

THE FE-C SYSTEM AT PRESSURE AND IMPLICATIONS FOR EARTH'S CORE. Nancy. L. Chabot¹, Andrew J. Campbell², William F. McDonough², David S. Draper³, Carl B. Agee³, Munir Humayun⁴, Heather C. Watson⁵, Elizabeth Cottrell⁶, and Sarah A. Saslow⁷, ¹Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd., Laurel, MD, 20723, (Nancy.Chabot@JHUAPL.edu), ²Department of Geology, ⁷University of Maryland, College Park, MD, 20742, ³Institute of Meteoritics, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM, 87131-1126, ⁴National High Magnetic Field Laboratory and Department of Geological Sciences, Florida State University, Tallahassee, FL, 32310, ⁵Lawrence Livermore National Laboratory, Livermore, CA, 94550, ⁶Department of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, DC, 20560.

Introduction: Between 5-10% of Earth's core is composed of elements lighter than Fe-Ni. Considering the cosmochemical availability of elements, along with their atomic weights and ability to alloy with Fe-Ni, the elements H, C, O, Si, and S have been suggested as possible significant contributors to the light element component of Earth's core [e.g. 1]. How trace elements partition between Earth's solid inner core and liquid outer core will depend on the light element composition. The composition of the light elements in Earth's core continues to be a major outstanding question in Earth science.

Noting the strongly pressure dependent nature of the volatility of C, Wood [2] suggested that C should be a significant component of the light element content of terrestrial planetary cores, and in particular, of Earth's core. The presence of C in planetary cores may significantly influence their evolution by affecting the first solid to crystallize, and in his study, Wood [2] advocated that Earth's solid inner core could be composed of Fe₃C rather than solid Fe-Ni. Though Fe₃C is a sub-solidus phase at 1 atm [3], at higher pressures, the Fe₃C stability field increases and Fe₃C can coexist with metallic liquid. The work of Wood [2] suggested that at the high pressures applicable to planetary cores, the stability field of Fe₃C is large, such that any planetary core, even if it contained only 1 wt% C or less, would first solidify Fe₃C.

In this study, we experimentally examine the Fe-C system at 5 GPa. The experiments are conducted at a pressure of 5 GPa primarily to stabilize the equilibrium formation of Fe₃C and liquid metal. Conducting experiments at 5 GPa allows us to map out the Fe-C phase diagram and compare our results to the predicted 5 GPa Fe-C phase diagram [2].

Experimental and Analytical Methods: All experiments were conducted at the University of New Mexico in a multi-anvil press at a pressure of 5 GPa. The run temperatures ranged from 1200 to 1600°C. Starting powders of Fe, Ni, and C were contained in alumina capsules. Trace elements of Ag, As, Au, Bi, Co, Cu, Ga, Ge, Ir, Mo, Os, Pb, Pd, Pt, Re, Ru, Sb, and W were added to the starting mixtures at concentrations of a few hundred ppm each. Run durations varied between 30 minutes to just over 6 hours. A time series

at 1250°C consisting of four experiments was conducted; the series showed that equilibrium partitioning behavior was achieved for all of the elements studied in a time of less than 30 minutes. All samples were analyzed for Fe, Ni, and C during the same 24-hr session using the JEOL 8900L electron microprobe at the Carnegie Institution of Washington. Trace element concentrations were analyzed by laser ablation inductively coupled plasma mass spectrometry (ICP-MS) at either the University of Chicago or the University of Maryland. Images of two runs are shown in Fig. 1.

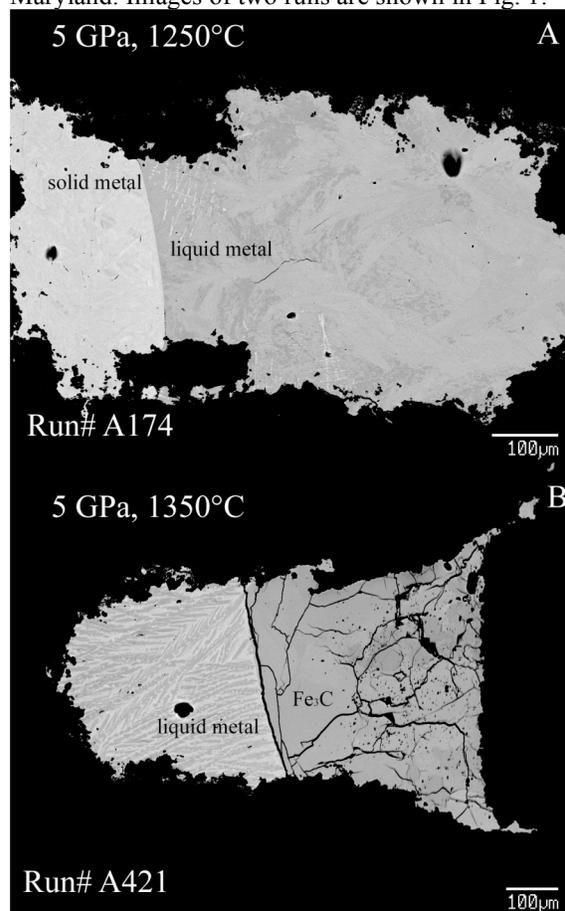


Fig. 1. Back scattered electron (BSE) images are shown. **A.** Run #A174 produced coexisting solid metal and C-bearing liquid metal. **B.** Run #A421 contained C-bearing liquid metal and Fe₃C.

Results and Implications: The phases produced in our 5 GPa experiments differ from those predicted by the 1 atm phase diagram [3], which is not surprising due to the difference in pressure. Figure 2a shows the phase information from our experiments overlaid on the 1 atm Fe-C phase diagram. In Fig. 2b, we compare our experimentally determined phases to those of the calculated 5 GPa Fe-C phase diagram presented in Wood [2]. Based on our experimental results, at 5 GPa the Fe-Fe₃C eutectic is at a temperature between 1200-1250°C and at a composition of around 4.7 wt% C. In contrast, Wood [2] suggested that the Fe-Fe₃C eutectic at 5 GPa occurs at slightly over 1300°C and at 3.2 wt% C. The shifting of the eutectic composition to lower C compositions is a fundamental point that Wood [2] used to suggest that the first solid phase to crystallize in Earth's core is not Fe metal but Fe₃C. However, our 5 GPa experiments do not support the prediction of Wood [2] that the eutectic composition shifts to lower C contents with increasing pressure or the conclusion that the inner core is composed of Fe₃C. In Fig. 2c, we present a 5 GPa phase diagram consistent with our experimental run products, which is also in good agreement with the work of Hirayama et al. [4] and Fei et al. [5].

Our experiments also allow us to investigate the partitioning of trace elements in the Fe-C system at 5 GPa. Overall, our solid metal/liquid metal partitioning results are in good agreement with previously determined 1 atm values [6], suggesting a limited effect of pressure on the partitioning behavior in this pressure range. Trace element partitioning values in Fe₃C in our experiments are consistent with cohenite/kamacite measurements in iron meteorites [7-9] and suggest an inner core of Fe₃C for Earth would create negligible fractionations in the Pt-Re-Os system.

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References: [1] Hillgren V. J. et al. (2000) *Origin of the Earth and Moon*, The Univ. Arizona Press, 245-263. [2] Wood B. J. (1993) *Earth Planet. Sci. Lett.*, 117, 593-607. [3] Okamoto H. (1990) *Binary Alloy Phase Diagrams, Vol. 1*, ASM International, 842-848. [4] Hirayama Y. et al. (1993) *Geophys. Res. Lett.* 20, 2095-2098. [5] Fei Y. et al. (2007) *LPS XXXVIII*, Abstract #1231. [6] Chabot et al. (2006) *Geochim. et Cosmochim. Acta* 70, 1322-1335. [7] Campbell A. J. and Humayun M. (1999) *LPS XXX*, Abstract #1974. [8] McDonough W. F. (1999) *LPS XXX*, Abstract #2062. [9] Gangopadhyay A. et al. (2006) *LPS XXXVII*, Abstract #1456.

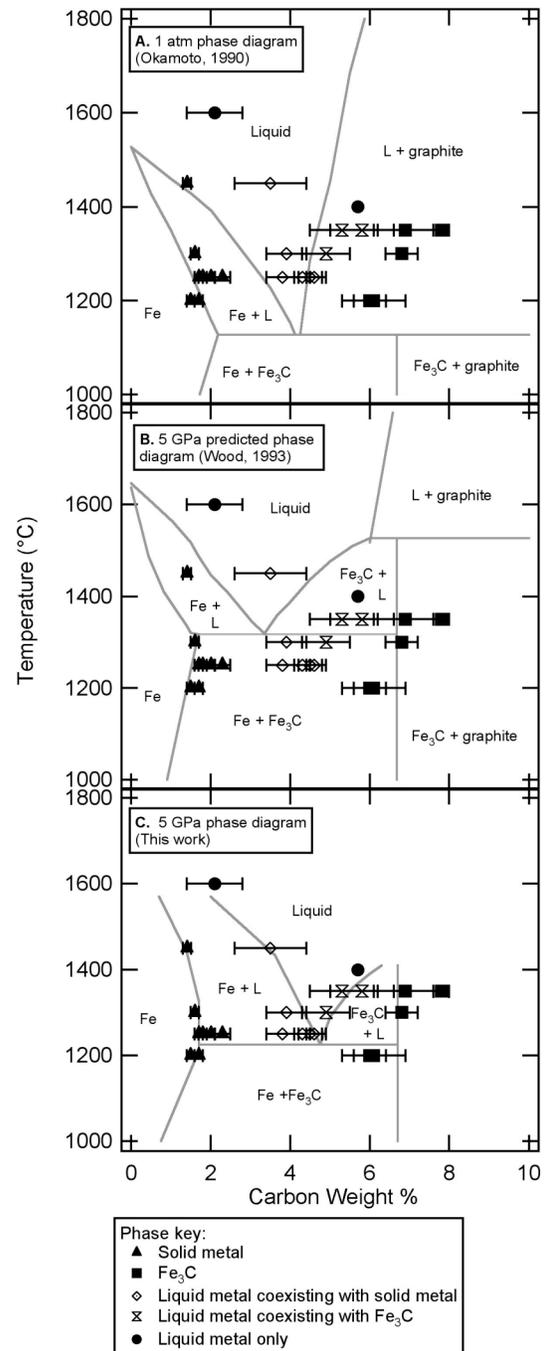


Fig. 2. Our experimental results are compared to the **A.** 1 atm Fe-C phase diagram [3] and **B.** a predicted 5 GPa Fe-C phase diagram [2]. **C.** Phase boundaries consistent with our experimental runs at 5 GPa are drawn. (For simplicity, the body-centered cubic δ solid phase of Fe is neglected in the phase diagrams.)