LOW-TEMPERATURE THERMAL HISTORY OF MARTIAN METEORITE ALH84001 FROM (U-Th)/He THERMOCHRONOMETRY.

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Introduction: The thermal history of Martian meteorite ALH84001 is controversial, and has been suggested to involve as many as two to five shock metamorphic events on Mars [1, 2]. It is generally agreed that a major shock event at ~4.0 Ga reset the $^{40}Ar/^{39}Ar$ and U-Th-Pb systems, but the timing and intensity of later, relatively low-temperature, event(s) is not well constrained. To better understand the thermal history after the primary shock at ~4.0 Ga, we applied single grain (U-Th)/He themrochronometry to merrillite and apatite crystals from ALH84001, 34.

Results: With the exception of two analyses (57 Ma, 3.4 Ga), thirty phosphate grains yielded (U-Th)/He ages in the range of 0.1-1.9 Ga with a broad peak at 0.3-0.7 Ga (eleven samples) or 0.1-1.0 Ga (twenty samples) (Figure 1). The large range of ages is probably due to the effect of partial resetting on a range of diffusion domain sizes and the fact that most grains are fractured portions of originally larger grains. Examination of previously reported back-scattered electron (BSE) images of phosphates indicates that the average dimensions of fracture-free areas, approximating original diffusion dimensions, are approximately 40-50 μm in diameter.

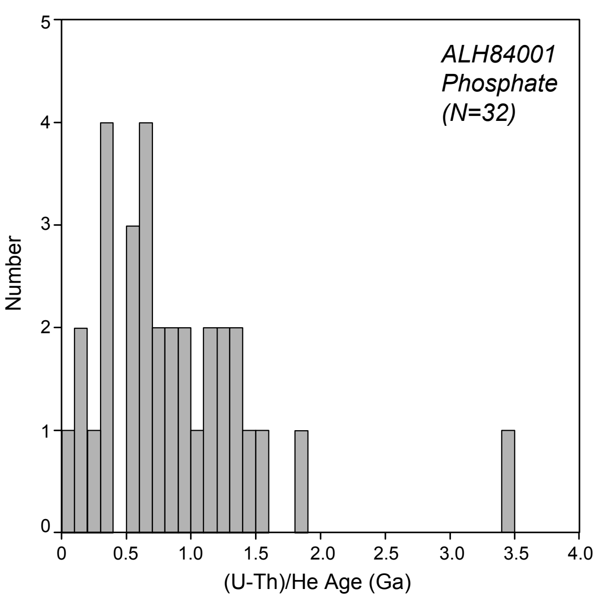

Fig. 1. Distribution of single grain (U-Th)/He ages obtained from merrillites and apatites in ALH84001 Martian meteorite.

Thermal History: Kirschvink et al. [3] obtained stable, but slightly oblique natural remanent magnetization (NRM) orientations from two adjacent pyroxene grains closely related with the carbonate-bearing globules, and suggested that these magnetic properties are from the cooling following the ~4.0 Ga-shock event. From these data, they concluded that (1) the related carbonates formed at low temperatures, and (2) the inner part of ALH84001 was not heated above ~110 ºC since carbonate formation at ~4.0 Ga.

Petrographic evidence suggests there was at least one thermal event after the carbonate formation [1, 2]. Treiman [1] assigned two or three post-carbonate impact events to explain the observed melting of feldspar and the carbonates crosscut by micro faults (his D3), rotation of the magnetized grains (D4), and ejection from Mars (D5). As he noted, the D4 and D5 could be from a single impact event at ~15 Ma. Greenwood and McSween [2] also noticed that some "old" feldspathic glass (presumably formed at 4.0 Ga) was intruded by plagioclase composition glass and silica glass veins with minor mobilization of the "old" feldspathic glasses and carbonate. They used this to suggest a intense shock event (although less intense than the 4.0-Ga event) after carbonate formation at 4.0 Ga, and suggested this event was likely associated with ejection from Mars at ~15 Ma.

Assuming that the ALH84001 apatites and merrillites have He diffusion characteristics similar to terrestrial apatites, the (U-Th)/He ages suggest that there was a significant partial degassing of ^{4}He in the ALH84001 phosphates after 4.0 Ga. At least two possible thermal histories can explain the observed age distribution. One is a single post-4.0 Ga shock event accompanying ejection at 15 Ma, as suggested by Greenwood and McSween [2]. In this case, ~87-95 % ^{4}He loss would be required to yield He ages of 0.7-0.3 Ga (or 81-98 % ^{4}He loss for 1.0-0.1 Ga). To induce such fractional loss in an average domain radius of ~25 μm, the temperature of the 15 Ma-shock would be up to ~430 ºC (diffusion domain radii of 15 μm and 35 μm yield maximum temperatures of 410 ºC and 460 ºC, respectively). These results are generally consistent with the estimates of 350-500 ºC from $^{40}Ar/^{39}Ar$ age spectra [4], although these do not agree with the low-temperature ejection suggested from NRM data [5]. Another possible scenario is that there was only minor heating (<40 ºC) associated with the 15-Ma ejection [5], and that the partial degassing occurred much earlier [1]. In this case, the timing of the pre-15

Ma event would be younger than the peak (0.3-0.7 Ga) of the age distribution. Such a pre-15 Ma, post-(0.3-0.7) Ga shock event would require higher fractional ^4He loss, therefore requiring higher shock temperatures or longer duration heating than those suggested for the former scenario.

In summary, the new (U-Th)/He data suggest at least one post-4.0 Ga thermal event, which may have produced the observed (post-carbonate) petrographic shock features. The (U-Th)/He age distribution can be interpreted either by (1) a single intense (maximum temperature of ~430 ºC) shock event at 15 Ma, or (2) stronger shock at sometime between (0.3-0.7) Ga and 15 Ma, followed by a minor shock at 15 Ma.

References: [1] Treiman, A. H. (1998) *MAPS 33,* 753-764. [2] Greenwood, J. P. & McSween, H. Y., Jr. (2001) *MAPS 36,* 43-61. [3] Kirschvink, J. L. et al. (1997) *Science, 275,* 1629-1633. [4] Weiss, B. P. et al. (2002) *EPSL 201,* 465-472. [5] Weiss, B. P. et al. (2000) *Science 290,* 791-795.