MELTING RELATIONS IN THE Fe-C-S SYSTEM AT HIGH PRESSURE: IMPLICATIONS FOR THE CHEMISTRY OF THE CORES OF THE TERRESTRIAL PLANETS. Y. Fei[1], Y. Wang[1,2], L. Deng[1,3], [1]Geophysical Laboratory, Carnegie Institution of Washington, 5251 Broad Branch Rd., N.W., Washington DC 20015, USA (e-mail: fei@gl.ciw.edu), [2]Department of Geology, Peking University, Beijing 100871, P.R. China, [3]Institute of Physics, Southwest Jiaotong University, Chengdu 610031, P.R. China

Introduction: It has been determined that the density of the Earth's core constrained from seismic data is significantly lower than that of pure iron measured experimentally at high pressure and temperature. The density deficit in the core (both liquid outer core and solid inner core) led to the conclusion that the Earth's core must contain several wt% of one or more light elements (lighter than iron) in addition to Fe-Ni alloy [1]. Carbon (C) and sulfure (S) are the prominent candidates among the proposed light elements, because of their high solar system abundance and strong chemical affinity for Fe.

The amount of light elements presented in the cores of the other terrestrial planets such as Mercury, Venus, and Mars is less well constrained because of lack of seismic observation and limited cosmochemical information. Because all terrestrial planets underwent mantle-core differentiation and possibly crystallization of inner core at high pressure and temperature, started from a similar initial chemical composition, it is expected that the chemical outcome of the different planetary cores is governed by the equilibrium process at high pressure and temperature. In order to evaluate the chemical and physical evolution of the planetary cores, we need knowledge of melting relations in the Fe-light elements system at high pressure and temperature. We have systematically investigated the melting relations in the system Fe-FeS up to 25 GPa [2-4]. These studies revealed new iron-sulfur compounds (Fe_3S_2, Fe_2S, and Fe_3S) stable at high pressures and change of melting relations. We have also determined the effect of pressure on the eutectic melting temperature. The results have important implications for the thermal and physical state of the cores of Mercury and Mars [5].

Carbon is another important light element to be considered. There are very limited experimental data on melting in the Fe-C system at high pressure. The prediction of the melting relation as a function of pressure from thermodynamic calculations [6] needs to be experimentally verified. In this study, we report new experimental results on the melting relations in the Fe-C and Fe-C-S systems up to 25 GPa. In particular, we examine the solubility of carbon in metallic iron and the effect of pressure on the eutectic temperature and composition.

Experimental procedure: A series of phase equilibrium experiments in the system Fe-C were performed in the multi-anvil apparatus at the Geophysical Laboratory. Experimental procedure including high-pressure techniques and assembly preparation is similar to that described by *Bertka and Fei* [7]. Starting materials with different carbon contents (2, 3.2, 4, 4.3, 5 and 6 wt% carbon) were prepared by mixing fine powder of pure iron and graphite. Starting material in the Fe-C-S system was also prepared, with composition of 5 wt% carbon, 5 wt% sulfur and 90 wt% iron. The starting materials were packed into MgO capsules and then compressed to pressures of interest at room temperature. Both piston-cylinder apparatus and multi-anvil device were used in our study. Various well-calibrated high-pressure assemblies (18/11, 10/5, 8/3) were used to achieve different pressure ranges [7]. After reached the experiment pressures, samples were heated at 100 K/min to the set values of temperatures. High temperatures were generated using either a graphite heater (<6GPa) or a Re heater at higher pressures. The duration for each experiment varied from 1 hour to 5 hours, depending on the experiment temperature. Temperatures were measured with a W5%Re-W26%Re thermocouple, and the thermocouple wires were inserted axially into the center of the assembly through a 4-bore alumina rod. Melting relations were determined with a JEOL JXA-8900 electron microprobe and SEM, based on quench textures and chemical composition analyses of the quenched phases. Powder X-ray diffraction technique was also used to identify phases and determine unit cell parameters.

Results: We have carried out extensive experiments at 5, 10, 20, and 25 GPa to determine the melting relations in the Fe-C system as a function of pressure. The eutectic melting occurs at a temperature between 1513K and 1523K at 5 GPa, that is about 75K lower than the calculated value in previous study. The eutectic temperature increases linearly with increasing pressure, with a measured value of 1975K at 25 GPa (Figure 1). The solubility of carbon in metallic iron also increases with increasing pressure, whereas the eutectic composition is relatively insensitive to pressure increase. Our study presents directly experimental measurements of the melting relations in the Fe-C system at high pressure and temperature, which can be used to evaluate the incorporation of carbon into the planetary cores and its distribution between the inner and the outer cores if the core solidifies.

We also conducted experiments in the Fe-C-S system. Preliminary data indicate that iron with 5wt%S and 5wt%C forms one miscible liquid at 20 GPa and 1823 K. With decreasing temperature, a nearly S-free Fe-C alloy solidifies, coexisting with a Fe-C-S melt.

Discussion and implications: The measured eutectic melting temperatures in the Fe-C system at high pressure are significantly lower than the predicted values. Previous study over-estimates melting temperatures by about 100K and 200K at the core-mantle boundary pressures of Mercury (~10 GPa) and Mars (~24 GPa), respectively, if carbon is a significant component of the cores of Mercury and Mars. The extrapolation to the Earth's core pressure would lead to an even large overestimation of the core temperature. *Wood* [6] predicted the Earth's inner core would be made of Fe_3C on the basis of his calculations because the both carbon solubility in metallic iron and the carbon content at the eutectic point decrease with increasing pressure. In contrary, the measured solubility of carbon in metallic iron increases with increasing pressure and the eutectic composition remains constant. Based on our experimental results, the inner core would crystallize as metallic iron with dissolved carbon if the core contains less than 4 wt% carbon. If both carbon and sulfur present in the core, the solid inner core is nearly S-free, but it could contain significant amount of carbon, based on the partitioning of S and C between solid and liquid.

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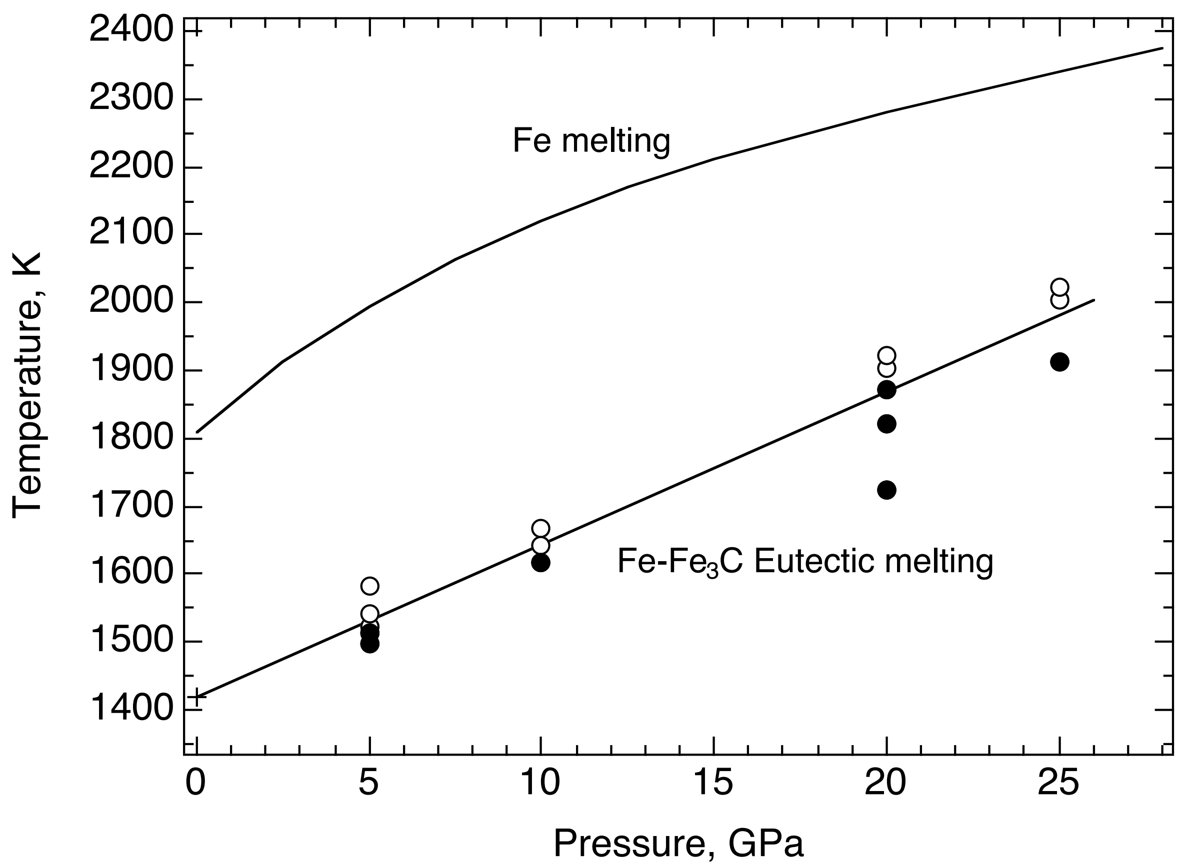

Figure 1. Eutectic temperature as a function of pressure in the Fe-C system. The solid and open circles represent solid assemblage and partial melting, respectively. The solid line represents the best-fit to the experimental data. The Fe melting curve is from *Shen et al*. [8].