THE ORIGIN OF FeNi-METALS IN EUCRITES AND IMPLICATION FOR IMPACT HISTORY OF THE HED PARENT BODY. A. Yamaguchi[1], C. Okamoto[2], M. Ebihara[1,3], [1]National Institute of Polar Research, Department of Polar Science, School of Multidisciplinary Science, Graduate University for Advanced Studies, Tokyo 173-8515, Japan (yamaguch@nipr.ac.jp), [2]Graduate School of Environmental Studies, Nagoya University, Nagoya 464-8601, [3]Department of Chemistry, Tokyo Metropolitan University, Hachioji, Tokyo 192-0397.

Introduction: HED meteorites, the largest group of achondrites, are mostly breccias indicating a heavy meteorite bombardment on the parent body. The HED parent body experienced an impact bombardment ~4.1-3.5 Gyr ago [1]. The evidence of the impact brecciation of HEDs is consistent with the presence of the cratered surface of asteroid 4 Vesta [2], a possible parent body of HED meteorites. However, the nature of projectiles that caused HED cataclysm has been poorly known. Another unresolved issue is the genetic relationship between HEDs and mesosiderites. Mesosiderites are an enigmatic group of meteorites composed of almost equal amounts of metals and HED-like materials. Many workers suggested that mesosiderites are polymict breccias formed by impacts on the surface of Vesta-like asteroid [e.g., 3].

We performed petrologic and geochemical comparison among anomalous eucrites Dhofar 007 and EET92023 (Dho/EET) and several brecciated eucrites to better understand the impact processes occurred on the parent body. We determined bulk chemical compositions, especially focusing on the platinum group elements (PGEs) (Os, Ir, Ru, Pt, Rh, Pd) [4,5] because the PGE abundances are excellent indicators for identifying projectile materials. Polished thin sections (PTSs) were made from the portions adjacent to those for the bulk chemical analyses, and examined by a SEM and an EPMA, focusing on the occurrence of FeNi-metals, likely carrier phases of siderophile elements in eucrites.

Brecciated eucrites: *EET92003 monomict eucrite.* The PTS is composed of fine-grained, recrystallized basaltic clasts and a clastic matrix with gradational boundaries. Compositions of pyroxene in the clasts and matrix clustered around $Wo_{\sim13}En_{\sim38}$, and plagioclase compositions are $An_{93.2\text{-}84.6}$. Fine FeNi-metal grains (Ni/Co = 3.6-3.7) occur in the clastic matrix. There is a large (260 x 170 µm), fine-grained (<2-3 µm) assemblage of sulfide (FeS) and FeNi-metal. The grain sizes are smaller than the resolution of electron beam, but ~1-11 wt% of Ni is detected.

ALHA76005 polymict eucrite. This is one of the most studied polymict eucrites [e.g., 6]. The PTS displays a clastic matrix, composed of a variety of mineral fragments, and dark impact melt clasts (<1.5 mm). The compositions of pyroxene and plagioclase vary widely (pyroxene: $Wo_{5.4}En_{64.5}$ - $Wo_{12.1\text{-}33.5}En_{21.5\text{-}38.4}$, plagioclase: $An_{93.2}Or_{0.1}$ to $An_{67.0}Or_{2.5}$). FeNi-metal grains occur as fragments in the matrix and inclusions in pyroxene fragments and impact melt clasts. Two grains of FeNi-metal were analyzed. The Ni concentrations are 4.7 wt% (Ni/Co = 3.9) and 3.3 wt% (Ni/Co = 20.1).

GRO95633 polymict eucrite. The PTS is a clastic matrix, composed of mineral fragments of pyroxene, plagioclase, silica minerals, and oxide phases. The compositions of low-Ca pyroxene show a narrow range ($Wo_{\sim1\text{-}2}En_{40.8\text{-}61.9}$), and those of plagioclase are $An_{90.1\text{-}95.5}$. The silicate fragments and matrix are extensively darkened due to the presence of very fine opaque minerals (FeS?) along cracks and fractures probably formed by shock (i.e., shock darkening). There are relatively, large subrounded FeNi-metal grains (<120 µm) (Ni/Co = 12.5-15.5) with FeS along the rims.

Bulk chemical data. The bulk Ni concentrations vary from 27.6 ppm (ALH76005) to 296 ppm (EET92003). The range is similar to those of howardites [7]. The PGE abundances also vary significantly (CI x 0.004-~0.05). The CI-normalized Ni/Ir ratios (Ni/Ir_{CI}) have a wide range; The Ni/Ir_{CI} ratios of ALH76005, EET92003, and GRO95633 are 0.58, 3.0, and 0.23, respectively. The Pt/Ir_{CI} ratios have a limited range (ALHA76005: 0.83; EET92003: 0.73 and GRO95633; 0.88). The relative abundances of PGEs in ALH76005 and GRO95633 are within the range of IIIAB, and ALH76005 is in the range of mesosiderite metals. The PGE ratios of EET92003 are similar to those of IAB iron meteorites.

Anomalous eucrites, Dhofar 007 and EET92023: Dho/EET are coarse-grained gabbroic eucrites [8,9], composed of Mg-rich pyroxene and plagioclase. Dhofar 007 contains a minor portion of clastic matrix. We studied a coarse-grained clast in Dhofar 007. The textures and bulk chemistries of Dho/EET are broadly similar to those of cumulate eucrites. These eucrites contain significant amounts of FeNi-metals (kamacite and taenite). The presence of taenite is not reported in other cumulate eucrites.

Although typical cumulate eucrites have low-Ca pyroxene with thick augite lamellae, the low-Ca pyroxenes in these meteorites has very fine exsolution lamellae, indicating rapid cooling at high temperatures (~1100 °C). The zoning profiles and the presence of cloudy taenite suggest that Dho/EET are cooled very slowly at lower temperatures [8,9].

The Ni/Ir_{CI} (1.03 for EET92023 and 0.83 for Dhofar 007) and Pt/Ir_{CI} ratios (1.02 for EET92023 and 0.49 for Dhofar 007) suggest the relationship with the metallic portions in mesosiderites [8,9].

Discussion: Monomict eucrites contain a small amount of Fe-metal which either formed during of the magma or by some reduction of pyroxene and oxide. Such metal would have low Ni (<0.01-0.1 wt%) and low Ni/Co (<~5) (e.g., Camel Donga) [e.g., 10]. During igneous possesses, because Ni and PGEs are partitioned into metallic core, monomict eucrites are generally depleted in Ni and PGEs. In contrast, the FeNi-metal incorporated as fragments of projectiles has high Ni/Co (>~10), mostly occurs in clastic or impact melt matrices in breccias [7]. Both types of Fe-metals occur in the brecciated eucrites. The relatively high Ni/Co ratios suggests that some FeNi-metals in our samples are of meteoritic origin. The PGE abundances of the brecciated eucrites suggest the presence of ~0.4-5.3 wt% of chondritic materials. However, we could not find such amounts of chondritic materials in the PTSs although more detailed observations of several PTSs are required. The abundance patterns of PGEs suggest that the FeNi-metals with high Ni/Co in the brecciated eucrites were derived from iron meteorites.

In Dho/EET, FeNi-metals occur in coarse-grained crystalline rocks, not in a clastic and/or impact melt matrix as observed in polymict eucrites (e.g., ALH76005). Thus, these metals were not simply incorporated by brecciation. The occurrence of FeNi-metal is similar to those in silicate clasts in some mesosiderites. The basaltic clasts in Mt. Padbury contain a significant amount of FeNi-metals although igneous textures are roughly preserved. These metallic phases could have been injected along minor cracks and fractures from the metallic portion of the mesosiderite [11]. Alternatively, the precursor of Dho/EET were partially melted by strong heating, and mixed with FeNi-metals by shock. The incorporation of metal at high temperatures is consistent with the absence of the fractionation of siderophile elements, compared to those in basaltic clasts in some mesosiderites [11].

The PGE signatures in brecciated eucrites (ALH76005 and GRO95633) and anomalous eucrites (Dho/EET) are similar to those of metallic portions of mesosiderites and IIIAB iron meteorites, implying that mesosiderites and HED meteorites form a continuum in terms of the metal abundance. The petrologic differences observed in these eucrites reflect the redox reaction caused by metal-silicate mixing, which significantly affected the silicate clasts in mesosiderites, but did not take place in the case of HED meteorites [3,12]. The degrees of metamorphism would have been controlled by the degrees of mixing, sizes of silicate and metal clasts, and temperatures. Dho/EET have low abundance of FeNi-metal (~1 wt%), and thus escaped from redox reaction. These rocks formed regions distant from the impact sites. Thus, both HED meteorites and mesosiderites can be formed by a single cratering event by impacts of metallic projectiles [e.g., 13].

In this scenario, the thermal histories of brecciated HED meteorites and anomalous eucrites, Dho/EET can be explained in terms of large cratering events and later metamorphism. Dho/EET experienced injection of FeNi-metal and recrystallization at high temperatures. Subsequently, these eucrites were excavated from the deep interior, cooled rapidly, and buried by thick ejecta as deeply as mesosiderites were. Similarly, several crystalline eucrites (e.g., EET90020, Moore County) experienced an impact excavation from hot interior by a large cratering event [14]. The cratering events may have occurred in a hot crust, which effectively caused subsequent thermal metamorphism. Dho/EET may provide an additional evidence for large cratering events on the HED parent body.

The presence of unrecrystallized clastic matrix and relatively low abundance of FeNi-metal (and low abundances of siderophile elements) suggests that the brecciated eucrites (e.g., ALH76005) and other polymict eucrites and howardite [7] were escaped from major thermal metamorphism after impacts. These rocks were not buried deeply by the impact ejecta.

This scenario is consistent with the geologic history of the asteroid 4Vesta inferred from the presence of large craters (up to 460 km in diameter) [2,15]. As in the case of EET92003, the parent body could have been impacted by various types of projectiles.

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