URANIUM-LEAD ISOTOPIC SYSTEMATICS OF THE MARTIAN METEORITE ZAGAMI

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Introduction: The crystallization age of Zagami has been well established by the Rb-Sr and Sm-Nd isochron techniques. Isotopic analysis on purified mineral fractions yield Rb-Sr ages of 178±3, 174±14, and 163±19 Ma [1-2], and a Sm-Nd age of 163±7 Ma [2]. Whole rock and leachate pairs have also been analyzed for U-Th-Pb isotopes and yield a ^{232}Th-^{208}Pb age of 230±5 Ma and a ^{238}U-^{206}Pb age of 229±8 Ma [3]. Chen & Wasserburg [3] interpreted the ~230 Ma U-Th-Pb ages as the time of U-Th-Pb fractionation of an ancient reservoir. They hypothesized that this fractionation event was associated with shock metamorphism of a ~4.5 Ga rock. The goal of this study is to investigate the U-Pb isotopic systematics of Zagami in the context of the well defined Rb-Sr and Sm-Nd crystallization ages. Below preliminary results on Zagami maskelynite, pyroxene, and whole rock fractions are presented. These results demonstrate that the U-Pb isotopic system records both the age of formation of the Zagami source region and the age at which this source region was disturbed.

Analytical Techniques: A two gram aliquot of Zagami (A23.15) was obtained from the Meteorite Museum at the University of New Mexico. This fragment is from the coarse grained portion of the meteorite [see 4] and is adjacent to A23.12b1 which was dated by the Rb-Sr and Sm-Nd methods by Nyquist et al. [2]. The fragment was sonicated for ~20 minutes in quartz distilled water before being crushed. A small fragment was broken off and set aside for whole rock analysis. The remainder was crushed using a sapphire mortar and pestle and sieved at 75, 100, 200, and 325 mesh. The mineral fractions were derived from the 75-100 mesh size fractions using a Frantz isodynamic separator and hand-picking. The maskelynite and Mg-pyroxene fractions were visually estimated to be >99.9% pure.

The whole rock sample was finely crushed and then leached with 0.5M acetic acid at 25ºC for 10 minutes prior to dissolution. The mineral fractions were leached with both 0.5M acetic acid and 1N HCl at 25ºC for 10 minutes prior to dissolution. The mineral leachate data presented below are from the 1N HCl solutions. The concentrations of Sr and Nd were determined on small aliquots of the mineral fractions by mass spectrometry in order to determine the abundances of Sr and Nd to insure the proper spike/sample ratios. The spiked samples were then passed through standard anion exchange columns to separate U and Pb. Lead blanks run during the coarse of the investigation were 15-25 pg.

U-Pb Isochron Plots: Below the ^{238}U-^{206}Pb and ^{235}U-^{207}Pb isochron plots of Zagami mineral and whole rock residues (R) and leachates (L) are presented [Figs. 1-2]. Maskelynite and Mg-pyroxene residues define a slope that corresponds to an age of 186±13 Ma and an initial ^{206}Pb/^{204}Pb ratio of 12.88±0.03. On a ^{235}U-^{207}Pb isochron plot, these fractions define a slope corresponding to a relatively imprecise age of 225±180 Ma and an initial ^{207}Pb/^{204}Pb ratio of 12.72±0.03. These ages are concordant with the Rb-Sr and Sm-Nd ages determined by Shih et al. [1] and Nyquist et al. [2]. As a result the simplest interpretation of this U-Pb data is that these ages represent the crystallization ages of the rock. Note that the whole rock residue and leachates fall above the isochrons on Figures 1 and 2, indicating that they contain a component of radiogenic Pb that is not in equilibrium with the mineral residues. From these diagrams it cannot be determined if the Pb is a terrestrial or martian contaminant.

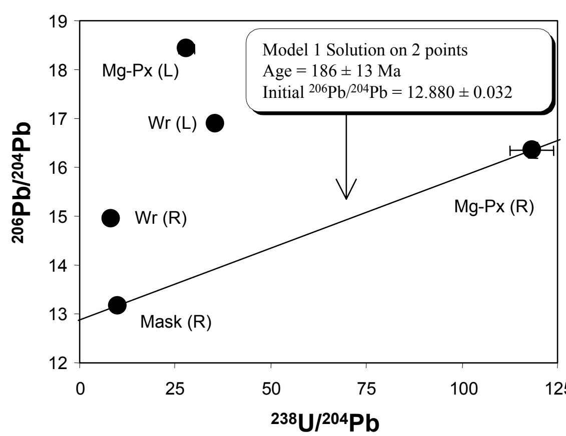

Figure 1. A ^{238}U-^{206}Pb isochron plot of Zagami whole rock and mineral fractions. R = residues and L = leachates. All U-Pb ages calculated using the Isoplot program of Ken Ludwig.

The initial ^{206}Pb/^{204}Pb and ^{207}Pb/^{204}Pb ratios determined from the ^{238}U-^{206}Pb and ^{235}U-^{207}Pb isochrons can be used to estimate the μ value (^{238}U/^{204}Pb ratio) of the source region from which Zagami formed assuming source formation at 4.55 Ga. The μ value calculated from the U-Pb isochron diagrams ranges from 3.8 to 3.9. This value is significantly lower than the value estimated for bulk silicate Earth and implies that

Mars: (1) inherited a larger volatile element component, (2) did not experience as much volatile element loss as Earth, or (3) had significantly less Pb partitioned into its core.

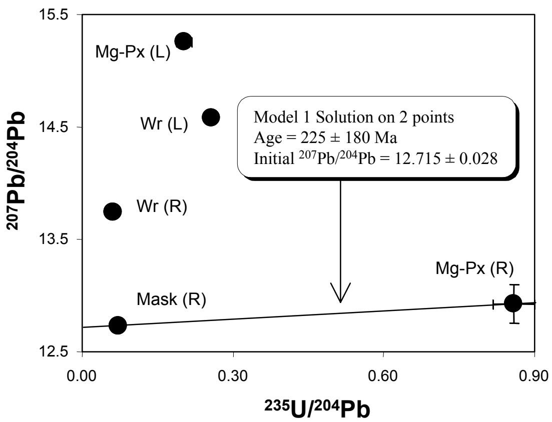

Figure 2. A ^{235}U-^{207}Pb isochron plot of Zagami whole rock and mineral fraction data. The slope of the line corresponds to an age similar to the ^{238}U-^{206}Pb age, but has larger uncertainty. This is due to the small amount of radiogenic ^{207}Pb produced as a result the low abundance of ^{235}U.

U-Pb Concordia Diagram: A U-Pb concordia diagram is presented in Figure 3. This is a plot of the radiogenic Pb component present in the mineral and whole rock fractions. It is calculated from the total Pb present in the mineral and whole rock fractions after

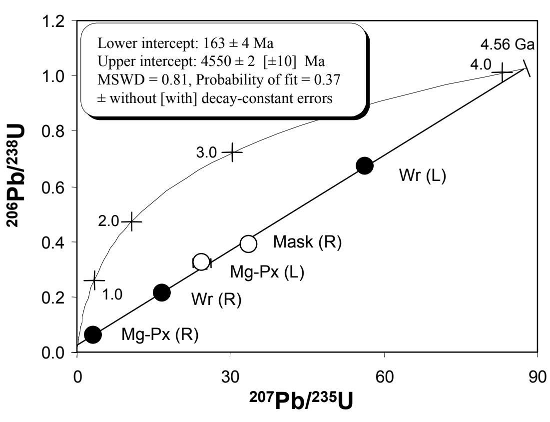

Figure 3. Concordia diagram of Zagami whole rocks and mineral fractions. Radiogenic Pb component is calculated by subtraction of primordial Pb with ^{207}Pb/^{204}Pb = 10.293; ^{206}Pb/^{204}Pb = 9.3066; Chen & Wasserburg [7]. Upper and lower intercepts are defined by Mg-Px (R), Wr (R), and Wr (L) solid circles and yield ages of 4550±10 Ma and 163±4 Ma, respectively.

subtraction of primordial Pb. The discordia formed from the Zagami whole rock and mineral fractions intersect concordia at an upper intercept of 4550±10 Ma and at a lower intercept of 163±4 Ma. The classic interpretation of this diagram is that the upper intercept is the age of crystallization of the rock, and the lower intercept is the age of an event that disturbed the rock through fractionation of U from Pb. In this case, however, the concordia diagram appears to define the age of formation and disturbance of the Zagami source region. This stems from the fact that primordial Pb isotopic compositions are used in calculating the radiogenic Pb component in the mineral and whole rock fractions. In this interpretation the upper intercept represents the time of source formation and the lower intercept represents the time that this source was disturbed, presumably by the formation of Zagami.

The age defined by the upper concordia intercept is 4550±10 Ma and is concordant with the ε^{142}_{Nd} - ε^{143}_{Nd} two stage model age of 4513^{+33}_{-27} Ma defined by the martian meteorite suite [5-6]. This suggests that source formation, and presumably planetary differentiation, occurred very early in the history of the solar system. The lower intercept is concordant with the Rb-Sr, Sm-Nd, ^{238}U-^{206}Pb, and ^{235}U-^{207}Pb isochron ages defined for Zagami. Thus, the U-Pb disturbance of the Zagami source reion, represented by the lower intercept, appears to have coincided with the formation age of the meteorite.

It is important to note that the Zagami whole rock and mineral fractions that lie off of the ^{238}U-^{206}Pb and ^{235}U-^{207}Pb isochrons fall on the discordia between 163 and 4550 Ma. This suggests that these fractions contain an ancient radiogenic Pb component that was added to the meteorite after 163 Ma but lies on or near concordia at 4550 Ma. Thus, the addition of this component to the leachates and whole rocks would drive these fractions above the U-Pb isochrons and along discordia. The ancient age required of this component implies that it is derived from Mars. Assuming a single stage growth model for the radiogenic end-member, its minimum μ value, based on the most radiogenic leachate is ~9. This suggests that if this radiogenic component is derived from the martian crust, the crust formed very early in the history of the planet. Thus, the U-Pb data are consistent with the Rb-Sr, Sm-Nd, and Hf-W isotopic data that suggest that Mars had a relative simple two stage evolutionary history characterized by early planetary differentiation.

References: [1] Shih et al. (1982) G*CA* **46,** 2323-2344. [2] Nyquist et al. (1995) *LPSC* **XXVI,** 1065-1066. [3] Chen & Wasserburg (1986) *GCA* **50,** 955-968. [4] McCoy et al. (1992) *GCA* **56,** 3571-3582. [5] Borg et al. (2001) *LPSC* **XXXI,** Abstract #1036, CD-ROM.. [6] Borg et al. (in press) *GCA*. [7] Chen & Wasserburg (1983) *LPSC* **XIV,** 103-104.