New Research on Purported Martian Biosignatures in Meteorite Allan Hills 84001: 1996 to 2011

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Using the latest and most advanced analytical instrumentation available, a research team at Johnson Space Center (JSC) has reexamined the hypothesis about potential biosignatures in the Martian Meteorite Allan Hills 84001 (ALH84001). The team's results and conclusions present strong evidence for possible biological activity on Mars during its first 600 million years of evolution.

By reassessing the leading alternative non-biologic hypothesis that heating produced the tiny magnetites, researchers discovered that the results of this study of Martian meteorite ALH84001 reinforce the original hypothesis that biology played a role in the formation of the carbonate disks and their associated tiny magnetite crystals. The heating hypothesis for the formation of the magnetites has been favored by many researchers for about a decade, but it is now shown to be an implausible explanation not supported by either theory or by new detailed observations of the ALH84001 meteorite.

It is well known that ALH84001 preserves evidence of interaction with water while on Mars in the form of microscopic carbonate disks present in many cracks and crevices in this meteorite. These carbonate disks are believed to have precipitated 3.9 billion years ago on Mars at the beginning of the Noachian epoch—the time of the oldest, still-exposed Martian surface, and perhaps the time when Martian oceans were present. Embedded in cracks and veins throughout these carbonate disks are nanocrystal magnetites (Fe_3O_4) with unusual chemical and physical properties, whose origins have become the source of considerable scientific debate. Various research teams from around the world have suggested that these magnetites are the product of partial thermal decomposition of the host carbonate in which the iron-rich carbonate was heated by meteorite impacts and thermal events, resulting in the loss of some of its carbon dioxide. This process is theorized to leave only the iron oxide behind as magnetite crystals. Alternatively, the origins of magnetite and carbonate may be unrelated; that is, magnetite is not directly related to or formed from the carbonate, but has been washed into the carbonate disks during and after the time when the disks were formed from Martian ground or surface water.

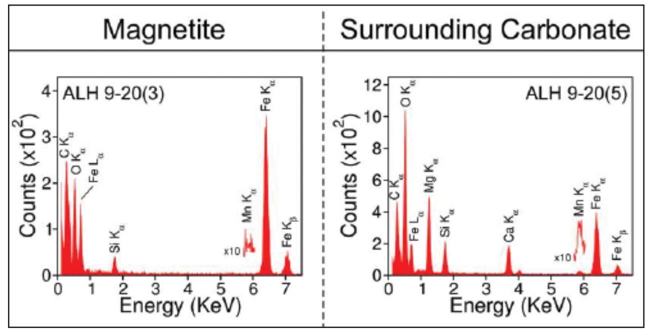

Fig. 1. *Energy-dispersive x-ray spectrometry spectra of chemically pure magnetite (left) and host carbonate (right). While the carbonate contains both manganese and magnesium, the magnetite crystal is chemically pure and contains neither element as would be expected if the magnetite was a product of carbonate decomposition.*

The team sought to resolve these hypotheses through the detailed characterization of the compositional and structural relationships of the carbonate disks and associated magnetites within the cracks and crevices of the rock in which they are embedded. Extensive use of state-of-the-art focused ion beam milling techniques, along with microanalysis by high-resolution transmission electron microscopy, have been used for sample preparation and analysis. The team then compared their observations with those from experimental thermal decomposition studies of iron carbonates under a range of plausible geological heating scenarios.

The JSC team concluded that the vast majority of the nanocrystal magnetites present in the carbonate disks could not have formed from the enclosing carbonate by any of the currently proposed thermal decomposition or shock scenarios. Instead, the team found considerable evidence in support of an alternative origin for the magnetite, unrelated to any shock or thermal processing of the carbonates. In the favored hypothesis, the magnetites were brought in from somewhere else and added to the carbonates as the carbonates crystallized.

In natural iron-rich carbonate systems, minor and trace elements such as manganese and magnesium are often associated with the carbonates. When these carbonates

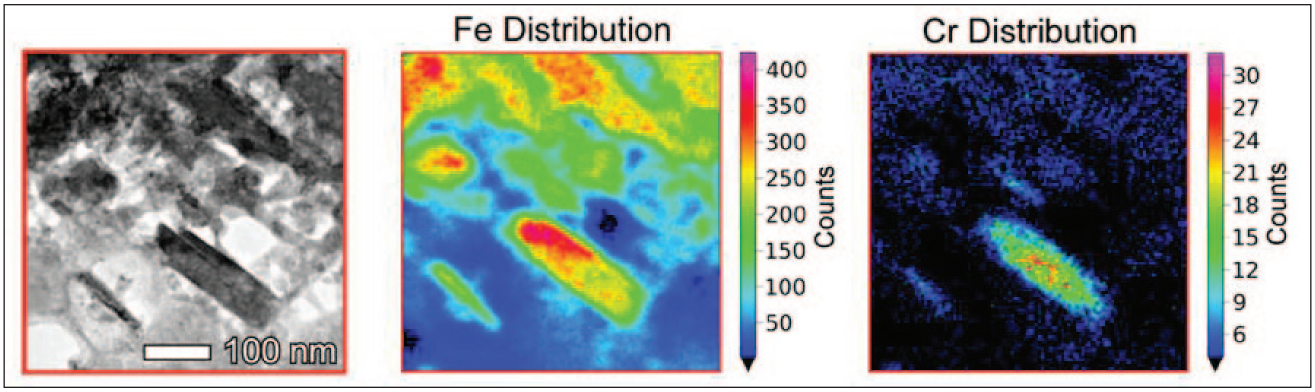

Fig. 2. Magnetite embedded in carbonate (left); energy-dispersive x-ray spectrometry maps of region at left showing the distribution of iron and chromium (center and right). This magnetite crystal is impure, containing minor chromium.

are decomposed by thermal processes, the resulting Fe_3O_4 will contain trace levels of the host carbonate's minor and trace elements. However, for magnetites produced from biological processes, the resulting Fe_3O_4 will contain no contaminant trace elements such as manganese and magnesium. In some kinds of Earth bacteria (magnetotactic bacteria), Darwinian-derived processes purify magnetites—even in the presence of magnesium and manganese—by excluding the contaminant elements, making these magnetites more efficient detectors of the Earth's magnetic field. Detailed analysis of selected magnetites within ALH84001 shows no trace element contaminants for the majority of the magnetites (figure 1). Most are identical to the unique population of magnetites known to be formed on Earth by biology. A few ALH84001 magnetites contain minor chromium and/or aluminum; neither element is present in the host carbonate. This indicates that these impure magnetites formed elsewhere before being incorporated into the carbonate and are not a product of thermal decomposition (figure 2). Additionally, a fraction of magnetites are present in carbonate that contains little to no iron, indicating the magnetites had to form elsewhere prior to being embedded in carbonate.

The scientific results offer strong support to the original 1996 hypothesis and show that most of the alternative arguments are invalid. The original hypothesis advanced by the JSC team was that 3.9 billion years ago, the carbonates were precipitated in cracks and hollows of a cooled Martian volcanic rock with the help of Martian microbes. These carbonates trapped or included tiny crystals of magnetite identical in specific properties to those known to be formed on Earth by specialized bacteria. The original hypothesis proposed that there could have been conditions on Mars favoring habitability for life, and which could have supported active biogenic processes.

While the new work does not prove that the biogenic hypothesis is true, it does show that the most popular alternative non-biologic hypotheses (thermal decomposition or shock decomposition of iron-rich carbonate) to explain the properties of ALH84001 simply do not fit the evidence in the meteorite. This new discovery removes the single most important obstacle to the acceptance of the original hypothesis of the JSC group—which proposed that ALH84001 contained evidence of past life on Mars—by showing that thermal decomposition models are unlikely. Evidence supporting the possibility of past life on Mars, which has been slowly building up during the past decade, include signs of past surface water such as the remains of rivers, lakes, and possibly oceans; signs of current water near or at the surface; water-derived deposits of clay minerals and carbonate outcrops in old terrain; and the identification of methane in the Martian atmosphere.