Ar-Ar Age of NWA-1460 and Evidence For Young Formation Ages of the Shergottites.

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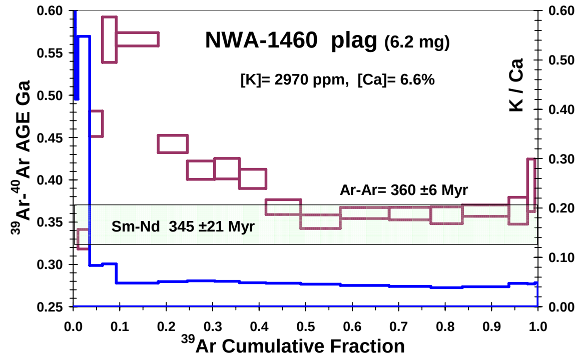
Summary & Introduction. Agreement of Ar-Ar, Sm-Nd, and Rb-Sr ages for NWA1460, and the inconsistency between a low shock-heating temperature for Zagami and the proposition that a 4.0 Gyr-old Zagami lost most of its ^{40}Ar are inconsistent with ancient formation ages for these shergottites, but are consistent with relatively young igneous formation ages.

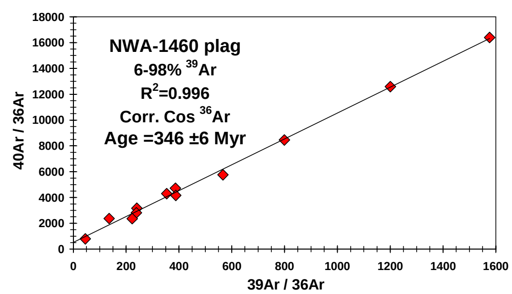
Radiometric dating of several martian shergottites using the Sm-Nd, Rb-Sr and U,Th-Pb techniques indicate igneous formation times of ~160-475 Myr (1, 2). A recent interpretation of U,Th-Pb data on insoluble minerals in some shergottites is that these meteorites are actually 4.0 Gyr old (3). These authors suggest that martian acidic weathering has affected minerals such as phosphates that are important components of the isochrons in these radiometric systems, causing the ages to be reset. If this claim were true, it would have the important implication that the martian surface is older than previously thought. Strong rebuttals have been made against this old age interpretation (e.g., 4) and will be expanded here.

The K-Ar chronometer, as implemented through the ^{39}Ar-^{40}Ar technique, measures only the age of the main K-containing mineral, feldspar (maskelynite),. Feldspar is not very soluble in acidic brines and is a component mineral of the Pb-Pb isochrons presented by (3). Unfortunately, martian shergottites commonly contain trapped excess ^{40}Ar, likely inherited from the igneous melt, which causes their Ar-Ar ages to appear older than ages obtained from the other radiometric systems (5). Feldspar separates from a few shergottites with reported ages of <200 Myr suggest slightly older Ar-Ar ages in the range of 200-250 Myr. Thus, in principle, the older, discordant Ar-Ar ages might also be interpreted as being consistent with ancient shergottite formation, where shock heating events have degassed much of the ^{40}Ar resulting from in situ decay.

NWA-1460. This new, 70 g, basaltic shergottite (6) gave a Sm-Nd isochron age of 345 ±21 Myr and a Rb-Sr isochron age of 336 ±14 Myr (2). We made an Ar-Ar age analysis on a 6.2 mg plagioclase separate of NWA1460 (Fig. 1). Higher temperature extractions (41-98% ^{39}Ar release)

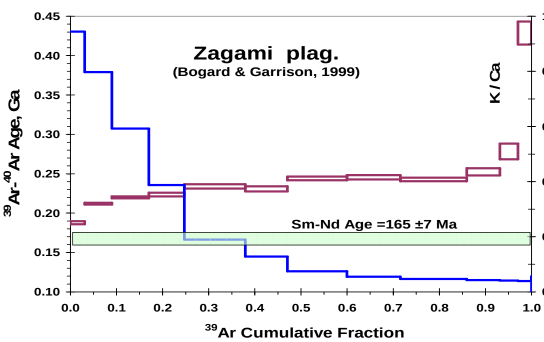


show an Ar-Ar age plateau with an average age of 360 ±6 Myr. The first few extractions (<4% ^{39}Ar release) give evidence in the Ar composition of effects terrestrial weathering, and are not further considered. Those extractions releasing ~4-40% of the ^{39}Ar indicate a trapped martian ^{40}Ar component relative to the plateau age. An isochron plot (Fig. 2) of those extractions releasing 6-98% of the ^{39}Ar define an Ar-Ar age of 346 ±6 Myr and a ^{40}Ar/^{36}Ar intercept of 516 ±134.. Because a proper isochron plot must contain only one ^{36}Ar component, and because these data contain both cosmogenic and trapped ^{36}Ar, we have subtracted cosmogenic ^{36}Ar using the ^{36}Ar/^{37}Ar ratios (7). (Not subtracting this ^{36}Ar component produces considerable isochron scatter.) An isochron plot, corrected for cos-^{36}Ar,

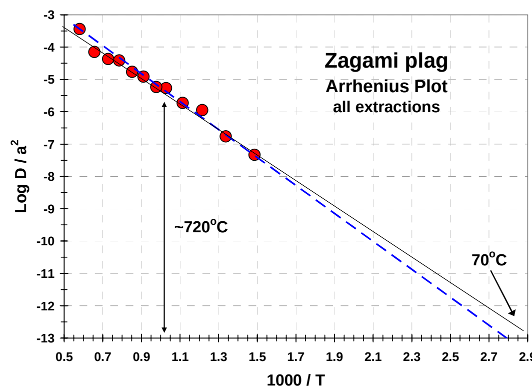


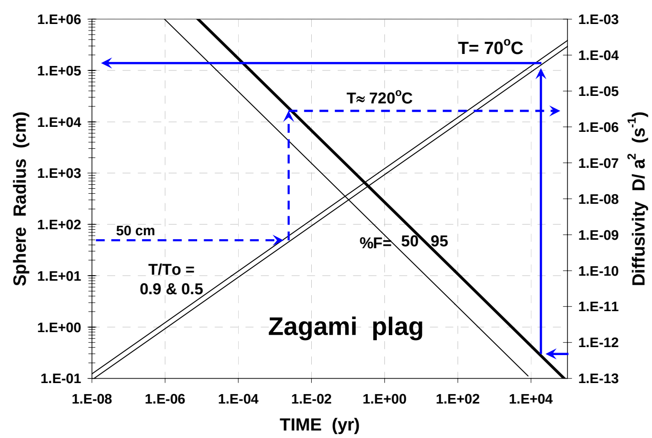
of only those data releasing 41-98% of the ^{39}Ar, gives an age of 345 ± 22 Myr. Thus, the Ar-Ar age of NWA1460 is in agreement within mutual uncertainties with both the Sm-Nd and Rb-Sr ages. Concordance of ages by different techniques is a strong indicator that igneous formation is the event being dated.

Zagami Age Implications. The Ar-Ar age spectrum of a plagioclase separate of Zagami (Fig. 3; ref. 5) gives somewhat older ages compared to the Sm-Nd age of 165 ±7 Myr (8). An isochron plot of those extractions releasing 3-100% of the ^{39}Ar, corrected for cosmogenic ^{36}Ar, gives an age of 223 ±6 Myr. The isochron age obtained by applying no corrections to the ^{36}Ar data is 209 ±2 Myr. Our preferred interpretation of the older Ar-Ar age is that Zagami released some trapped martian ^{40}Ar, primarily at higher temperatures. If however, Zagami actually formed 4.0 Gyr ago, as suggested by (3), then Zagami would had to have lost by diffusion a large fraction of the ^{40}Ar* that formed in situ. The ^{40}Ar* loss would have been >98% if the degassing event occurred by shock-heating at the time of Mars ejection ~3 Myr ago.



Zagami Thermal Model. Figure 4 presents a well defined Arrhenius plot for ^{39}Ar diffusion in Zagami, consistent with Ar diffusion from a single phase. Extrapolation of this diffusion trend to a temperature of 70°C (343K), the estimated shock-heating temperature for Zagami (9), gives a value for D/a^2 of around 10^{-13}. Thermal cooling of a sphere and gas diffusion in a solid have similar analytic forms, where time is common to each, and thus can be compared in a common model (Fig. 5). The diagonal lines labeled T/To give those combinations of cooling time and sphere radius required to cool to 90% and 50% of the initial temperature. The diagonal lines labeled %F give those combinations of cooling time and D/a^2 diffusion value required to produce 50% and 95% loss of ^{40}Ar. Because the Ar diffusion coefficient is strongly temperature dependent and the thermal coefficient is not, most Ar diffusion occurs in the earlier states of cooling of an object. Further, we noted above that dagassing of a 4.0 Gyr-old Zagami to yield an age of ~0.22 Gyr would require >95% loss of ^{40}Ar. Projecting a value of D/a^2 of $\sim 3\times10^{-13}$ for the 70°C shock heating temperature of Zagami over to the 95% Ar loss line, then projecting this to the line representing T/To≅0.7, then projecting onto the axis giving sphere radius (i.e., the solid blue line), we obtain a required ejected radius for Zagami of ~10^5 cm. The impossibility of such a large size means Zagami could not have been thermally degassed of most of its ^{40}Ar by the shock event that heated it to 70°C. If we assume a more reasonable ejection radius for Zagami of ~50cm (dotted blue projection line), Figs. 4 & 5 indicate Zagami would have to be heated to ~720°C to lose so much ^{40}Ar by diffusion. Because a reheating temperature an order of magnitude higher than the estimated shock-heating temperature is very unlikely, we conclude that Zagami has not lost a significant amount of its ^{40}Ar by diffusion and does not have an ancient formation age.





References. (1) Nyquist et al. Space Sci Rev. 96, 2001; (2) Nyquist et al., LPXC37, #1723, 2006; (3) Bouvier et al., EPSL 240 221, 2005; (4) Nyquist, LPI Contri. #1320, 2006; (5) Bogard & Garrison, MaPS 34, 451, 1999; (6) Irving & Kuehner, LPSC 34, #1503, 2003; (7) Garrison et al., MaPS 35, 419, 2000; (8) Nyquist et al., LPSC 26, p1065, 1995; (9) Fritz et al., MaPS 40, 1393, 2005;