

IN-SITU ANALYSES OF HIGHLY SIDEROPHILE ELEMENTS IN FE-NI METAL OF ORDINARY CHONDRITES. S. Okabayashi¹, T. Yokoyama¹, N. Nakanishi¹, and H. Iwamori^{1,2}, ¹Department of Earth and Planetary Sciences, Tokyo Institute of Technology, Tokyo, Japan (okabayashi.s.aa@m.titech.ac.jp), ²Department of Solid Earth Geochemistry, Japan Agency for Marine-Earth Science and Technology, Kanagawa, Japan.

Introduction: Ordinary chondrites (OCs) are by far the most abundant class of meteorites that have not been experienced extensive differentiation including core-mantle segregation. They are characterized by relatively small but abundant Fe-Ni metal grains (<~100 μm). Fe-Ni metal grains in OCs occur in chondrules (“interior grains”), at the surface of chondrules (“margin grains”), and in matrix (“isolated grains”). Although Fe-Ni metal is one of the major components in OCs, the formation processes of metal grains have been still veiled.

Kong and Ebihara [1,2] reported that metal grains of some OCs did not possess the solar Co/Ni ratio. The authors thus ruled out direct condensation in the solar nebula for the sole or major origin of OC metals. Alternatively, they suggested that reduction of FeO in silicate during chondrule heating formed OC metals because apparent metal-silicate partition coefficients for some elements (e.g., W, Mo) were consistent with those obtained in melting experiments that simulated the chondrule formation [1,2].

Highly siderophile elements (HSE: Ru, Rh, Pd, Re, Os, Ir, Pt, Au) in Fe-Ni metal grains are key tracers for studying the origin of OC metals due to their significantly high affinity to metals relative to silicates. Previous works on in-situ analyses of HSEs for individual OC metal grains presented positive correlations between refractory HSEs (Ru, Re, Os, Ir, Pt), whereas these elements did not show any meaningful correlation with volatile HSEs (Pd, Au) [3]. Such discrepancy between refractory and volatile HSEs cannot be explained by the simple reduction of FeO in silicate suggested by [1, 2].

The goal of this study is to understand the processes that fractionated HSEs in OC metals. In this study, in-situ analysis using LA-ICP-MS was performed for measuring HSE concentrations in Fe-Ni metal grains. One of the obstacles to illuminating the metal formation is thermal metamorphism on OC parent bodies. In this study, therefore, we specifically focused on the type-3 OCs to minimize the effect of parent body thermal processing.

Experimental: Slabs of Richfield (LL3.7), NWA 6910 (L3.3) and Sahara 97210 (L/LL3.2) were cut into small pieces and embedded in petropoxy 154 resin. Their surface was polished, and then mapped by SEM-EDS (S-3400N, Hitachi High-Technologies) to classify the observed Fe-Ni metals into interior, margin, and isolated grains. The areas of Fe-Ni metal grains were also

measured and the grains with >20 μm diameter were dedicated for LA-ICP-MS analysis.

We utilized a Ti:sapphire UV-fs laser (IFRIT, Cyberlaser) with quadrupole ICP-MS (XSERIES 2, Thermo Scientific) for LA-ICP-MS analysis. Fourteen siderophile elements including HSEs (Fe, Co, Ni, Cu, Mo, Ru, Rh, Pd, W, Re, Os, Ir, Pt, Au) were measured by spot analysis (~20–40 μm). During the analysis, Mg, Si, and S were also monitored to avoid beam overlaps from silicate and sulfide phases. The laser repetition rate was fixed at 10 Hz, and the fluence was varied (8–15 J cm^{-2}) depending on the size of metal grains and concentration of elements. The pits produced after 60 s ablation were ~20–40 μm in diameter. An iron meteorite, Chinga (ung), the standard of our LA-ICP-MS analysis, was measured each after 10 spots of sample measurements. The data acquisition was made in the time-resolved analysis mode. The concentrations of siderophile elements were calculated by using the signal of ⁶¹Ni as for the internal standard.

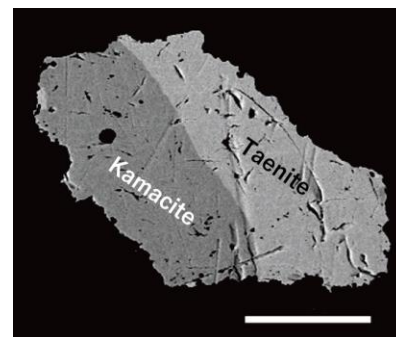


Figure 1. BSE image of an Fe-Ni metal grain embedded in silicate (Richfield). Dark and bright regions are kamacite (low-Ni) and taenite (high-Ni), respectively. Scale bar represents 40 μm .

Results and Discussion: Most of the metal grains in OCs are, even for type-3 samples, known to have experienced kamacite-taenite segregation during the parent body process [4] (Fig. 1). The OC metal grains analyzed in this study presented clear positive correlations in the Pd and Au vs. Ni diagrams (not shown), indicating that Pd and Au were redistributed between kamacite and taenite during the parent body process and thus lost their original abundances when the metal grains have initially formed. On the other hand, almost no correlations were observed in the diagrams of the other HSEs (Ru, Rh, Re,

Os, Ir and Pt) vs. Ni (not shown). Therefore, we deduce that the initial abundances for these HSEs are preserved in the OC metal grains analyzed.

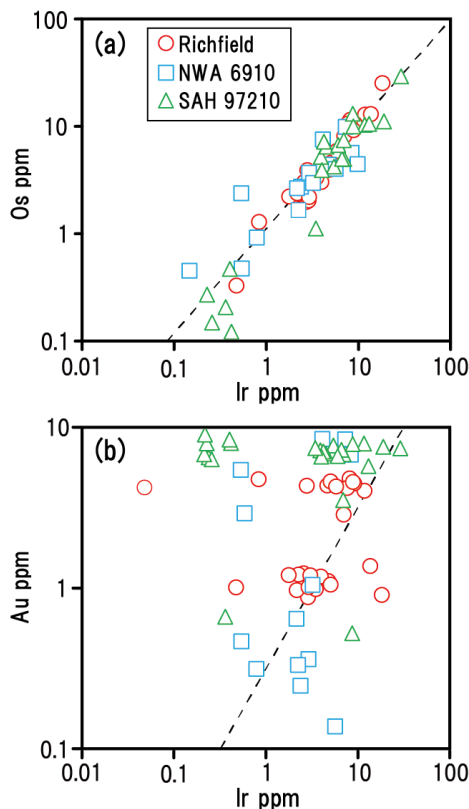


Figure 2. Diagrams of (a) Os vs. Ir and (b) Au vs. Ir abundances in Fe-Ni metal grains of type-3 OCs. The diagrams similar to (a) are given when Re, Ru, Pt, and Rh abundances are plotted against Ir, while Pd vs. Ir diagram resembles (b). Dashed lines represent CI ratios [6]. Typical analytical errors are ~10%.

Figure 2 shows the abundances of HSEs plotted against Ir abundance in the Fe-Ni metal grains of type-3 OCs. A strong positive correlation can be seen in the Os vs. Ir diagram over a wide range of Ir abundance that spans nearly three orders of magnitude. In addition, the Os/Ir ratios in individual Fe-Ni metal grains are nearly chondritic (Fig. 2a). Such a positive correlation with the chondritic abundance ratio is observed between the other refractory HSEs (Ru, Rh, Re and Pt) and Ir. However, such positive correlation cannot be observed between volatile HSEs (Pd and Au) and Ir (Fig. 2b). This discrepancy between refractory and volatile HSEs is difficult to explain with a simple reduction model for metal formation [3].

By contrast, recondensation of metal vapor during chondrule formation has been suggested for the origin of margin metal grains in CR chondrites [5]. In this case,

the abundances of volatile and refractory HSEs should be higher and lower in margin grains, respectively, when compared to those in interior grains. In this study, HSEs concentrations in interior, margin, and isolated grains were comparable to each other without any significant differences. This result indicates that interior, margin, and isolated grains have a common origin other than evaporation and recondensation of metal vapor during chondrule formation.

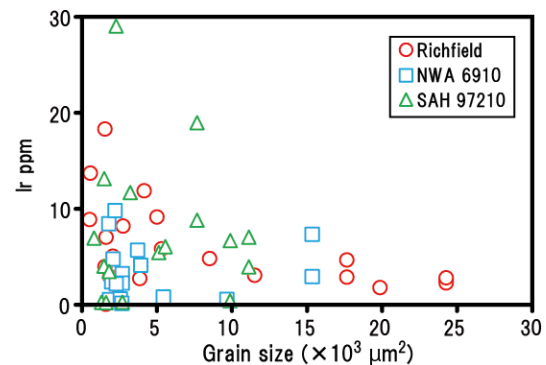


Figure 3. Plot of Ir abundance against the grain size of Fe-Ni metal in type-3 OCs. The smaller grains have wide variation of Ir abundance. Typical analytical errors are ~10%.

A negative correlation can be seen between the size and Ir abundance for Fe-Ni metal grains of OCs analyzed in this study (Fig. 3). The Ir abundance varied from 0.2 to 29 ppm for smaller metal grains (<5000 μm^2), while the range of variation decreased with the increase of metal size. This correlation was the case for the other refractory HSEs (Ru, Rh, Re, Os and Pt). This result is consistent with the mixing of refractory-rich and refractory-depleted metals for the origin of Fe-Ni metal [3,7]. The variety of abundances for refractory HSEs in small metal grains is interpreted as the result of various mixing rates. It should be noted that this mixing model can coexist with the FeO-reduction model. The mixing of condensed metal (refractory-rich) [8] and FeO-reduced metal (refractory-depleted) is the possible explanation for HSEs fractionation in OCs metal.

References: [1] Kong P. and Ebihara M. (1996) *GCA*, 60, 2667-2680. [2] Kong P. and Ebihara M. (1997) *GCA*, 61, 2317-2329. [3] Campbell A. J. and Humayun M. (2003) *GCA*, 67, 2481-2495. [4] Meftah N. et al. (2016) *Meteoritics & Planet. Sci.*, 51, 696-717. [5] Connolly H. C. et al. (2001) *GCA*, 65, 4567-4588. [6] Anders E. and Grevesse N. (1989) *GCA*, 53, 197-214. [7] Grossman J. N. and Wasson J. T. (1985) *GCA*, 49, 925-939. [8] Berg et al. (2009) *ApJ*, 702, L172-L176.