

**AN EVALUATION OF EVIDENCE FOR EARLY SOLAR SYSTEM PROCESSES PRESERVED IN THE HIGHLY SIDEROPHILE ELEMENTS OF CHONDRITE COMPONENTS** M.F. Horan<sup>1</sup>, C.M.O'D. Alexander<sup>1</sup> and R.J. Walker<sup>2</sup>, <sup>1</sup>Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road NW, Washington DC 20015 (horan@dtm.ciw.edu; alexande@dtm.ciw.edu), <sup>2</sup>Department of Geology, University of Maryland, College Park MD (rjwalker@geol.umd.edu).

**Introduction:** The highly siderophile elements (HSE: including Re, Os, Ir, Ru, Pt, Pd) share the common characteristic that they are strongly partitioned into metal relative to silicates. Their volatilities and redox behaviors, however, are dissimilar. Metallic Re, Os and Ir are among the most refractory of the chemical elements. Palladium and some oxidized species of Re and Os, in contrast, are comparatively volatile. Rhenium, Os and possibly Ru can be soluble in oxidized aqueous solutions. In terrestrial peridotites, Os, Ir, Ru and Pt can form refractory phases that persist though melting and metasomatism [1]. As a consequence of these diverse chemical behaviors, the HSE present in primitive meteorites have the potential to record the earliest solar system processes, including nebular evaporation and condensation, the formation of metal, and thermal metamorphism and aqueous alteration in planetesimals. In addition, the <sup>187</sup>Re-<sup>187</sup>Os isotope system ( $\lambda = 1.67 \times 10^{-11} \text{a}^{-1}$ ), comprising two of the HSE, can potentially provide chronologic information about these processes.

The compositionally, texturally, and presumably genetically diverse components (chondrules, metal, and fine matrix) that comprise chondrites should have HSE distributions that reflect differences in their formation, assemblage and chemical evolution. Earlier work has shown, not surprisingly, that the magnetic susceptibility of chondrite components is the best predictor of their HSE contents [2]. Here we present characterization of the distribution of the HSE and corresponding Re-Os isotopic data among components in Ochansk, a H4 fall with shock stage S3.

**Results:** A 2.5 g sample of Ochansk was crushed gently; metal was separated with a hand magnet, and nonmagnetic fractions were sieved into size fractions and further divided using a Franz magnetic separator. Abundances of Re, Ir, Ru, Pt and Pd were obtained by isotope dilution using a MC-ICP-MS; Os abundances and isotopic compositions were obtained by N-TIMS [3]. Processing blanks for all samples discussed here are negligible.

Rhenium-Os isotopic data for a bulk sample of Ochansk and from magnetically separated components are shown in Fig. 1. Metal fractions have higher Re/Os and more radiogenic <sup>187</sup>Os/<sup>188</sup>Os than the bulk sample, while nonmagnetic fractions have lower Re/Os and less radiogenic Os. All of the samples lie closely about a 4.57 Ga reference line (Fig. 1), and suggest

that the dominant fractionation of Re and Os (i.e., between the metal and nonmagnetic fractions) occurred early in the history of the solar system, and has been maintained since then. Most of the weakly magnetic and nonmagnetic fractions deviate from the reference line beyond their analytical uncertainties (which are much smaller than the symbols in Fig.1) and reflect limited, late open-system behavior of Re and/or Os, and likely the other HSE. For example, the nonmagnetic sample that deviates most from the reference line may have recently gained as much as 18% of its Re. Other nonmagnetic fractions show evidence for a possible gain in Os (or loss of Re) of as much as a few percent.

Abundance data for the HSE in components from Ochansk are shown in Fig. 2. The metal data show little fractionation between HSE relative to the bulk sample, despite a nearly tenfold variation in concentration. Finer metal has higher concentrations than coarser metal fractions. All nonmagnetic components have much more highly fractionated HSE, showing both lower Re/Os and lower Pd/Ir, compared to the bulk meteorite. The least magnetic fractions have the lowest absolute abundances of HSE, and the lowest Re/Os and Pd/Ir.

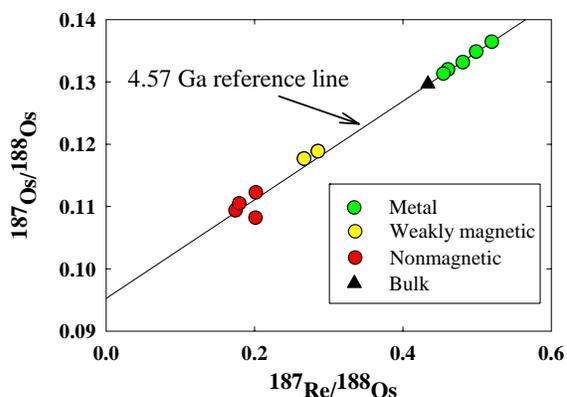


Fig. 1. Re-Os isotopic diagram of components separated from Ochansk.

**Discussion:** Models to explain the distribution of HSE in chondrite components must account for the following observations. First, metal has uniform, unfractionated HSE abundances, but wide variations in HSE contents, consistent with [2]; nonmagnetic components have substantially lower, highly-fractionated

HSE abundances. The HSE abundances in the non-magnetic fractions, however, would be 10 to 1000 times lower than those measured if the nonmagnetic fractions had formed in equilibrium with metal, given metal-silicate bulk distribution coefficients ( $D$  values) of  $>10^4$  for HSE, and their concentrations in the metal.

**HSE in metal:** If metal incorporated variable proportions of refractory HSE carriers which formed as nebular condensates or evaporative residues, as suggested by [2], then our data suggest that the HSE carriers would have been solid below the condensation temperature of Pd but above the condensation temperature of Fe. At nebular pressures of 10 Pa, however, the expected condensation sequence is Fe first, then Pd, or simultaneous Fe and Pd condensation. Calculations in [4] suggest that, at higher-than-canonical nebular pressures in a metal-rich environment, Pd would have condensed at higher temperature than Fe.

Significant oxidation and sulfidization of metal grains clearly occurred during metamorphism of the H chondrites. If both processes were diffusion controlled (i.e., all grains were oxidized/sulfidized to the same depth) and if the diffusion rates for the HSE were slower, then the residual material from smaller grains would have higher HSE contents. Indeed, HSE contents of the metal fractions are inversely correlated with their grain size. The relationship between individual grain size and HSE concentration might be more precisely quantified using microbeam techniques.

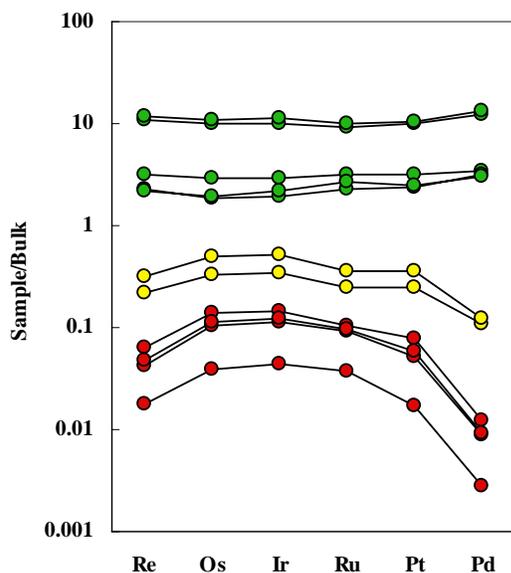


Fig. 2. HSE abundances in magnetically separated fractions, normalized to the bulk sample. HSE are arranged in order of decreasing condensation temperature from left to right. Symbols as in Fig. 1.

Reductive or evaporative addition of metal to pre-existing metal grains could also lead to the formation of hybrid metal with variable HSE abundances. Metal

that formed as a product of reduction of FeO in silicate would be expected to have low abundances of HSE. At least some fraction of the metal in ordinary chondrites was likely formed by FeO reduction during chondrule formation [5], or produced from troilite by evaporative loss of sulfur. Precipitation of this metal onto previously formed HSE-rich metal could yield the variable HSE contents measured in the metal fractions. Reduction of FeO might also occur during metamorphism in the parent body, by reaction with carbon or organic matter [6]. As with oxidation, the finest metal fractions would be expected to have the highest concentrations of HSE, as observed here.

**HSE in nonmagnetic fractions:** One possible explanation for an apparent overabundance of HSE in the silicate fraction is that metal was incompletely removed from the less magnetic fractions. The HSE contents and ratios of the weakly magnetic fractions indeed suggest they may contain up to about 5% metal. This cannot account for the HSE data for the nonmagnetic fractions, however. Palladium concentrations are more than 200 times lower than in metal, implying that metal contaminants comprise less than 0.5% of the nonmagnetic fractions. Because other HSE occur in significantly higher abundances than Pd, they must be dominated by a non-metal HSE-bearing component that is different from that in the metal fractions.

Low Re/HSE ratios measured in the nonmagnetic fractions may result from incomplete condensation of Re, if some Re were present as the oxidized species, as suggested by [2]. Indeed, of the HSE discussed here, Re requires the lowest oxygen fugacity for oxidation to the more volatile  $\text{ReO}_2$ . It also is plausible that Re present in the nonmagnetic fractions was mobilized and removed during aqueous alteration prior to metamorphism and transferred to the metal, which would be more apparent as *depletions* in the silicates than as *enrichments* in the metal, as observed. The smooth variation of Os, Ir, Ru, Pt and Pd contents, in contrast with Re, with condensation temperature in the nonmagnetic fractions is consistent with some kind of volatility control.

**References:** [1] Luguet *et al.* 2007, *Geochim. Cosmochim. Acta* 71, 3082-3097. [2] Rambaldi E.R. *et al.*, 1978, *Earth Planet. Sci. Lett* 40, 175-186. [3] Walker R.J. *et al.* 2002, *Geochim. Cosmochim. Acta* 66, 4187-4201. Horan M.F. *et al.*, 2003, *Chem. Geol.* 19, 5-20. [4] Campbell A.J. *et al.*, 2001, *Geochim. Cosmochim. Acta* 65, 163-180. [5] Lauretta D.S. and Buseck P.R., 2003, *Meteoritics Planet. Sci.* 38, 59-79. Zanda B., 2004, *Earth Planet Sci Lett.*, 224, 1-17. [6] Humayun and Campbell 2002 *Earth Planet Sci. Lett.* 198, 225-243..