Origin of metal in mesosiderites. N. Sugiura and K. Ichimura, University of Tokyo

Introduction:

Mesosiderites are a kind of differentiated meteorites whose parent body accreted before chondrite parent bodies. Hence they may remember the earliest history of the solar nebula.

They are breccias mainly consisting of basaltic silicates and metallic iron. Two models on the origin of the metal have been proposed. 1) The metal was derived from a core of a projectile that brecciated the basaltic surface [1]. 2) The metal was derived from the core of the mesosiderite parent body that was completely disrupted and re-assembled [2]. In these models, since the mesosiderite metal is chemically unfractionated unlike the metal from iron meteorites, the metal has to be molten when the impact occurred. It is also to be noted that olivine which should be the main constituent of the mantle of an asteroid is rare in mesosiderites, which seems to be a weak point of both models explained above.

Hf-W systematics of mesosiderites was studied by [3]. W isotopic compositions of some mesosiderite metal are more radiogenic than those of magmatic irons. However, least radiogenic W in some mesosiderites is similar to those in many magmatic irons, suggesting early accretion of the parent body (if the metal was derived from the core). [4] reported Mn-Cr systematics of the Vaca Muerta mesosiderite. The inferred initial $^{53}Mn/^{55}Mn$ ratio from the whole rock isochron obtained from four Vaca Muerta clasts is (3.3 ± 0.6) $x10^{-6}$, which corresponds to an absolute age of 4563.4 (+0.9/-1.1) Ma which is similar to that of quenched angrites and about 2 Ma younger than the differentiation of the HED parent body mantle. The $^{26}Al/^{27}Al$ initial ratios for two clasts from Vaca Muerta are (40.7 ± 7.1) $x10^{-7}$ and (33.8 ± 5.0) $x10^{-7}$, respectively [5]. These correspond to ages 2.65 (+0.17/-0.20) Ma and 2.84 (+0.14/-0.17) Ma from CAI formation, respectively. In order for a magma-ocean to have formed by this time (~2.7 Ma after CAI formation), the parent body has to have accreted by ~1.2 Ma after CAI formation. This is much earlier than the accretion age of the ordinary chondrite parent body. Thus the sources for both metal and basaltic silicates in mesosiderites formed quite early. But it is not known when the metal and silicates assembled. It is also to be noted that internal isochron ages (as opposed to bulk isochrons and model ages) of mesosiderites are young due to slow cooling at low temperatures.

NWA 1878 mesosiderite:

NWA 1878 is a type B (rich in Opx) mesosiderite. It contained abundant fine-grained metal (Fig.1). The metal grains are somewhat sintered with each other but one can postulate that they were initially small spheroids and the size is well sorted. As we do not have good software for estimating the original grain sizes, spheroids were manually fitted to the grains. A grain size was determined as a radius of a sphere that has the same area with a spheroid. Because the manual fitting is somewhat subjective, the obtained grain size distribution (Fig.2) may have some uncertainties. But regardless of the uncertainties, we can see that the grains are small and well sorted. Compared with chondrules in ordinary chondrites, the metal grains are definitely small [6]. The mesosiderite metal sizes are also smaller and better sorted than metal grains in ordinary chondrites [6].

Discussion:

At present we do not have reliable estimate of metal grain size distributions that are derived by impact disruption of molten core metal. The metal size produced by such disruption would be initially determined by the balance between differential stress and/or centrifugal force of rotation on the liquid metal and surface tension. Later on, the sizes tend to increase by mutual collisional accretion and tend to decrease by friction with the nebula gas if it was present. (Note that the impact disruption must have occurred early before the accretion of the ordinary chondrite parent body. Hence the nebula gas was likely to be present.) Then, the mechanism that determined the metal size distribution may be analogous to that determined the cosmic spherules size distribution. The typical size of cosmic spherules is ~1 mm. The entry speed of cosmic spherules into the air is much faster than the velocity of molten metals relative to the nebula gas. (This velocity is expected to be smaller than the impact velocity of the projectile which is expected to be similar to the escape velocity of the parent body.) Therefore, unless the surface tension of the molten metal is much smaller than that of molten silicate, we expect the size of molten metal derived from impact disruption of a core is larger than 1mm. Therefore, we think that the mesosiderite metal was not derived from a core.

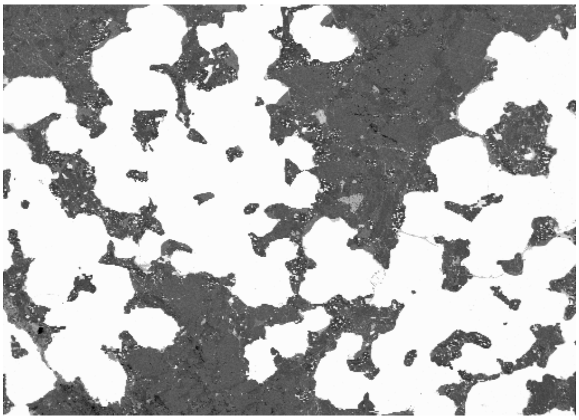

Fig.1 Back-scattered electron image of NWA 1878. The field of view is 3.6 mm. White grains are metal and dark grains are mainly pyroxene.

If the mesosiderite metal grains were not derived from a core, then from where they could be derived? We propose that they may be chondritic metal that formed during chondrule formation events. Compositionally, this is consistent because the mesosiderite metal is compositionally unfractionated. Also, it is well known that some metal grains that were lost from chondrules (we know that chondrules are depleted in siderophile elements), failed to accrete onto the ordinary chondrite parent bodies. This is the explanation of the difference in the iron abundances among H, L and LL chondrites (Urey-Craig diagram). The fate of the missing metal has not been clarified. It is possible that small metal grains were carried away by the nebula gas flow and ended up on the mesosiderite parent body. (We do not think that the mesosiderite metal was the one lost from ordinary chondrites because the mesosiderite metal formed much earlier than ordinary chondritic metal. But we think chondrule formation events occurred during the earlier epoch before formation of ordinary chondrites.)

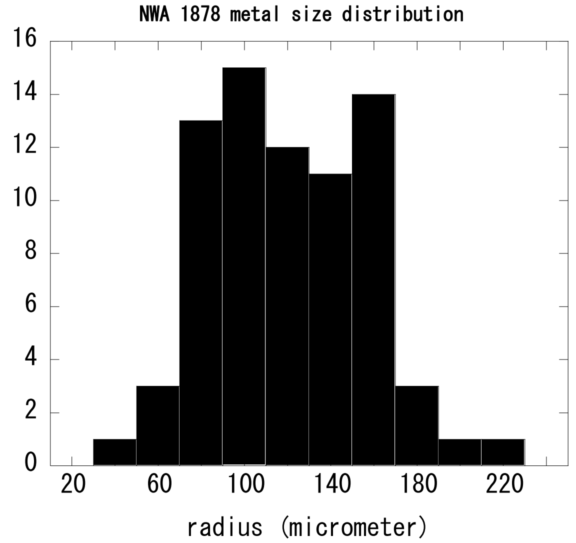

Fig.2 Grain size distribution of metals seen in Fig.1. The radius is that of a sphere with an area equal to the fitted spheroid.

If the mesosiderite metal is chondritic (produced during chondrule formation events), it means that the mesosiderite surface is very old and may still remember the nebula environment in the early solar nebula. The chondritic origin of mesosiderite metal is still very speculative. One difficulty against such an origin is the absence of such metal in eucrites and angrites. There are, however, ways to get around such difficulties. For instance, if abundant chondritic metal accreted on the surface of the HED parent body, it would sink by mantle overturn because of gravitational instability. The mesosiderite parent body may have avoided such an overturn because the near surface region had enough strength due to low temperatures resulting from brecciation. We think that further studies concerning the chondritic origin of the mesosiderite metal is worthwhile.

References:

[1] Rubin A. and Mittlefehldt D.W. (1993) Icarus, 101, 201-212. [2] Scott E.R.D. (2001) Meteorit. Planet. Sci., 36, 869-881. [3] Quitte et al., (2005) Geochim. Cosmochim. Acta, 69, 1321–1332. [4] Wadhwa et al. (2003) Geochim. Cosmochim. Acta, 67, 5047–5069. [5] Schiller et al., (2010) Geochim. Cosmochim. Acta, 74, 4844-4864. [6] Kuebler K. E. and McSween H. Y. Jr. 1999, Icarus, 141, 96-106.