Effect of Phase Transition and High Pressure on Trace Element Partitioning Between Metal and Sulfide Melt

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Introduction

It has been proposed, on the basis of Os isotope measurements of mantle-derived rocks, that material from the core becomes entrained in the overlying mantle flow, and makes its way to the Earth's surface (Walker et al. 1995 and Brandon et al. 1998,1999,2003). Radioactive isotopes of both Re and Pt decay into isotopes of Os; these isotopic systems are useful for investigating the evolution of the core because all of the participating elements are highly siderophile, and have very long decay constants. Plots of ^{186}Os/^{188}Os and ^{187}Os/^{188}Os in mantle derived materials trended towards a point that would require a mixing between the mantle and a source enriched in Re, Os and Pt (Brandon et al. 2003).

Walker et al. (1995) and Brandon et al. (2003) hypothesized that the ^{186}Os and ^{187}Os-enriched source may have been generated due to crystallization of the solid inner core and consequent increases in Pt/Os and Re/Os in the outer core. Walker and Brandon assumed that Re, Os and Pt partitioning between the solid inner core and liquid outer core of the Earth was similar to the partitioning in iron meteorites, and they assumed that the effect of pressure on partitioning and the effect of any phase transitions in the metal does not affect the outcome of their model.

This project was designed to test some of the assumptions of the Walker and Brandon hypothesis. Specifically, I examined the effects of pressure change and also change in crystal structure on the partitioning of Re, Os, and Pt between solid Fe metal and sulfide melt. The fcc to hcp crystal structure change in the Fe metal phase was induced by the addition of Ru.

References

Brandon, A. D. et al. (1998) Coupled ^{186}Os and ^{187}Os evidence for core-mantle interaction. *Science*, Vol. 280, pp.1570-1573.

Brandon, A. D. et al. (1999) ^{186}Os-^{187}Os systematics of Hawaiian picrites. *Earth and Planetary Science Letters*, Vol. 174, pp.25-42.

Brandon, A. D. et al. (2003) ^{186}Os-^{187}Os systematics of Gorgona Island komatiites; Implications for early growth of the inner core. *Earth and Planetary Science Letters*, Vol. 206, pp.411-426.

Chabot, N. L. et al. (2003) An experimental test of Henry's Law in solid metal-liquid metal systems with implications for iron meteorites. *Meteoritics & Planetary Science*, February 2003, Issue 2, Vol. 38, pp.181-196.

Chabot, N. L. and Jones, J. H. (2003) The parameterization of solid metal-liquid metal partitioning of siderophile elements. *Meteoritics & Planetary Science*, October 2003, Vol. 38, Issue 10, pp.1425-1436.

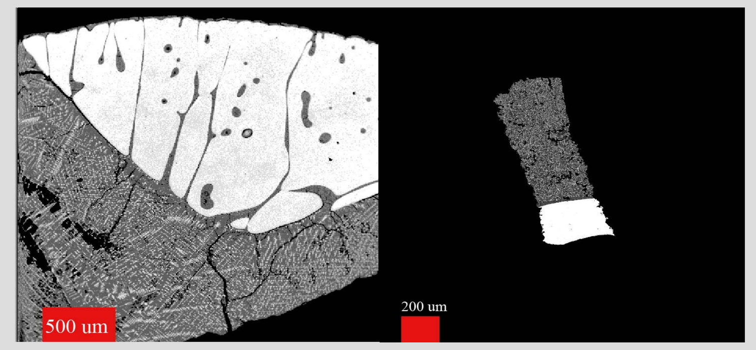
Walker, R. J. et al. (1995) Osmium-187 enrichment in some plumes: Evidence for core-mantle interaction? *Science*, Vol. 269, pp.819-822.

Methods

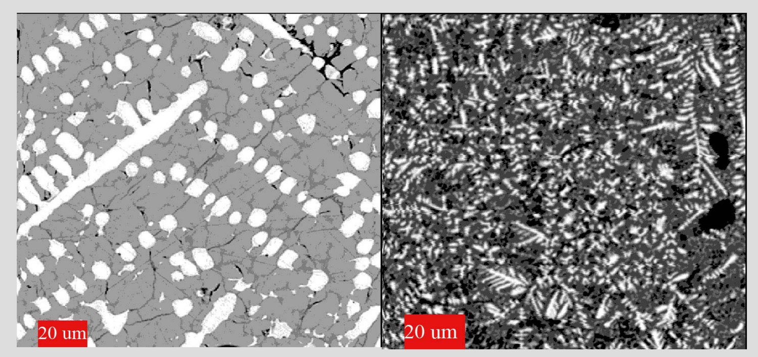
Starting materials:
Mixtures of Fe, FeS, Ru powders.
5000 ppm Ni and 500 ppm each of Re, Os, Pt as trace elements.

1 bar experiments:
Sealed silica tubes in a tube furnace.
Temperature 1350 to 1550 ˚C.
Run time 6 to 96 hr.,varying with T.
Drop quenched in water.

6 GPa experiments:
Multi-anvil press, 18/11 assembly.
MgO sample capsule.
Temperature 1100 to 1500 ˚C.
Run time 24 hr.



1 bar experiment 6 GPa experiment

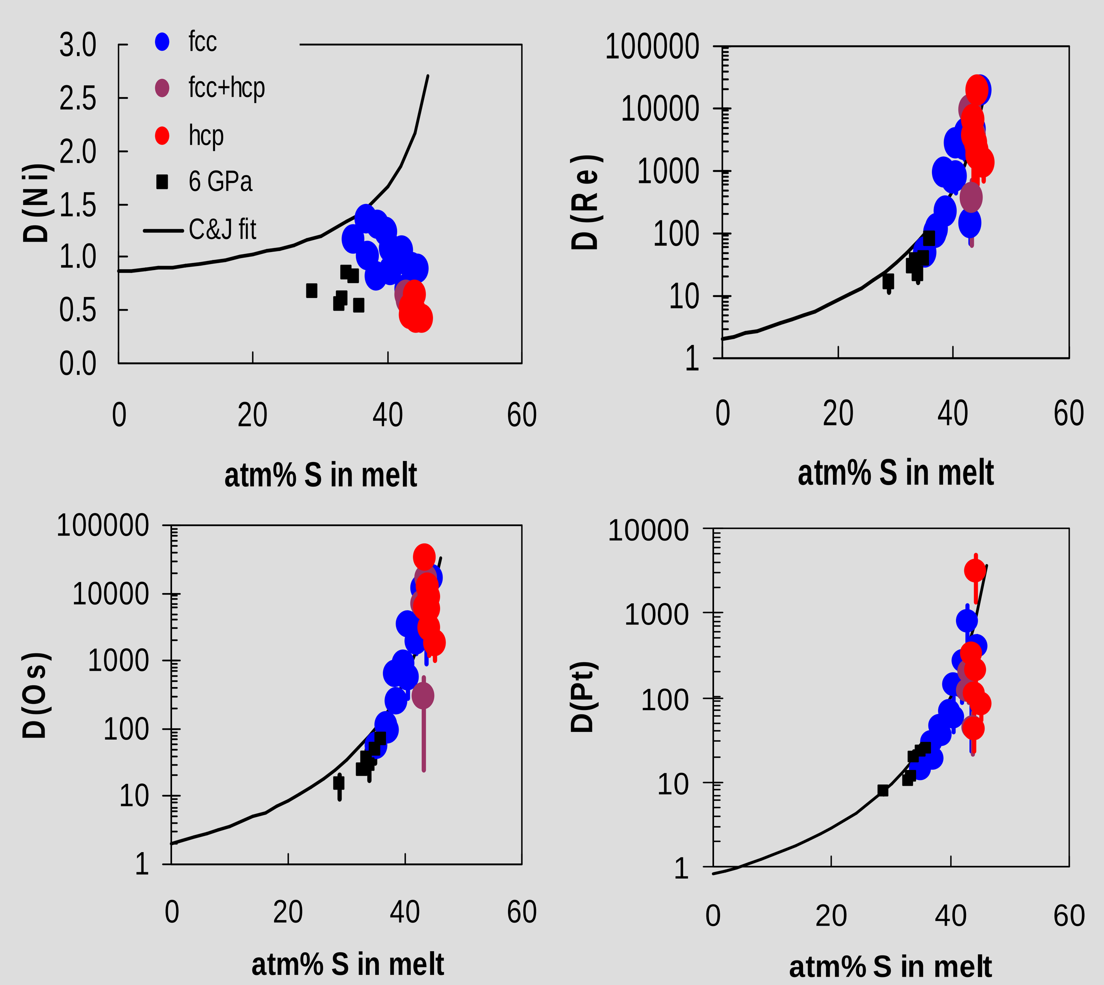


Electron microprobe analysis:
Major elements (Fe, Ru, S) and Ni measured.
Metal compositions from average of 6 points.
Melt compositions determined from average of up to 100 analyses, each covering a 10 µm x 10 µm area due to dendritic quench pattern.

Laser ablation ICP-MS analysis:
Trace elements (Ni, Re, Os, Pt) measured.
Line scans, or single spots when area limited.
Beam size 35 to 80 µm.
Average of 5 analyses, ensuring that broad area of quenched melt region is analyzed.
Standardized to probe analysis for Fe; Hoba (IVB iron meteorite) used as calibrant.
Reported uncertainties are 2σ error on the mean.

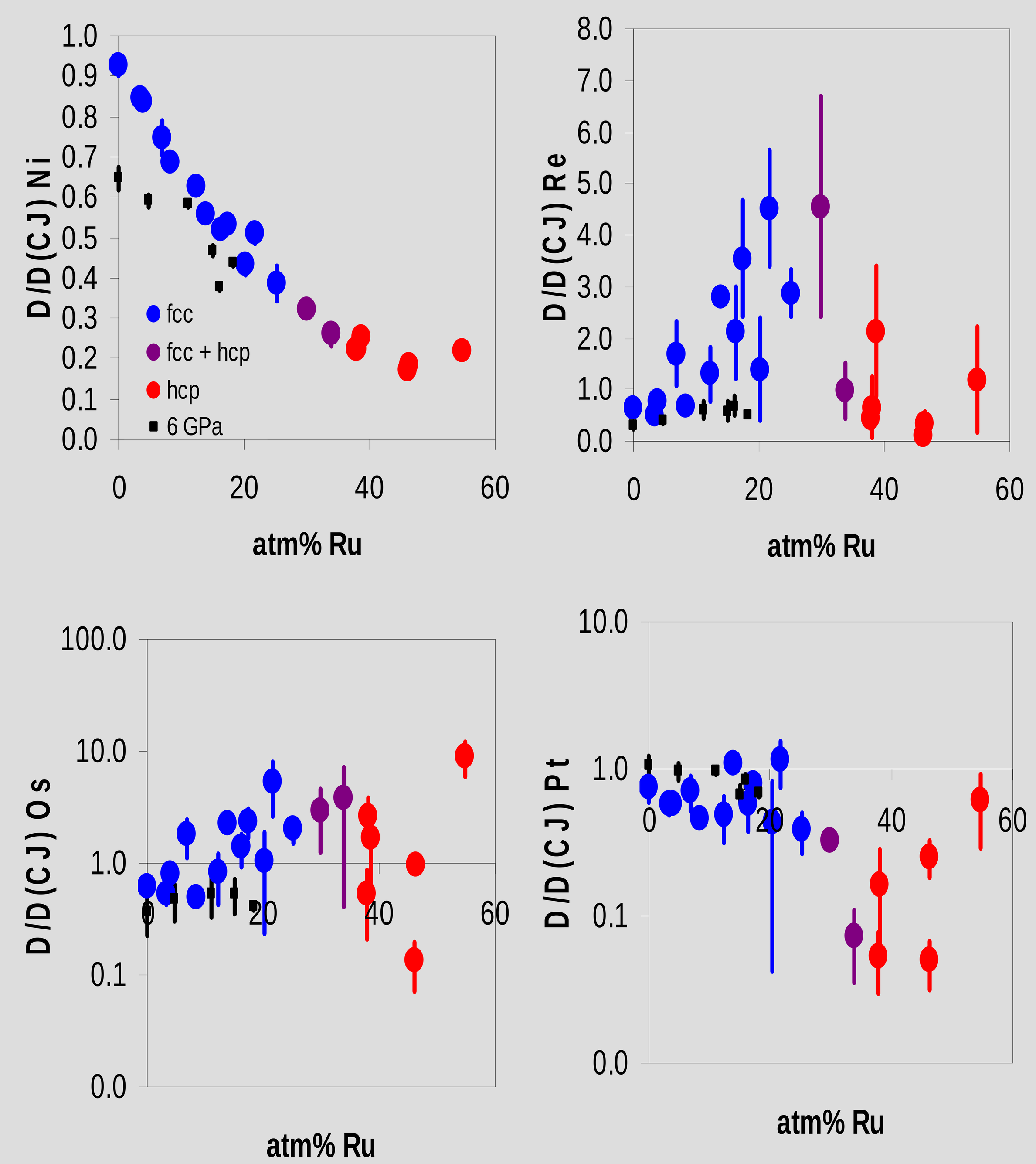
Results

Variations in S and Ru both affect the D values, and these must be deconvoluted. Partitioning of siderophile elements between metal and melt in the Fe-S system is well constrained by a large number of data (e.g., Chabot et al. 2003). The experimental data plotted with the Chabot and Jones (2003) parameterizations are shown below. The experimental data was divided by the parameterized partition coefficients to remove the effect of S on the D values.



The normalized partition coefficients were then plotted against the atomic percent of Ru in the solid metal phase, shown on the right. For the one atm experiments, a least squares fit line was used to determine the normalized partition coefficient both for the fcc metal trend and the hcp metal trend at 31.5 atm% Ru for Re, Os and Pt.

For the 6 GPa experiments, a least squares fit line was used to determine the normalized partition coefficients for Re, Os and Pt at 0 atm% Ru. The crystal structure change produced an hcp/fcc ratio of 0.26 $\pm$ 0.13 for Re and 0.34 $\pm$ 0.15 for Pt, and showed no resolvable effect on Os. The 6 GPa increase in pressure produced ratios of 0.35 $\pm$ 0.06 for Re, 0.44 $\pm$ 0.12 for Os and 1.67 $\pm$ 0.10 for Pt.



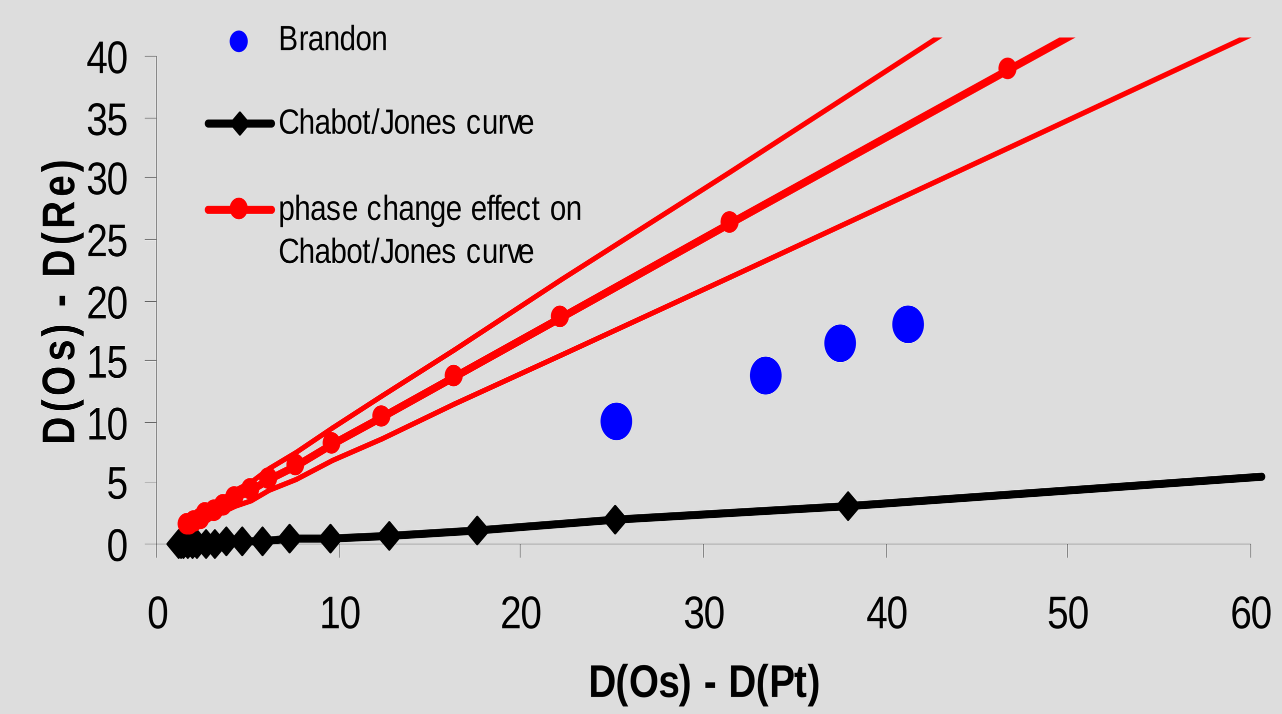
Discussion

Brandon et al. (2003) developed four models of Earth core crystallization based on their analysis of Os-Re and Os-Pt fractionation in Gorgona Island komatiites. Each of the four different models couple different degrees of Re-Os and Pt-Os fractionation to different crystallization histories of the inner core. Dividing Raleigh Fractionation equations for Re and Os in order to produce a ratio due to the fractionation between the two elements produces the equation

$$\frac{C_{Re}}{C_{Os}} = \frac{C_{O\,Re}}{C_{O\,Os}}(1-f)^{-(D_{Os}-D_{Re})}$$

This equation shows that the important factor in the fractionation of the two elements with regard to core crystallization is the difference in the D values between the two elements. D_{Os}-D_{Pt} vs. D_{Os}-D_{Re} for the parameters of the core crystallization models proposed by Brandon et al. (2003) are contrasted with the experimental partitioning data for fcc Fe in the figure below.

The effect of the phase change, as determined in this study, is to move the Chabot and Jones curve in the needed direction, but it overshoots the Brandon et al. (2003) models.



For the effect of 6GPa of pressure, the Brandon values fall within the corrected Chabot and Jones curve in the graph, suggesting that the elevated pressures found in the Earth's core can make the models proposed by Brandon et al. feasible. The large errors in the graph are due to the large $2\sigma_m$ values in the D values of osmium in the high pressure experiments.