EARLY THERMAL EVOLUTION AND SIZES OF THE HED AND MESOSIDERITE PARENT BODIES: NEW CONSTRAINTS FROM Lu-Hf CHRONOLOGY.

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Introduction: The HEDs make up the largest suite of crustal igneous rocks available from asteroids. Silicate clasts in the mesosiderite metal-silicate breccias are also dominated by crustal rocks that resemble the HEDs in many ways. Silicate petrology in both groups of meteorites range from strikingly similar fine-grained basalts to coarse grained orthopyroxenites. Mesosiderites furthermore contain rare fragments of coarsegrained dunite. The crustal rocks on the mesosiderite parent body were at some point brecciated and mixed with molten metal. Existing chronological data and new Lu-Hf age data suggest that not only were the crustal rocks from these two parent bodies strikingly similar in terms of bulk chemistry, petrology and oxygen isotopes, they also both had an early igneous evolution (prior to the MPB metal-silicate mixing event) that prevailed for approximately 150 My. This would suggest that the two parent bodies were both of considerable size. The HED parent body is believed to be Vesta, which due to its large size has survived largely intact up to the present. If the mesosiderite parent body had a similar size what happened to it?

Analytical technique: Hf isotopes were measured on the same sample digestion with a multiple-collector inductively coupled plasma mass spectrometer (MC-ICP-MS) coupled to a CETAC Aridus desolvating nebuliser. Samples were processed using a new sample digestion and Lu-Hf separation scheme, involving fusion with a $LiBO_4$ fluxing agent [1]. Typical Hf and Lu blank/sample ratios were respectively <2 and 0.1‰, and are negligible. External reproducibility of the ^{176}Hf/^{177}Hf ratios was better than 35 ppm. Lu/Hf ratios determined by our method reproduced to <0.2%.

Lu-Hf data on chondrites and eucrites: Using this technique we have, for the first time, defined a ^{176}Lu-^{176}Hf chondrite whole rock isochron [2]. The new chondrite isochron has allowed us to determine a λ^{176}Lu of 1.983±0.033 x $10^{-11}y^{-1}$ assuming a 4.56 Gy chondrite formation age. The chondrite isochron is significantly different from a whole rock isochron determined for the cumulate eucrites [3]. Data on three cumulate eucrites [3] together with our analysis of the Bilanga diogenite align on a statistically significant Lu-Hf isochron defining an age of 4349±73 My, using our new λ^{176}Lu value. This implies a genetic relationship between diogenites and cumulate eucrites, and further confirms that cumulate eucrites are at least 100 Ma younger than basaltic eucrites. This is considerably younger than the 4470±22 My age determined for the cumulate eucrites by [3] using a λ^{176}Lu of 1.93 x $10^{-11}y^{-1}$. The Lu-Hf isochron for the cumulate eucrites plus Bilanga and our new decay constant implies that magmatic activity persisted on the eucrite parent body for more than 150 My. This is consistent with Pb-Pb ages of three cumulate eucrites of 4399±35 (Serra de Magé), 4426±94 (Moama), and 4484±19 My (Moore County) [4].

Basaltic eucrites do not form a statistically significant isochron [3] but the slope and intercept of the data is identical within analytical error to the chondrite isochron and thus consistent with early formation of the basaltic eucrites.

Lu-Hf data on mesosiderites: We have measured Lu-Hf isotopes of uncharacterized silicates from the type 1A mesosiderite Vaca Muerta. These data plot within error on the Lu-Hf isochron defined by the cumulate eucrites [3]. If the initial ^{176}Hf/^{177}Hf was the same in the mesosiderite and HED parent bodies as we would expect given the close resemblance of the two groups of meteorites this implies synchronous evolution of the gabbros on the parent bodies. More analysis of Lu-Hf systematics in gabbro clasts from Vaca Muerta will be used to further test this idea and to derive an independent initial ^{176}Hf/^{177}Hf for the MPB.

Sizes of the HED and mesosiderite parent bodies: The spectral resemblance between HED meteorites and Vesta and the unique nature of the reflectance spectra suggests that the HED parent body is identical to the third largest asteroid, the 520 km diameter 4 Vesta [5]. This is consistent with evidence for prolonged magmatic activity on the HED parent body that requires a parent body with a diameter of several hundred kilometers. Thermal models of 4 Vesta suggest that temperatures 140 My after formation had dropped to 1200 K 40 km below the surface and to 1400 K 90 km below the surface [6]. These temperatures should be considered lower limits for the actual temperatures attained in Vesta as the model in [6] did not include a regolith cover on the surface of Vesta. Given the abundant evidence for brecciation of the surface of Vesta it seems unlikely that there was no regolith and thus that the interior of Vesta was kept hot longer than found in [6]. The thermal conductivity of a regolith is two to three orders of magnitude below the conductivity of solid rocks and even a thin regolith cover may therefore have a significant effect on the thermal evolution of the asteroid [7].

For the mesosiderites, the exceptionally slow metallographic cooling rates, young Ar-Ar ages and evidence of an extensive complex igneous evolution also suggests that the diameter of the parent body was 200-400 km or similar to the HED parent body and Vesta [8].

What happened to the mesosiderite parent body? The large inferred size of the mesosiderite parent body should allow us to locate its parent asteroid. The size of the asteroid should make it easily observable and at the same time very resilient to impacts. It requires a 300-350 km projectile to catastrophically disperse a Vesta-sized asteroid. Such large projectiles are few and far between and the chance of a collision within the first 500 My therefore only 1% [9]. A more recent disruption appears implausible as some of the crustal fragments produced in the catastrophic colision would then have survived to the present, but none are observed [10]. Unless we have overestimated the size of the MPB it therefore seems difficult to understand why we do not observe it. The 264 km diameter M-type asteroid 16 Psyche is the only asteroid which has been suggested as a possible parent body for the mesosiderites [9]. This is, however, not without problems as Psyche is not favorably located to deliver meteorites to the Earth [9] and because the reflectance spectrum of 16 Psyche shows no evidence of pyroxene.

Mesosiderites and HEDs from the same body? The many similarities between the mesosiderites and HEDs and the absence of a plausible asteroid candidate for the MPB may be used to argue for a common parent body. There are, however, reasons to doubt that this could be the case [11]. One argument is that the howardites and mesosiderites are both breccias and therefore should be representative of the surfaces of their parent bodies, yet there are no reports of howardites containing mesosiderite-like clasts. However, this may not rule out a common parent body as the howardites could have formed prior to the metal-silicate mixing event and thus be representative samples of their parent body crust at the time where they formed. Redox trends and extreme Eu/Sm ratios are only observed in mesosiderites and have been taken as evidence for a more complex igneous evolution involving remelting episodes for the MPB [11]. Alternatively, these features could have formed in situ in the mesosiderites as a direct consequence of mixing hot metal with cold silicates [12-14].

Having two very large asteroids with near identical properties is in itself unlikely. In todays' asteroid belt there are only four asteroids with an IRAS diameter of more than 300 km; 1 Ceres, 2 Pallas, 4 Vesta and 511 Davida. These four large asteroids are all of different spectral types and the only one which appears to be differentiated is Vesta.

The poorly constrained nature of the metal-silicate mixing event adds to the complexity of the problem. It is not easy to explain how molten metal can be mixed with surface rocks, showing brecciated texture - which to many implies a surface setting - and at the same time show evidence of cooling slower than any other rock type that we have studied. Several very different scenarios have been suggested and none of them seems consistent with a common origin for the mesosiderites and HEDs. The most recent model invokes a breakup and reassembly event to mix molten core metal with cool crustal silicates [14]. Although it is possible the the HED meteorites could also be derived from large fragments of crustal material on such a rubble pile parent body it seems highly unlikely that the reassembled parent body would covered by a basaltic surface like Vesta.

Although no single observation may be used to completely rule out a common parent body for the HED and mesosiderites there is currently no model that can accomodate the complex features of HEDs and mesosiderites in the same parent body.

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