ~ 100° C). It's very likely that the carbonate globules in question had a low-temperature aqueous origin, and were *"relatively undisturbed by subsequent processes"* (Gibson et al. 2001).	Carbonate globules can also form on Earth with no biological influence at all, at high temperatures (above 650° C) (Harvey & McSween 1996). Carbonate globules do not appear to have any characteristics that compel to think they were likely to have been made by living processes (Schopt 1999).
Presence of mineral magnetite	Sometimes biogenic magnetite crystals have been produced outside the cells by terrestrial bacteria, resulting in a fairly wide range of shapes (Kirschvink 1999). Although ~75% of the magnetite crystals are truly of inorganic origin, the remaining are physically and chemically identical to the magnetite crystals produced by certain marine bacteria, thus becoming *"overwhelmingly likely to be of biogenic origin"* (Thomas-Keptra et al. 2001). There is no known natural terrestrial inorganic mechanism that can explain such coincidence.	Including the suppossedly biogenic type, many of the crystals contain defects of a kind that should not be present if they were crystallized in the stable environment inside a cell (Bradley et al. 1997). In addition to the kind of magnetite crystals sometimes associated with biogenic activity, there also are a *"whole zoo"* of different shapes of magnetite crystals (Kerr 1997).
Presence of complex organic molecules	Whereas all the detected amino acids are most likely terrestrial contamination, a portion of detected PAHs are most likely Martian indigenous (Gibson et al. 2001). In Earth, PAHs are often formed through the breakdown of biological molecules. Detected PAHs closely resemble those produced biologically in Earth (Gibson et al. 2001).	PAHs are so ubiquitous, even on meteorites, that they don't have any biotic implications at all (Oró 1998). There is no evidence that "martian" PAHs have even been formed when Mars still had liquid water (Knoll 1998). Regarding PAH concentration is greatest in association with carbonate globules and practically nil on the outmost layer, a chemical explanation results more likely than biogenic origin (Becker et al. 1997). Some organic matter associated with the carbonate globules is due to terrestrial contamination, while remaining organic material is actually from Mars, but might had been originated by *"exogenous delivery"* (Becker et al. 1999).

Content of tubelike structures	Structures that vividly look like pieces of fossilized bacteria occur near the globules (McKay et al. 1996). Viable cells have already been reported in the size range 80-100 nm (Kajander & Ciftcioglu 1998).	The morphology of the nanostructures are so tiny that they couldn't possibly contain even the minimum requirements to be alive (Maniloff et al.1997). The visual nanostructures can be entirely explained as side and angles views of finely layered crystal structures and protuding ledges along fractures planes (Bradley et al. 1997).

ALH84001 present after ten years of meticulous scrutiny

Four main reflections can be derived from ALH84001's case. They are:

i) The significance of the theme under discussion

The basic topic concerning ALH84001 is not a trivial one. On the contrary, in case alien life were definitively proved to have existed beyond any reasonable doubt, a mankind intellectual revolution would immediately take place, establishing an indelible turning point as no previous or future scientific discovery could ever remotely trigger.

Not in vain, every single scientist in the world would like to achieve the immortal honour that such discovery will have rewarded him or her immediately after its general acceptance. Therefore, it is quite logic that serious investigators in first contact with any potential evidence of past alien life at once have become pro biased, while the rest of the scientific community naturally has reacted by playing devil's advocate [1].

To complicate things even more, not only personal ambition but also politics and money are certainly involved in this unresolved topic. In fact, after 1996 spectacular claim NASA budget, which previously had been reducing year after year, received a massive injection of funding, particularly provided to develop the "new" topic of astrobiology.

ii) The difficulty of its final resolution

Achieving a final and general accepted verdict in this sort of controversy is extremely difficult. This is not a case about the validity of some new model – where a thumb down will unquestionably end the discussion after its first prediction goes wrong. This is a complex case based on limited and ambiguous evidence, obtained by pushing the limits of available technology, where an extraordinary conclusion has been stated.

Precisely, in summarizing their findings, McKay and his team (1996, 1997) were careful to point out that each observation was capable of an alternative explanation involving an inorganic process, but that the most likely explanation that satisfied all of them was that the features really were "*evidence for primitive life on early Mars"*.

[1] Currently, there is a comparatively unimportant controversy going on – the discovery of a Kuiper Belt object, $2003UB_{313}$, larger than Pluto – that exemplifies the point: on the one hand, protagonists immediately have been underlining the great importance of their finding – the discovery of "the 10th planet" – while on the other hand, an indifferent majority has been minimizing it – "just another KBO of many more that are going to be discovered, and likely even more larger than this one". No one knows how this mini dispute will end.

Reasonably, the main counter argument of the "opposition" was to call all the observed evidence as "circumstantial", just based on the coincidence between some otherwise unrelated characteristics of ALH84001.

A very similar dispute also recently occurred between scientists that claimed to have found very ancient terrestrial microfossils, as old as 3.5 billion-year-old, and those who denied such possibility. The former base their case in *"strongly suggestive"* evidence (Schopf 1993), while the latter argue that the evidence is not clear enough (Brasier et al. 2002). There is even another claim for 3.85 billion-year-old possible life evidence (Mojzsis et al. 1996).

If such debates on *terrestrial fossils* still remain open today, it is clear that the case for *alien fossils* is far more complicated. A lot of water will run under the bridge until ALH84001 evidence for past life in Mars becomes completely elucidated. Such "lot of water" actually means analyzing many more new Martian rocks, especially those collected in situ – either robotically or by human beings.

iii) The properness of the supplied evidence

In retrospect, 1996 McKay's team claim was not a simple hunch. Although ambiguous, there was potential evidence in ALH84001 to support the case for Martian past life.

After ten years of punctilious research, the strongest evidence is yet the instance of the magnetite crystals, especially after the detailed investigation performed by Thomas-Keptra and colleagues (2001). Until an inorganic process – so far never observed before – could plausibly explain its full responsibility for having created crystals of exact physical and chemical identity as those usually made by particular terrestrial bacteria, magnetite crystals in ALH84001 will remain as the flagship of Martian relic life evidence.

Conversely, the other pro biotic arguments do show weak points. The carbonate precipitates evidence highly depends on the assumption of a low temperature aqueous origin, which is highly controversial; the presence of the complex organic molecules can be easily explained just due to abiotic processes; the micro size of the observed "fossils" results one full order of magnitude smaller than the possible smallest organism on Earth [2].

Objectively, the current general consensus is that non-biological processes are much more likely to be responsible for the remarkable features observed in ALH84001.

iv) The legacy of ALH84001

Only a dozen years ago, very few scientists were dedicated to serious research about alien life. However, the challenge for resolving ALH84001 secrets has resulted highly stimulating indeed. Whatever would be its final place in Science's history, ALH84001 already deserves full credit for having triggered copious investigation of the possibilities of life in Mars, provoking plenty of skeptical scientists to do a lot of new work.

[2] An eighteen expert panel on microbial life concluded in 1998 that the lower cutoff size range for life has to be the equivalent to the volume of a sphere of 200 nanometers in diameter (Vogel 1998).

Conclusions

There are some remarkable features in the Martian meteorite ALH84001that might represent compelling evidence for possible relic life on the red planet, being magnetite crystals the strongest one. Nevertheless, such claim still remains controversial, since much of the evidence is circumstantial and seems to rely on the coincidence of some otherwise unrelated characteristics of the meteorite.

A final resolution of ALH84001 controversy most likely will remain stand-by until much more evidence can be obtained from close examination of new Martian rocks. Either McKay and collaborators end as heroes or villains, at least the ALH84001 rock will remain for ever as the material cornerstone of the new astrobiology science.

References

Bada, Jeffrey L., Glavin, Daniel P., McDonald, Gene D., Becker, Luann, 1998. *"A Search for Endogenous Amino Acids in Martian Meteorite ALH84001"*. Science, 16 January 1998, Vol. 279, N° 5349, pages 362-365

Becker, Luann, Glavin, Daniel P., and Bada, Jeffrey L., 1997. *"Polycyclic Aromatic Hydrocarbons (PAHs) in Antartic Martian Meteorites, Carbonaceous Chondrites, and Polar Ice"*. Geochimica et Cosmochimica Acta 61 (1997), pages 475-481

Becker, Luann, Popp, Brian, Rust, Terri, and Bada, Jeffrey L., 1999. *"The origin of organic matter in the Martian meteorite ALH84001"*. Earth and Planetary Science Letters, 1999. Vol. 167, pages 71-79

Bradley, John P., Harvey, Ralph P., and McSween, Hap Y. Jr, 1997. *"No 'Nanofossils' in Martian Meteorite"*. Nature, 4 December 1997, Vol. 390, N° 6659, pages 454-456

Brasier, Martin D., Green, Owen R., Jephcoat, Andrew P., Kleppe, Annette K., Van Kranendonk, Martin J., Lindsay, John F., Steele, Andrew, and Grassineau, Nathalie V., 2002. *"Questioning the evidence for Earth's oldest fossils"*. Nature, 7 March 2002, Vol. 416, pages 76-81

Gibson, Everett K. Jr., McKay, David S., Thomas-Keprta, Kathie L., and Romanek, Christopher S., 1997. *"The case for relic life on Mars"*. Scientific American, Dec97, Vol. 277, Issue 6, pages 58-65

Gibson, Everett K. Jr., McKay, David S., Thomas-Keprta, Kathie L., Wentworth, S. J., Westall, F., Steele, Andrew, Romanek, Christopher S., Bell, M. S., Toporski, J., 2001. *"Life on Mars: evaluation of the evidence within Martian meteorites ALH84001, Nakla, and Shergotty"*. Precambrian Research, 106, pages 15-34

Harvey, Ralph P., and McSween, Hap Y. Jr, 1996. *"A possible high-temperature origin for the carbonates in the martian meteorite ALH84001"*. Nature, 4 July 1996, Vol. 382, N° 6586, pages 49-51

Kajander, E. Olavi, and Ciftcioglu, Neva, 1998. *"Nanobacteria: An alternative mechanism for pathogenic intra- and extracellular calcification and stone formation"*. Proceedings of the National Academy of Sciences of the United States of America, 7 July 1998, Vol. 95, Issue 14, pages 8274-8279

Kerr, Richard, 1997. *"Putative Martian Microbes Called Microscopy Artifacts"*. Science, 5 December 1997, Vol. 278, pages 1706-1707

Kirschvink, Joseph L., and Vali, Hojatollah, 1999. *"Criteria for the Identification of Bacterial Magnetofossils on Earth or Mars"*. 30th Annual Lunar and Planetary Science Conference, 15-29 March 1999, Houston, Texas.

Knoll, Andrew, H., 1998. *"A Martian Chronicle"*. The Sciences, July/August 1998, pages 20-26

McKay, David S., Gibson, Everett K. Jr., Thomas-Keprta, Kathie L., Vali, Hojatollah, Romanek, Christopher S., Clementt, Simon J., Chillier, Xavier D. F., Maechling, Claude R., Zare, Richard N., 1996. *"Search for Past Life on Mars: Possible Relic Biogenic Activity in Martian Meteorite ALH84001"*. Science, 16 August 1996, Vol. 273, N° 5277, pages 924-930

McKay, David S., Gibson, Everett K. Jr., Thomas-Keprta, Kathie L., and Vali, Hojatollah, 1997. *"No 'Nanofossils' in Martian Meteorite: A Reply"*. Nature, 4 December 1997, Vol. 390, N° 6659, pages 455-456

Maniloff, Jack, Nealson, Kenneth H., Psenner, Ronald, Loferer, Maria, and Folk, Robert, 1997. *"Nanobacteria: Size Limits and Evidence"*. Science, 20 June 1997, Vol. 276, pages 1776-1777

Mojzsis, Stephen J., Arrhenius, Gustaf, McKeegan, K. D., Harrison, T. M., Nutman, A. P., and Friend, C. R. L., 1996. *"Evidence for life on Earth before 3800 million years ago"*. Nature, 7 November 1996, Vol. 384, pages 55-59

Oró, John, 1998. *"The case for life on Mars, part I: an 'open' skeptical view"*. BioAstronomy News,10 (2), pages 1-6

Romanek, Christopher S., Grady, Monica M., Wright, I. P., Mittlefehldt, D. W., Socki, R. A., Pillinger, C. T., and Gibson, Everett K. Jr., 1994. *"Record of fluid-rock interactions on Mars from the meteorite ALH84001"*. Nature, 17 November 1994, Vol. 372, pages 655-657

Schopf, J. William, 1993. *"Microfossils of the Early Archean Apex Chert: New Evidence of the Antiquity of Life"*. Science, 30 April 1993, Vol. 260, pages 640-646

Schopf, J. William, 1999. *"Cradle of Life: The Discovery of Earth's Earliest Fossils"*. Princeton University Press, 1999

Thomas-Keprta, Kathie L., Clemett, Simon J., Bazylinski, Dennis A., Kirschvink, Joseph L., McKay, David S., Wentworth, Susan J., Vali, Hojatollah, Gibson, Everett K. Jr., McKay, Mary Fae, and Romanek, Christopher S., 2001. *"Truncated hexa-octahedral magnetite crystals in ALH84001: Presumptive biosignatures"*. Proceedings of the National Academy of Sciences of the United States of America, 27 February 2001, Vol. 98, Issue 5, pages 2164-2169

Vogel, Gretchen, 1998. *"Finding Life's Limits"*. Science, 20 November 1998, Vol. 282, page 1399

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