Re, Os, AND Ir FRACTIONATION IN ORDINARY CHONDRITE METAL.

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Introduction: We present Re, Os, and Ir contents and interelement ratios determined by laser ablation ICP-MS on individual ordinary chondrite metal grains. The origin of platinum group element (PGE: Ru, Rh, Pd, Os, Ir, Pt) fractionation in ordinary chondrite metal has been proposed to be the result of solid metal-liquid metal separation occurring in molten planetesimals, prior to the assembly of the ordinary chondrite parent bodies [1]. There are compelling reasons to believe that early planetesimals formed while ^{26}Al was live, resulting in melting of these objects [1]. Impact disruption of such molten planetesimals is proposed to produce the present generation of chondrules and metal observed in ordinary chondrites. Such a model potentially accounts for the 6 m.y. age difference between chondrules and CAIs, the absence of ^{26}Al in chondrules, and the Re/Os fractionation observed by [1]. The elements under consideration here: Re, Os and Ir are refractory elements, with Re and Os having very similar condensation temperatures, such that large Re/Os fractionations are not anticipated in Fe-Ni condensates. Large fractionations of the Re/Os ratio are known from magmatic iron meteorites, where Os is preferentially partitioned into solid Fe alloy. Although both Re and Os are concentrated into the solid, the small fractionation induced is magnified by fractional crystallization yielding a range of a factor of 3 in Re/Os ratios between members of a single magmatic iron meteorite group. Thus, prior fractionation of metal in molten planetesimals is a potential means of producing the observed Re/Os fractionations in ordinary chondrite metal. In addition to Re/Os fractionation, this process also produces large Ir/Os fractionations. To determine the origin of ordinary chondrite metal, we have performed microanalysis of Re, Os, Ir and Pt in individual Fe-Ni grains in the matrices of three ordinary chondrites: Allegan H5, Weston H4 and Soko Banja LL4.

Analytical: Prior to laser ablation, polished slabs of each of these chondrites were examined by SEM to select and characterize individual metal grains. Laser ablation analyses were performed with a CETAC LSX-200 system attached to a magnetic sector Finnigan Element™ ICP-MS [2]. Typical laser pit sizes were ~50 µm in diameter and ~25 µm in depth. Analytical procedures for Allegan followed [2,3], in which Fe, Co, Ni and PGEs were determined with a precision of 10-15%. To obtain more precise results on spot analysis, the magnet was positioned at mass 185 and rapid scans of the accelerating voltage were performed to acquire the following isotopes: ^{185}Re, ^{192}Os, ^{193}Ir and ^{195}Pt, with a 1 ms settling time per peak. This procedure increased the duty cycle of the measurement process to 95%, improving precision of the interelement ratios (2-5%). This procedure was followed for Soko Banja and Weston. Sensitivity factors were calculated from analyses of the Hoba IVB iron meteorite [2, 3].

Results: Analysis of metal grains are shown in Figs. 1 and 2.

Weston H4: analysis of 6 kamacite grains revealed very little compositional variation, *e.g.*, Re/Os= 0.13±0.3 (1σ) and Ir/Os= 1.02±0.06 (1σ). The Re/Os ratio varies from 1.3-2.3xchondritic, and the Os content averages 1.9±0.2 ppm (1σ), consistent with H chondrite metal separates [1]. The fraction of metal present in average H chondrite falls is 16±1 % [4], and the average H chondrite Os abundance is 0.89±0.03 ppm [1], yielding 5.6 ppm Os in the metal, if metal was the sole host of Os. Our data imply that less than half the Os and Ir inventory of H chondrites are present in metal. This is not true of Re which ranges from 50% to 100% in metal. Thus, the suprachondritic Re/Os ratios of H chondrites is due to Os deficiency in metal.

Allegan H5: both taenite and kamacite grains were analyzed, which have complementary Os abundances: 2.5-3.5 ppm in taenite, 1-2 ppm in kamacite, consistent with taenite-kamacite partitioning observed in iron meteorites. The kamacite and taenite in Allegan plot below and above, respectively, of the kamacite Os in Weston, compatible with a similar bulk metal Os content of 2 ppm. Both types of metal show variations in Re/Os at constant Os contents, and chondritic Ir/Os ratios. Two kamacite grains in Allegan were found to have higher Os contents, 6 ppm, chondritic Ir/Os, and subchondritic Re/Os= 0.04-0.06. Such grains may be complementary to typical OC metal.

Soko Banja LL4: both kamacite and taenite grains were analyzed, which exhibit Os abundances of about 7±2 ppm, with no observable distinction between kamacite and taenite. It should be noted in Fig. 1 that metal from Soko Banja has significantly higher Os abundances than metal in H chondrites, consistent with a lower total metal in LL chondrites. The fraction of metal present in average LL chondrite falls is 2.4±1.6 wt.% [4], and the average LL chondrite Os abundance is 0.387 ppm [5], yielding ~15 ppm Os in the metal, if metal was the sole host of Os. As with Weston and Allegan, Soko Banja metal grains have an Os content about a factor of 2 lower. The Re content varies from 0.5-1.4 ppm, compared with a calculated value of 1.1 ppm Re for LL chondrite metal having chondritic Re/Os ratios and 15 ppm Os. Most Soko Banja metal grains have Re≤ 1.1 ppm, with a single kamacite grain having higher Re=1.4 ppm and Os=16 ppm. Another Soko Banja kamacite grain has low Os, suprachondritic Ir/Os and Re/Os= 0.83 and is interpreted to be a decomposed sulfide. Excluding this grain, Soko Banja metal has chondritic Ir/Os.

Fig. 1. Re/Os ratio *vs*. Os abundance in ordinary chondrite metal. Trends depicted are for magmatic irons [7, 8]; filled squares: Allegan kamacite; filled diamonds: Allegan taenite; open squares: Weston kamacite; gray squares: Soko Banja kamacite; gray diamond: Soko Banja taenite; crosses: WR ordinary chondrite [1]; thick crosses: separated ordinary chondrite metal [1]. CI chondrite Re/Os= 0.075 [9].

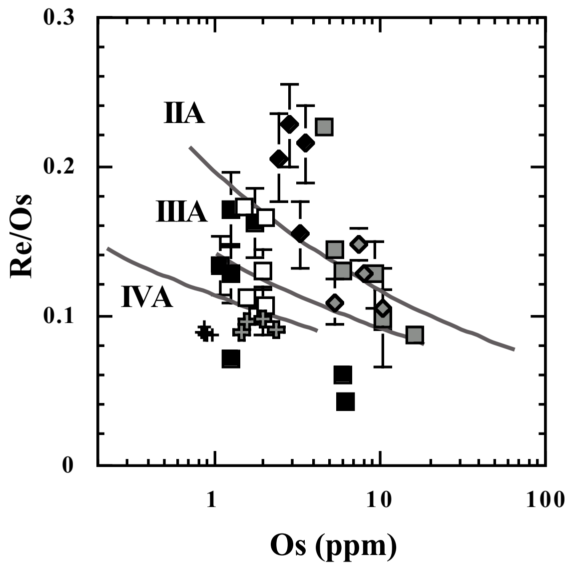
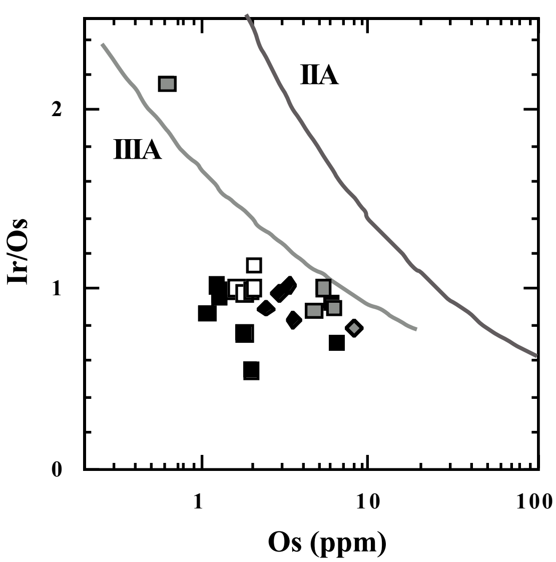


Fig. 2. Ir/Os ratio *vs*. Os abundance in ordinary chondrite metal. Trends depicted are for magmatic irons from data of [6]; other symbols, as in Fig. 1, above. Chondritic Ir/Os ratio= 0.98 [9]. Errors ≤ ± 10%.



Discussion: One characteristic of magmatic iron meteorite fractionations is the large range in Os abundances (*e.g.*, 4 orders of magnitude in IIAB irons) accompanying variations in the Re/Os (*e.g.*, factor of 3 in IIAB irons) and Ir/Os ratios. Excluding some metal apparently formed from troilite, the metal grains in ordinary chondrites show fairly limited ranges of Os abundances and Ir/Os ratios. This is not compatible with Re/Os and Ir/Os fractionation by solid metal-liquid metal separation on molten planetesimals, since in magmatic iron fractionation trends $D^{Re} \sim D^{Ir} < D^{Os}$ [6]. The Soko Banja grain with the lowest Os, and highest Ir/Os, exhibits a Re/Os ratio much higher than any iron meteorite. Kamacite grains in Soko Banja and Allegan with the highest Os contents do not behave consistently with iron meteorite fractionation trends, either. The majority of the grains show chondritic Ir/Os, constant Os, and variable Re/Os ratios. This fractionation is not compatible with a magmatic fractionation. The origin of the Re/Os fractionation observed here in OC metal is not entirely clear, but it appears that Re is partitioned 50-100% into metal, while Os and Ir are deficient in the metal, giving rise to large Re/Os fractionations. Such fractionations are observed even in an equilibrated ordinary chondrite like Allegan. Complementary fractionations have been observed in "matrix", a fine-grained metal and silicate mixture. Formation of the matrix metal by reduction of FeO should produce metal with quantitative extraction of PGEs and Re. How Os and Ir are sequestered separately from Re remains to be understood.

Conclusions: The PGE fractionation model proposed by [1] is not supported by the evidence presented here. Subsolidus redistribution of PGEs between kamacite and taenite dominates their present distribution. A few individual grains exhibit distinctly higher or lower elemental abundances, but a magmatic origin of such grains is not supported by their Ir/Os ratios. Metal in ordinary chondrites exhibits a net fractionation towards suprachondritic Re/Os ratios, compared with bulk ordinary chondrites. A complementary low Re/Os ratio host is required for mass balance, the nature of which is presently unclear. Analyses of matrix bearing fine-grained metal reveals the presence of significant PGE contents with low Re/Os ratios. A few large metal grains also have complementary Re/Os ratios and high Os abundances. The fractionations of Re/Os at reasonable Os contents (~2 ppm) observed in individual metal grains indicates that a more precise chronology can be obtained by analyzing individual metal grains for Re-Os systematics.

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