"MARTIANS" YOUNG AND OLD: ZAGAMI AND ALH84001.

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Abstract: New isotopic analyses of fine- and coarse-grained portions of the Zagami basaltic shergottite yield Rb-Sr isochrons of 186±5 and 183±6 Ma, respectively, and initial $^{87}Sr/^{86}Sr$ (I_{Sr}) = 0.722266±0.000051 and 0.721604±0.000057, respectively. The difference in I_{Sr} of ~9 ε-units shows that Sr-isotopic heterogeneities were carried into the crystallizing magma, probably by pyroxene phenocrysts. No isotopic heterogeneities were detected in Nd-isotopic analyses of the same samples, and regression of the combined Sm-Nd data for both lithologies gives an isochron age of 180±37 Ma. The data imply Zagami crystallized from a melt ~180 Ma ago. Sm-Nd analyses of "martian" orthopyroxenite ALH84001 give an internal isochron age of 4.50±0.13 Ga. Rb-Sr analyses are consistent with this age and independently give a (preliminary) age of 4.95±0.40 Ga and initial $^{87}Sr/^{86}Sr$ = 0.698±2. Variations in $^{142}Nd/^{144}Nd$ for the ALH84001 samples correlate with Sm/Nd ratios to give $^{146}Sm/^{144}Sm$ = 0.0011±0.0015, or 0.0022±0.0010 relative to CHUR. Young ages and extreme geochemical fractionation in the SNC meteorites remain a strong argument for their origin on a large, geologically active parent body, consistent with their hypothesized martian origin. However, the interpretation of the ~180 Ma ages of shergottites as magmatic ages is, in our opinion, problematic. In the context of their hypothesized martian origin, it seems most probable that these meteorites were ejected from Mars in a single large impact on old, varied terrain between 15 and 180 Ma ago.

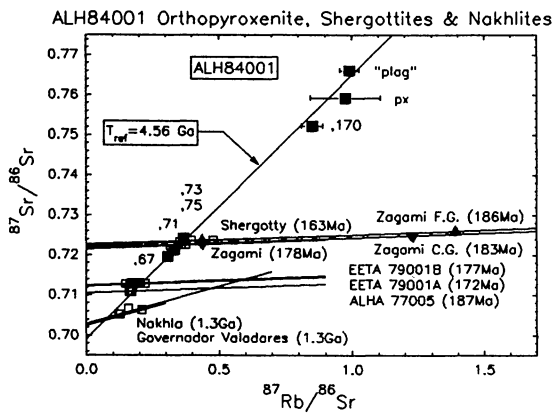

Figure 1. Rb-Sr data for "martian" meteorites. ALH84001 data plot along a 4.56 Ga isochron.

Zagami: Young, but discordant ^{39}Ar-^{40}Ar and Rb-Sr ages of the Shergotty basaltic shergottite led to the interpretation that the ages more likely represented impact-related resetting than a melting event, an interpretation reinforced by lack of complete Sr-isotopic equilibration among samples of Shergotty [1,2]. Later isotopic studies of other shergottites also showed lack of isotopic equilibration, but analyses of Zagami gave concordant ages by the Rb-Sr [3], Sm-Nd [3], and U-Th-Pb [4,5] methods, and an ^{39}Ar-^{40}Ar age that was only slightly older [3]. The availability of Zagami samples of differing average grain size [6] presented an opportunity to test the degree of isotopic equilibration within and between them. Zagami Consortium samples A23.9b (fine-grained) and A23.12b1 (coarse-grained) were supplied courtesy of K. Keil. Analyses of bulk samples and pyroxene separates (density: 3.45-3.55 g/cm^3) have been completed. Results are shown in Figs. 1-3 compared to data for other "martian" meteorites.

ALH84001: Orthopyroxenite ALH84001 has been identified as a member of the martian meteorite clan [7]. Jagoutz et al. [8] reported an age of 4.56 Ga from Sm-Nd analyses of bulk rock leachates and residues, but the presence in ALH84001 of secondary phases such as carbonates [7] led to doubts about its validity [9]. Here, Rb-Sr and Sm-Nd analyses were made of aliquots of the samples analysed by INAA ([7] and D. Mittlefehldt, p. comm.), and of pyroxene separated by density and "washed" in 1N HCl. Rb-Sr analyses were also made of plagioclase separated by density and purified by handpicking. The results are shown in Figs. 1-3 compared to those for Zagami and other SNC meteorites.

Discussion: The strong preferred orientation of pyroxene grains in the fine-grained Zagami lithology was easily recognized under the binocular microscope. Thin sections 992 and 994 described by [6] were made from material adjacent to our samples. Identical values of $^{87}Rb/^{86}Sr$ = 0.437 were

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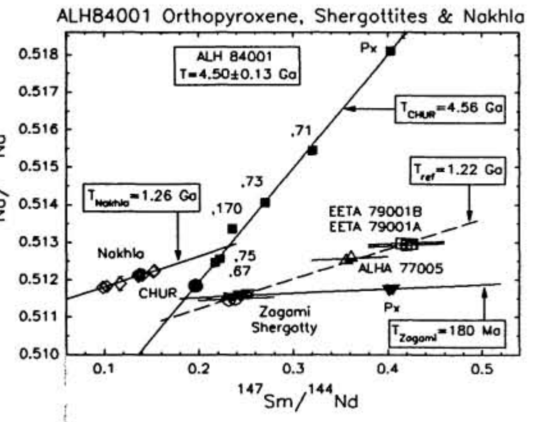

Figure 2. Sm-Nd data for "martian" meteorites. Bulk and px samples of ALH84001 give T=4.50 ±0.13 Ga.

measured for bulk samples of both lithologies, but $^{87}Sr/^{86}Sr$ in the fine-grained lithology was higher by 8.6±0.4 ε-units than in the coarse-grained lithology. This difference is ~75% of the difference between the $^{87}Sr/^{86}Sr$ ratio of Shergotty at the same Rb/Sr [2] and that of the coarse-grained Zagami sample. I_{Sr} of the latter is very similar to 0.724145±0.00005 found earlier for Zagami [3]. Mg-rich cores in Zagami pyroxenes have been interpreted as representing primary phenocrysts which were subsequently resorbed [10,11]. Sr isotopic heterogeneities in the phenocrysts apparently were not equilibrated between the fine- and coarse-grained samples either in the magma, or as Zagami crystallized in a lava flow >10 m thick [6,11].

The data for ALH84001 clearly indicate an old age. In addition to the isochron ages shown in the figures, a model age T_{CHUR} = 4.57±0.03 Ga relative to Nd evolution in a chondritic reservoir can be calculated for the pyroxene. Sm and Nd concentrations in the pyroxene were 0.06 and 0.09 ppm, respectively, similar to values measured by ion microprobe for ALH84001 orthopyroxene [12]. The only hint of an age significantly younger than 4.56 Ga is provided by the short-lived ^{146}Sm-^{142}Nd chronometer. A least squares fit to the ALH84001 $^{142}Nd/^{144}Nd$ data gives a low initial $^{146}Sm/^{144}Sm$ = 0.0011±0.0015. However, a model calculation using CHUR and the pyroxene datum (Fig. 3) gives $^{146}Sm/^{144}Sm$ = 0.0022±0.0010, similar to values found for some eucrites (cf. [13]). Additional analyses are required to more precisely define $^{146}Sm/^{144}Sm$.

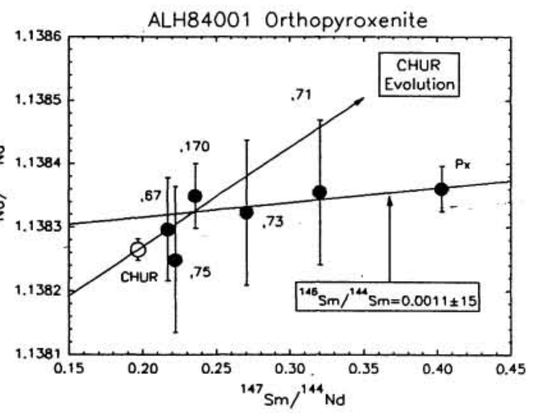

Figure 3. $^{142}Nd/^{144}Nd$ values for ALH84001 samples. Initial $^{146}Sm/^{144}Sm$ is found from the isochron slope.

Conclusions: Rocks ~4.5 Ga, ~1.3 Ga, and ~180 Ma in age are estimated to comprise ~4%, ~11%, and ~7% of the martian surface, respectively [14]. The probability of sampling these surfaces in three events is relatively low, ~40x less probable than the probability of sampling the largest surface unit three times. The ubiquitous presence of an ~180 Ma event among the shergottites links them together, and the ~1.22 Ga Sm-Nd whole rock "isochron" (Fig. 2) may link them to nakhlites. This suggests all the SNC meteorites might have been ejected from Mars in a single event. The reflectance spectra of the basaltic shergottites resembles that of the uplands regions of Mars [9], where old rocks like ALH84001 might be found. Thus, the "martian" rocks might have been ejected from Mars in a solid to semi-molten state in a single event ~180 Ma ago [3,13]. Alternatively, they may have been ejected ~15 Ma ago, the exposure age of ALH84001 [15].

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