

CRYSTAL STRUCTURE INFLUENCE OF FE ALLOYS ON ELEMENT PARTITIONING. Nancy L. Chabot¹, C. M. Corrigan¹, W. F. McDonough², H. C. Watson³, S. A. Saslow⁴, and T. J. McCoy⁵. ¹Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd., Laurel, MD, 20723, USA (nancy.chabot@jhuapl.edu). ²Department of Geology, ⁴University of Maryland, College Park, MD, 20742, USA. ³Geophysical Laboratory, Carnegie Institution of Washington, 5251 Broad Branch Rd. NW, Washington, DC, 20016, USA. ⁵Department of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, DC, 20560, USA.

Introduction: As a planetary core solidifies, how elements partition between the liquid core and the solid core will be affected by the crystal structure of the solid Fe alloy. Measurements of trace elements in iron meteorites with coexisting Fe-Ni kamacite (body-centered cubic structure: bcc, α) and taenite (face-centered cubic structure: fcc, γ) suggest that the structure of the solid metal can significantly affect partitioning behavior; kamacite/taenite partition coefficients for 14 elements were observed to vary from each other by an order of magnitude, from 0.2 to 2.0 [1, 2].

The crystal structure of Earth's solid inner core has been and continues to be debated. The hexagonal close-packed (hcp, ϵ) phase of solid Fe is the densest of the potential Fe crystal phases, and studies have suggested that a wide stability field for hcp Fe exists, covering the pressure and temperature region relevant to Earth's core [e.g. 3, 4]. Other recent work [5] has suggested that the bcc state of Fe is the stable phase in Earth's inner core, contradicting previous work that had concluded that bcc Fe was mechanically unstable at the high pressures of Earth's core [6]. Studies of the density of Earth's inner core have suggested the possibility that the solid inner core contains a light element component [7, 8]. It has been proposed that the presence of either S or Si in Earth's inner core could potentially stabilize the bcc solid phase, depending on the concentration level of the light element [9], or that Earth's inner core could be composed of a mixture of Si-rich bcc and Si-poor hcp phases [10].

Recent Os isotopic studies have advocated that material from Earth's liquid outer core is being incorporated into the mantle [e.g. 11]. To produce the observed Os isotopic signature, Pt, Re, and Os must be fractionated from each other during the ongoing solidification of Earth's inner core. It has been suggested that the crystal structure of the solid inner core may enhance the fractionation of Pt from Re and Os, since Pt is an fcc element while Re and Os are stable in the hcp phase [12]. Currently, data are lacking to determine how different crystal structures will influence partitioning behavior.

Here we present experimental data examining the partitioning of trace elements between bcc and fcc solids coexisting with a metallic liquid. Though the experiments differ from Earth's core conditions in important ways, such as being conducted at 1 atm and in the

Fe-Ni-P system, the results do provide some insight into the types of element fractionations that could be generated by different potential solid Fe alloy crystal structures in the inner core.

Experimental and Analytical Methods: In the Fe-Ni-P ternary system, there exists a phase field where a metallic liquid coexists with two solid metal phases, one with the bcc structure and another with the fcc structure. Our experiments were designed to take advantage of this three phase field and to examine the partitioning of elements between the two different solid phases. Consequently, starting mixtures from powders of Fe, Ni and P were used that had bulk compositions consistent with the three phase field, and run temperatures were 1100-1150°C. Trace elements were added at levels of about 100-400 ppm.

Experiments were conducted at 1 atm in Deltech vertical tube furnaces, either at the Applied Physics Lab or the Smithsonian Institution, using techniques similar to previous solid metal/liquid metal experiments [e.g. 13, 14]. Starting powders were contained in evacuated silica glass tubes, held at the run temperature for durations of 6-9 days, and quenched quickly by removing the tube and immersing it briefly in water. The major element composition of the run products were analyzed by electron microprobe, using a JEOL 8900L at the Carnegie Institution of Washington. Trace element concentrations were measured by laser ablation ICP-MS at the University of Maryland.

Figure 1 shows a back-scattered electron image of an experimental run product, with the contrast enhanced to show the two different solid metal phases. Solid metal was identified as bcc or fcc based on their easily distinguished Ni and P contents in this system. Overall, five separate experiments were analyzed, which were conducted with slight variations in temperature (1100-1150°C) and bulk compositions. All five experiments produced similar partitioning behaviors that were indistinguishable within error. Thus, the results we present are an average from these five runs.

Discussion: In contrast to the order of magnitude variation observed in iron meteorite kamacite/taenite partitioning between different elements [1, 2], the bcc/fcc partitioning values measured in our experiments only varied by about a factor of two, from 0.6-1.4. This difference is illustrated on Fig. 2, which along with showing the larger range observed in the iron meteorite Canyon Diablo [2] also shows the lack

of correlation between our experimental results and the iron meteorite measurements. Our partitioning results are from solids coexisting with a metallic liquid and consequently are from a higher temperature than the subsolidus partitioning that occurred between kamacite and taenite in the iron meteorite. A higher temperature could result in less extreme bcc/fcc partitioning behavior, with more elements having bcc/fcc partition coefficients close to a value of one, as seen in Fig. 2.

The higher temperature of our experiments makes the results more appropriate to the crystallization of planetary cores than subsolidus kamacite/taenite partitioning; a crystallizing core will have solid and liquid metal present, as in our experiments. Previous 1 atm experimental studies in the Fe-Ni-S [e.g. 13] and Fe-Ni-C [e.g. 14] systems have produced solid Fe-Ni metal in the fcc phase. Our new results of bcc/fcc partitioning preferences of elements can provide some insight into how to apply those partitioning studies to the crystallization of Earth's core if the solid core has a bcc structure, as has been proposed by some studies [5, 9, 10]. Our results suggest that the effect would be small and that most elements partition similarly between bcc and fcc metals. Acquiring similar knowledge about the hcp/fcc partitioning preferences would be useful to evaluate how a solid inner core with an hcp structure would influence element fractionations.

To account for the observed Os isotopic signature from mantle plume sources as sampling Earth's outer core [e.g. 11], Os has to be depleted in the liquid core relative to Re and Pt. Osmium partitions less into bcc than fcc metal while Re partitions equally between the two structures. Thus, a bcc solid inner core would act opposite to depleting Os relative to Re in the liquid core, since Re shows a greater affinity for bcc metal than Os does. Platinum and Os exhibit similar bcc preferences, which would not serve to fractionate the two elements but would not act against depleting Os in the liquid core, unlike the Re and Os differences.

References: [1] McDonough W. F. et al. (1999) *LPSC XXX*, 2062. [2] Watson H. C. et al (2005) *LPSC XXXVI*, 2141. [3] Yoo C. S. et al (1995) *Science* 270, 1473-1475. [4] Shen G. et al (1998) *GRL* 25, 373-376. [5] Belonoshko A. B. et al. (2003) *Nature* 424, 1032-1034. [6] Stixrude L. and Cohen R. E. (1995) *GRL* 22, 125-128. [7] Jephcoat A. and Olson P. (1987) *Nature* 325, 332-335. [8] Laio A. et al. (2000) *Science* 287, 1027-1030. [9] Vocadlo L. et al. (2003) *Nature* 424, 536-539. [10] Lin J. F. et al. (2002) *Science* 295, 313-315. [11] Brandon A. D. and Walker R. J. (2005) *EPSL* 232, 211-225. [12] Morgan J. W. et al. (1997) *LPSC XXVIII*, 1241. [13] Chabot N. L. et al. (2003) *MAPS* 38, 181-196. [14] Chabot N. L. et al. (2006) *GCA* 70, 1322-1335.

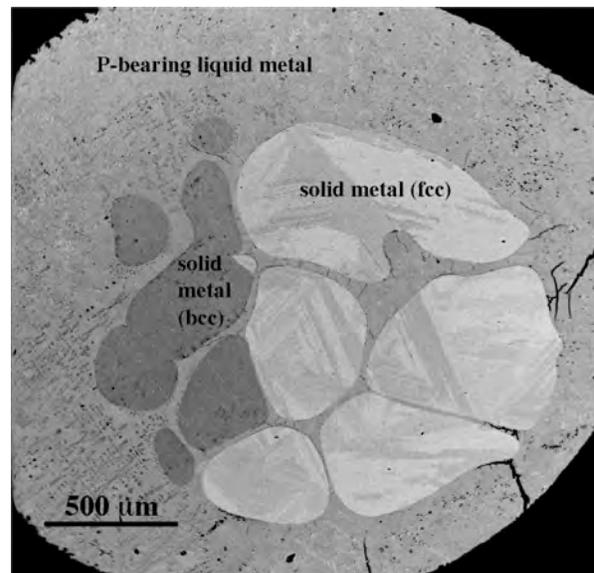


Figure 1: A back-scattered electron image of a run product, with the contrast enhanced to show the two different solid metal phases that were produced.

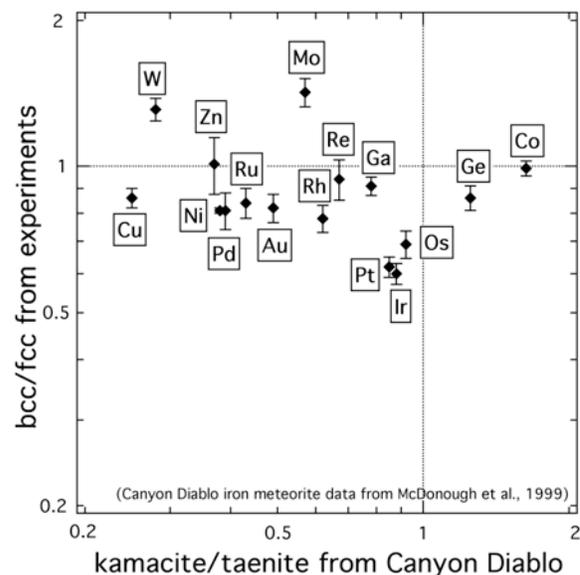


Figure 2: The bcc/fcc partitioning results from our experiments are compared to the concentrations observed in kamacite (bcc) and taenite (fcc) in the iron meteorite Canyon Diablo. Note the lack of correlation between the two data sets and the much larger range of values observed in the iron meteorite system as compared to the experiments.

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