Phosphate (U-Th)/He Thermochronology of Zagami and ALHA77005 Martian Meteorites.

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Introduction: Zagami is a basaltic shergottite with a main NZ (Normal Zagami) lithology consisting mostly of pyroxenes (pigeonite and augite) and maskelynite; and ~20% of the rock is comprised of a dark-mottled lithology with heterogeneously distributed pyroxenes and maskelynite, and shock-melt pockets. ALHA77005 is a lherzolitic shergottite with a gabbroic, olivine-rich composition. This meteorite is enriched in olivine and low- and high-Ca pyroxene, ~8% of the rock is comprised of maskelynite and ~2% of chromite and ilmenite. The objective of this research is to constrain temperature evolutions of Zagami and ALHA77005 by applying (U-Th)/He thermochronology to phosphates.

Analytical Methods: In order to identify and separate phosphates, small rock chips of Zagami (~1.5 mm × 1.0 mm × 0.2 mm) and ALHA77005 (~0.9 mm × 0.7 mm × 0.2 mm; 0.27 gram) were carefully crushed, and the resulting small fragments were sieved and scanned using SEM (Scanning Electron Microscope). Once identified, each phosphate aggregate was chemically mapped to characterize the morphological relationships between phosphate and other attached phases in the same aggregate. The chemical compositions determined through EDS (Energy Dispersive Spectroscopy) suggest most of the identified phosphates are merrillites. After petrographic examinations, the phosphate aggregates were wrapped with Nb tubes and degassed using a diode laser. Then the extracted gas was spiked with ^{3}He and analyzed using a quadrupole mass spectrometer. The degassed sample packet was dissolved in acids, spiked, after which its U-Th-Sm concentrations were determined using an ICP-MS. We originally intended to determine (U-Th)/He ages from each phosphate aggregate, however our preliminary results indicated that such single-grain analysis does not yield reliable (U-Th)/He ages, mainly due to low signal-to-blank ratios. Therefore, we grouped multiple phosphate aggregates with similar sizes together, and measured each group's overall ^{4}He and U-Th-Sm concentrations to determine (U-Th)/He ages.

Results: A total of 248 aggregates were analyzed: 165 from Zagami and 83 from ALHA77005. We arranged the aggregates into several groups, twelve for Zagami and five for ALHA77005. For Zagami, the twelve groups yielded widely scattered (U-Th)/He ages ranging from 19.8 Ma to 202.4 Ma with an average of 107.3 Ma and a standard deviation of 61.0 Ma (Figure 1). Among these twelve groups, five large aggregate fractions of 150-250 µm resulted in ages ranging from 110.7 Ma to 202.4 Ma (average = 146.6 Ma, standard deviation = 37.8 Ma). The average age corresponds to a fractional loss of 0.16 when a complete helium clock reset was assumed at 177 Ma [1]. The five mid-sized aggregate groups, ranging from 75-250 µm (combination of 3 aggregates of 125-150 µm, 1 aggregate of 75-150 µm, and 1 aggregate of 125-250 µm), yielded ages in the range of 19.8 Ma and 93.6 Ma (average = 51.2 Ma, standard deviation = 31.4 Ma). The two smaller aggregate fractions of 75-125 µm yielded ages from 99.6 Ma to 199.9 Ma (average = 149.7 Ma, standard deviation = 70.9 Ma). The most likely explanations for the old and tightly distributed ages for the largest size groups (Figure 1) is that the large aggregates in these groups have other phases attached around phosphate grains, efficiently preserving alpha particles ejected from the phosphates. According to our SEM examinations, the scanned phosphate portions in the aggregates in the largest group show a similar size to those in smaller groups, but the attached phases in the largest groups are much thicker (> ~40 µm) resulting in larger overall aggregate sizes. For smaller samples, the attached phases are not thick enough (< ~20 um) to completely shield alpha-recoil, thus yielding apparently younger (U-Th)/He ages. Therefore, we believe the ages from the larger aggregates (147 ± 38 Ma) are more reliable than the remaining aggregates (79 ± 62 Ma). The whole rock (U-Th)/He age of ~113 Ma calculated from Schwenzer et al. [2] corresponds to the lower limit of our estimates from the large phosphate aggregates.

For ALHA77005, four out of the five groups yielded relatively concentrated (U-Th)/He ages ranging from 5.9 Ma to 17.9 Ma, with the fifth group producing an exceptionally old age of 78.2 Ma. No apparent correlation is observed between the age and aggregate size.

Using SEM and optical microscopes, the natural occurrences of phosphates were examined in thin sections of Zagami ("4709-1" from the American Museum of Natural History; "USNM6545-4" from the Smithsonian Institution) and ALHA77005 ("ALHA77005 120" from NASA). According to our detailed image processing for multiple BSE (Back-Scattered Electron) images, all of the analyzed phosphate grains in Zagami contain numerous internal fractures which can serve as pathways for rapid He diffusion. The portions bounded by these visible fractures (fracture-free area: FFA) represent the maximum dimension of He diffusion domains. From measurements of 1379 FFAs for eight phosphate grains in Zagami, we concluded that the most representative FFA surface area is in the range of 2.5 - 3.5 μm. Although we are still in the process of measuring FFAs for ALHA77005, it is apparent that the FFAs for ALHA77005 are larger than those for Zagami.

Interpretations and Implications to Thermal History: The maximum shock temperature of Zagami was estimated using the following parameters: radius of parent body = 11 cm [2], maximum diffusion domain radius = 3 - 4 μm (from our FFA data), depth from parent body surface = 6.5 cm and 11 cm, thermal diffusivity = 0.01 cm^2/s [3], and ambient surface temperature = -70 °C. By assuming conductive cooling after the shock, we calculated the maximum peak shock temperatures of 250 – 350 °C. These results are generally consistent with previous estimates of post-shock temperature (220 ± 50 °C [1]).

References: [1] Nyquist L. E. et al. (2001) *Space Science Review*, *96*, 105-164. [2] Schwenzer S. P. et al. (2008) *Meteoritics & Planet. Sci.*, *43*, 1841–1859. [3] Min K. et al. (2004) *Geology*, *32*, 677-680.

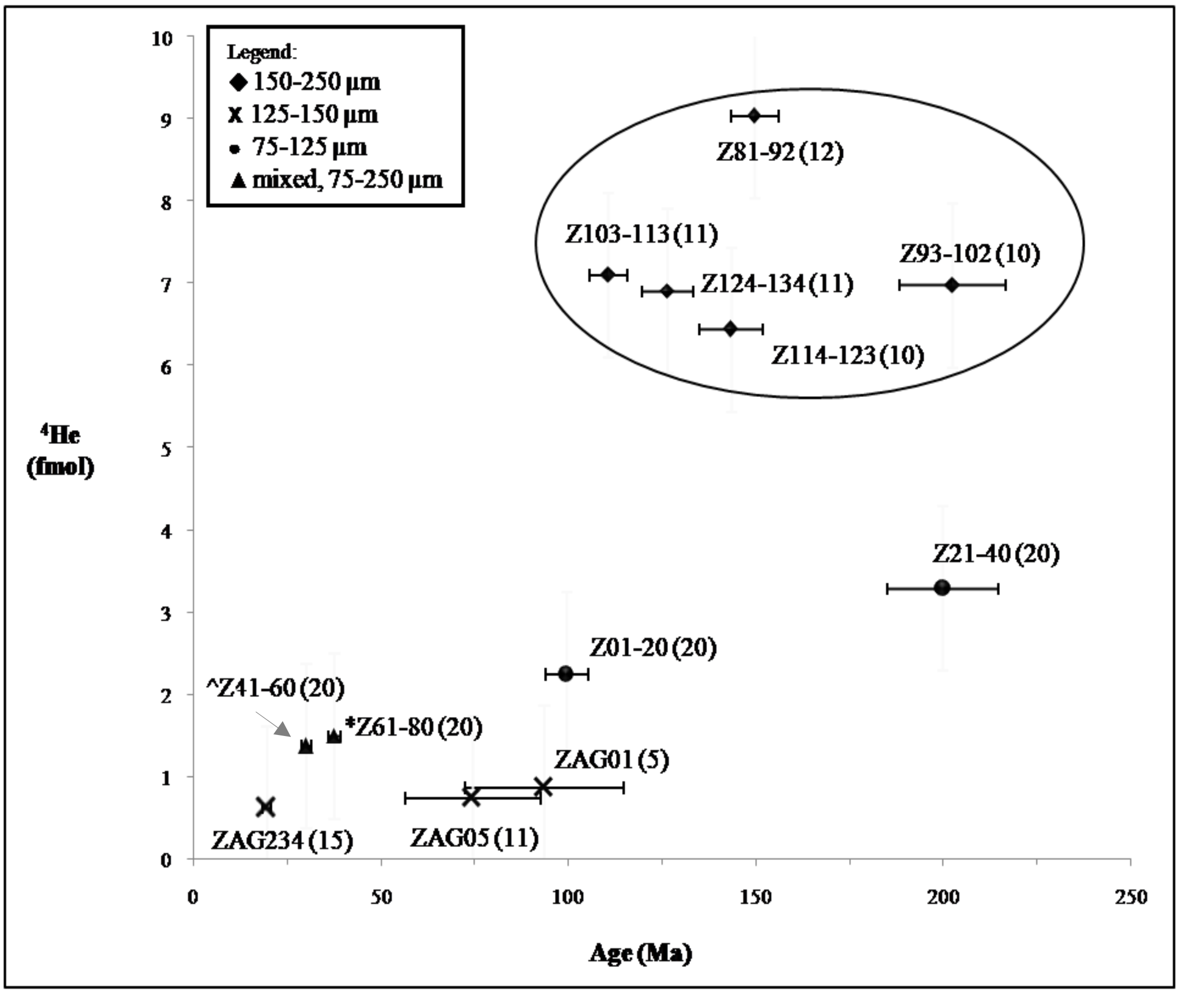

Figure 1. Total ^{4}He vs. Age Diagram for Zagami Samples
Each data point is labeled by the sample name. The number in each parenthesis represents the number of aggregates wrapped in a single packet. The large oval indicates the ages of the most reliable aggregates. Triangle symbols: sets with mixed fractions, (*) includes 16 aggregates ranging 125-150 μm, and 4 aggregates ranging 150-250 μm. (^) includes 7 aggregates ranging 75-125 μm, and 13 aggregates ranging 125-150 μm.