39Ar-40Ar DATING OF MESOSIDERITES: A CASE FOR MAJOR PARENT BODY DISRUPTION LESS THAN 4.0 GY AGO?

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Mesosiderites are basaltic regolith breccias with petrologic affinities to the howardites, but which have undergone a more complex parent body history. In addition to brecciation and metamorphism, mesosiderites experienced metal-silicate mixing, probably when the metal was molten. Nickel zoning in the metal and the abundance of tetrataenite suggests that this phase cooled slowly; early estimates were ~0.1°/My at 500°C (1), but recent measurements of Ni diffusion suggest that these cooling rates were faster by a factor of ~5-10 (2,3, J.Goldstein, pers.comm.). Such slow cooling would require burial to depths of tens of kilometers in relatively large (for asteroids) parent bodies. The initial temperatures from which mesosiderites cooled are not well defined; many mesosiderites apparently contain silicates heated to over 1150°C (3) and some contain melt clasts or matrix. Metal and silicate presumably cooled together; initially the cooling must have been rapid to preserve certain disequilibrium features in the silicates, then much slower at temperatures below ~500°C. Individual mesosiderites apparently experienced different metamorphic histories at temperatures above ~500°C, and it is likely that part of the metamorphism resulted from impact heating. However, the apparently incompatible characteristics of slow cooling, suggesting deep burial, and brecciated nature, suggesting a surface origin, are not readily explained by any model for their origin.

Very little published data exist on the chronologies of mesosiderites. Estherville gave a Rb-Sr age of 4.24 ±.03 Gy and an 39Ar-40Ar age spectrum that varied between 3.5 and 4.5 Gy (4). A few other mesosiderites showed disturbed Rb-Sr systematics with model ages as low as 3.6 Gy (5). Classical K-Ar ages of three mesosiderites were 3.23-4.25 Gy with large uncertainties (6). One investigation (7) calculated densities of particle tracks from the fission of extinct 244Pu (half-life, 82 My) in ten mesosiderites by subtracting from the total measured track densities those components expected from cosmic ray interactions and from fission of uranium. Six meteorites showed excess tracks attributed to 244Pu with densities that would suggest they cooled to temperatures of approx. 100°C at times of approx. 3.9-4.2 Gy ago. Track ages of 3.9 Gy or more would not be consistent with metal cooling rates of 0.1°/My, but would be consistent with rates of 1°/My.

We have analyzed nine samples of seven mesosiderites, including basaltic and gabbroic melt clasts from two (Vaca Muerta and Patwar) and specimens from three of the four metamorphic groups (8) and both compositional groups (3). 39Ar-40Ar ages on all samples indicate Ar loss by one or more events more recently than 4.0 Gy ago. A few samples gave reasonably well-defined plateau ages of approx. 3.6 Gy. A few additional samples gave ages that start at approx. 3.6 Gy at low extraction temperatures and increase to ages of 3.8-4.0 Gy. One sample (Pinnaroo) indicates major loss of Ar by an event at approx. 2.7 Gy or younger, but Ar released at high temperatures shows an age of ~3.6 Gy. None of the nine analyses show any evidence for 39Ar-40Ar ages older than 4.0 Gy. Essentially all analyses, however, give evidence of one or more events approx. 3.6 Gy ago. Figure 1 shows our 39Ar-40Ar age data (as a function of cumulative 39Ar release during stepwise temperature extraction) for four of these meteorites. Potassium concentrations for our samples ranged from lows of ~40ppm (Bondoc and Morristown) to highs of ~250ppm (Patwar) and ~350ppm (a plagioclase separate from Budulan). Age uncertainties are shown by the width of data boxes for individual extractions and are primarily due to corrections necessitated by production of 39Ar from Ca during neutron irradiation. In addition to radiogenic 40Ar, the samples also degassed 36Ar and 38Ar (in a ratio of ~0.65) produced by cosmic ray spallation and extra 38Ar at low temperatures produced in the irradiation by neutron capture on Cl.

Argon is released from these samples at relatively high extraction temperatures, as shown in Fig.1 by the temperatures by which 50% of the 39Ar released. This indicates that either a rather intense thermal event or very slow cooling would have been required to drive Ar from these meteorites ~3.6 Gy ago. For example, Ar closure temperatures (9) calculated from our diffusion data indicate that Ar diffusion from these mesosiderites would have ceased at ~350-500°C for cooling rates of 1°C/My and at ~700-900°C for cooling rates of 1°C/year. For the 1°C/My rate the Ar closure temperature is in the same region where Ni diffusion profiles that determine the metal cooling rates are established: the Ar ages would determine this time to have been ~3.6 Gy ago. It seems most unlikely that fossil fission tracks and Ni profiles in the metal could have survived the heating that produced the low Ar ages. Therefore, our Ar age data appear to be in contradiction to those 244Pu fission track ages of >3.9 Gy for approx. six mesosiderites (7).

Among the many theories of mesosiderite origins (e.g., 3,8,10), several assume that brecciation and silicate-iron mixing occurred early in solar system history, and that the slow metal cooling rates were produced during deep burial by processes such as crust-core mixing or by material still accreting to the parent object. Past chronological studies also generally assumed that mesosiderite ages reflected open isotope systems during slow cooling after formation at a time near 4.5 Gy ago (4,7). Our 39Ar-40Ar ages of ~3.6-3.8 Gy may be interpreted in two possible ways, depending on the precise metal cooling rate for mesosiderites. The ~3.6Gy age may be the time when very slow cooling deep inside the parent body brought closure for Ar diffusion and established metal cooling rates (at ~400-500°C). From this one might expect to see differences in apparent Ar ages among mesosiderites, which reflect variations in cooling times of different parts of the parent body; some age variations are present in our data. However, it seems unlikely that cooling at ~1°C/My could have occurred over a period longer than a few hundred My, as this would require temperatures of $\geq$1000°C at times of $\geq$4.2 Gy ago. Faster cooling rates, e.g. 10°C/My, would exacerbate this problem. In addition to a 4.2 Gy Rb-Sr isochron age for Esterville (4), we have obtained Rb-Sr and Sm-Nd whole-rock and mineral data for several mesosiderites which are consistent with isochron ages of approx. 4.5 Gy. Is is unlikely that Rb-Sr ages could survive resetting during slow cooling at such high temperatures, or that a parent object could sustain such temperatures for long times. Also, slow cooling at high temperature would be inconsistent with evidence for unequilibrated silicate textures (3). Consequently, those formation models that require mesosiderites to have formed ~4.5 Gy ago and immediately buried appear unlikely if the low-temperature cooling rate was 1°C/My or greater. If this cooling rate was less than 1°C/My, the young Ar ages could be consistent with early formation models, but the well-known problem of requiring very large parent bodies would become more difficult.

Another possible explanation for the 39Ar-40Ar ages is a major heating event(s) for mesosiderites at approx. 3.6-3.8 Gy ago. One theory of mesosiderite origin is that a catastrophic collision of two asteroids caused disruption of the mesosiderite parent body and subsequent deep burial when the material gravitationally reassembled (3). This event would cause resetting of Ar ages during or after the disruption at 3.6-4.0 Gy ago. The initially high temperatures of the mesosiderites fell too rapidly to significantly reset Rb-Sr or Sm-Nd ages, but the much slower cooling at temperatures below ~600°C was sufficient to maintain Ar loss and produce the metal cooling rates until ~3.6 Gy ago. This scenario would be consistent with a wider range of metal cooling rates (0.1-10°C/My, depending on the event time). A major, catastrophic event such as this could explain why Ar ages of mesosiderites appear to show a much greater grouping than do Ar ages of meteorites representing the HED parent body. In either of these two scenarios a complex history involving deep burial in a parent body and excavation by major disruption $<$4.0 Gy ago is required to explain both the slow metal cooling rates and the relatively young 39Ar-40Ar ages.

References: 1) Powell, G.C.A. 33, p789, 1969; 2) Dean & Goldstein, Meteoritics 19, p214, 1984; 3) Hewins, Proc. L.P.S.C. 14, pB257, 1983; 4) Murthy, Alexander, & Saito, Lunar Sci. XIV, p781, 1978; 5) Mittlefehldt, Bansal, Shih, Wiesmann, & Nyquist, LPSC XVII, p553, 1986; 6) Begemann, Weber, Vilcsek, G.C.A. 40, p353, 1976; 7) Crozaz & Tasker, G.C.A. 45, p2037, 1981; 8) Floran, Proc. LPSC 9, p1053, 1978; 9) Dodson, Cont. Min. Pet. 40, p259, 1973; 10) Wasson & Rubin, Nature 318, p168, 1985.