PALEOMAGNETIC EVIDENCE SUPPORTS A LOW-TEMPERATURE ORIGIN OF THE CARBONATE IN MARTIAN METEORITE ALH84001. Joseph L. Kirschvink[1], Altair Maine[1], and H. Vali[2], [1]Division of Geological & Planetary Sciences, Caltech 170-25, Pasadena CA 91125, USA; krschvnk@caltech.edu, [2]Department of Geology, McGill University, Montreal, Quebec, Canada.

Indirect evidence for life on Mars has been reported from studies of the carbonate phase on the Allan Hills Antarctica meteorite ALH84001[1]. However, there is at present a controversy concerning the temperature of formation of this material. One line of evidence, based on stable isotope relationships [2] and unstable mineral assemblages[1], argues that it formed at temperatures between 20° and 80° C, whereas another [3] suggests formation temperatures above 650° C.

Paleomagnetism has the ability to distinguish between these divergent end members, as the Neél (Curie) temperature of magnetite is 580° C, and blocking temperatures for grains of single magnetic domain size extend well below this. As the Neél (~Curie) temperature of pure magnetite is 580° C, a high-temperature origin of the carbonate would imply that both the pyroxenite ground mass and the carbonate veins had cooled together, and hence they would preserve the same direction through all parts of their blocking temperature and coercivity spectra. However, if the carbonate formed at low temperatures long after the pyroxenite had cooled, its NRM ought to be either a chemical remanent magnetization or a detrital remanent magnetization, and there would be ample opportunity for the vector direction of the Martian magnetic field to have changed relative to the pyroxenite ground mass of the rock. An intermediate level of heating in the presence of a magnetic field after formation of the carbonate could impart a secondary magnetic component in the lower portion of the blocking temperature spectrum.

Courtesy of Dr. D. McKay, we studied a single 20 mg chip of ALH84001, sub-sample 190 from its central breccia zone, which contained a fragment of the carbonate vein materials on one surface. Due to the unusually small size of the sample, we developed a clean-lab technique using acid-washed quartz-glass fibers for holding it and its sub-samples oriented stably during the paleomagnetic. Using this system and a DC-SQuID moment magnetometer system, we were able to obtain replicate measurements to better than 1% intensity, and 0.5° in direction, on magnetic moments as weak as 10^{-12} Am^2, equivalent to the saturation remanence produced by ~ 20 picograms of uniformly magnetized (SD) magnetite. After initial measurements of the natural remanent magnetization (NRM) of the sample, we were able to separate the carbonate from the pyroxenite using a thin diamond-impregnated copper wafering saw, all while maintaining accurate relative orientations.

We found that both the carbonate layer and the pyroxenite ground mass possess a stable natural remanent magnetization (NRM), implying that Mars had a substantial magnetic field during formation of the rock. Principal component analysis reveals that the carbonate has only one stable magnetic direction, whereas several components are present in the pyroxenite. However, the NRM direction from the carbonate layer differs by 50 to 80° from those of the pyroxenite, which rules out a high temperature origin for the carbonate. Analysis of the coercivity spectra, coupled with detailed measurements of the size and shape of individual single-domain magnetite crystals, places an upper limit of about 150° C for the formation temperature of the carbonate. Our results are compatible with the presence of ancient bacterial life on Mars.

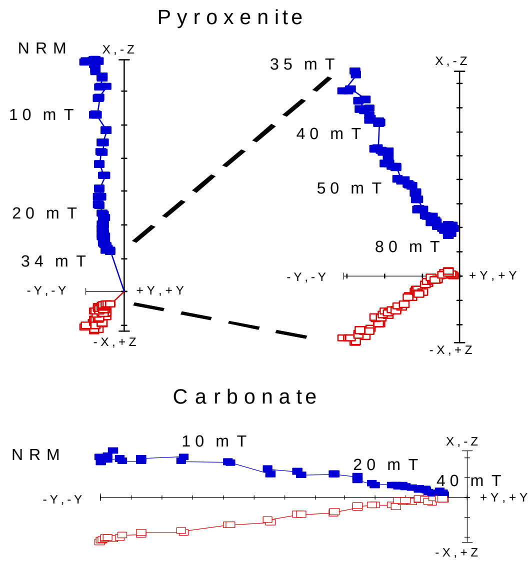

Figure 1. Orthogonal projection of the vector demagnetization data for the pyroxenite and carbonate sub-samples of a fragment of ALH84001. Solid symbols show projections of the vector on the X,Y plane, and open symbols show the Z,Y plane. The right-hand figure of the pyroxenite shows the data in the 35 to 80 mT region on an expanded scale. Units on the left-hand pyroxenite chart are 100 pAm^2/division, and 10 pAm^2/division for the other two diagrams.

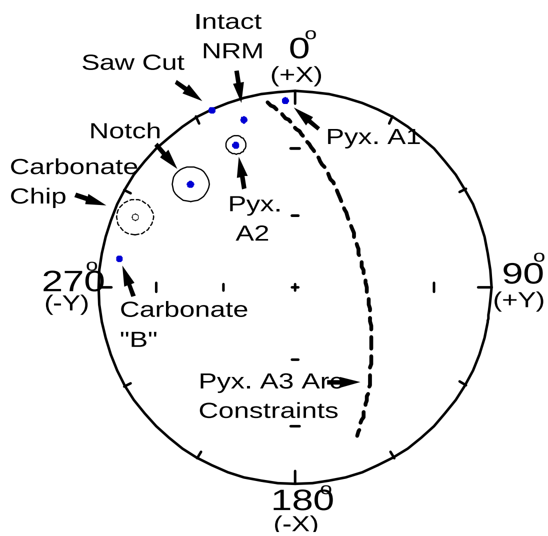

Figure 2 Directions of the magnetic components isolated from a single 20 mg fragment from the central breccia zone of ALH84001, plotted on an equal-area stereonet. As the sample is unoriented, all directions are with respect to the right-handed Cartesian coordinate system of the magnetometer. Solid symbols are on the lower hemisphere (+Z values), whereas open symbols and dotted lines are upper hemisphere (-Z values). Error circles (1σ) are shown around points with errors of 5° or larger. Labeled points are as follows: 'Intact NRM' is the direction for the natural remanent magnetization of the sample prior to the saw cutting. 'Pyx. A1, A2 and A3' are magnetic components isolated from the demagnetization analysis of the pyroxenite fragment, with the long dotted line showing the arc-constraint, or locus of possible directions[4], for the as-yet unresolved component A3. 'Carbonate "B"' is the univectoral component for the oriented carbonate sample, and the direction of the small carbonate chip broken off of the pyroxenite after the sawing cut is labeled 'Carbonate Chip'. The 'Notch' and 'Saw Cut' points represent the directions held by materials removed by the sawing operations, as calculated by vector subtraction. Note that the 'Notch' was centered on the boundary of the carbonate and pyroxenite layers, whereas the 'Saw Cut' was adjusted to remove material mainly from the pyroxenite; this agrees with the relative location of their respective directions.

References:

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