MELTING BEHAVIOR OF THE IRON-SULFUR SYSTEM AND CHEMICAL CONVECTION IN IRON-RICH PLANETARY CORES. J. Li[1] and B. Chen[1], [1]Department of Geology, University of Illinois, 1301 W. Green Street, Urbana IL 61801, USA, jackieli@illinois.edu.

Introduction: At present, Earth, Mercury and Ganymede are the only three solid bodies in the Solar System that possess intrinsic global magnetic fields. Dynamo simulation reveal that chemical buoyancy force associated with the formation of a solid inner core is critical for sustaining the Earth's magnetic field. Fluid motions in Mercury and Ganymede may be partially driven by chemical buoyancy force as well. The style of chemical convection and its influence on the thermal and chemical state and evolution of iron-rich cores are determined in part by the melting behavior of potential core-forming materials.

Sulfur is widely accepted as a candidate light element in iron-rich planetary cores. In order to understand the role of chemical convection in sulfur-bearing cores, we studied the high-pressure melting behavior of Fe-S mixtures containing 9 wt% sulfur using the synchrotron x-ray radiographic method in a large volume press.

Experimental Methods: Experiments were carried out at Beamline 13-ID-D of the Advance Photon Source, Argonne National Laboratory, using the T-25 multi-anvil module in the 1000 T large-volume press [1]. In our high-pressure cell assembly, the sample was surrounded by a boron nitride (BN) capsule, a cylindrical rhenium (Re) heater, a lanthanum chromate ($LaCrO_3$) insulating sleeve, and an octahedral pressure medium. To reduce x-ray absorption by the surrounding materials, we inserted two 0.625 mm by 2 mm rectangular-shaped graphite windows into the insulating sleeve and heater, along the x-ray path [2].

The radiographic imaging system consists of a non-doped YAG fluorescent screen, optical mirrors, a long working-distance magnifying lens and a CoolSNAP CCD camera. The CCD camera records two-dimensional intensity data at a preset exposure time of 0.5 s, which gives optimized image brightness. Contrast in the recorded radiographs reflects variable absorption by materials along the x-ray path.

Temperature was measured using a tungsten-rhenium (W5%Re-W26%Re) thermocouple, without considering the pressure effect on the electro-motive force (emf). A thin layer of MgO and platinum (Pt) powder mixture was packed near the thermocouple and used as in situ pressure standards. Uncertainties in temperatures and pressures were estimated at ± 30 K and ±0.5 GPa, respectively.

The cell assembly was compressed to a target ram load of 400 T at room temperature and then heated at a rate of 1 K/second. During heating, we monitored the x-ray radiograph to observe the appearance, movement and disappearance of liquid-solid boundary. After equilibrating at the final temperature, the experiment was quenched by shutting off the electrical power to the furnace. The recovered run product was cut into two halves along the axial direction of the cylinder, to expose the central section seen through the two graphite windows. The section was polished, carbon-coated, and analyzed for texture and chemical composition with a Scanning Electron Microscope (SEM) and an Electron Probe Micro-analyzer (EPMA) at the Geophysical Laboratory, Carnegie Institution of Washington.

Results and Discussions: We conducted one experiment (T0901) on an Fe/FeS mixture containing 9 wt% (15 at%) sulfur, using the single chamber assembly at 16 GPa. Two double-chamber experiments (T0898 and T0899) were carried out at about 14 GPa. In experiment T0898, a series of x-ray radiographs were recorded at temperatures between 1046 K and 1673 K, at the fixed ram load of 400 T (Fig. 1).

At temperatures below 1130 K, the sample appeared as a uniform dark area with relatively sharp and straight horizontal interfaces with the BN capsule. At temperatures between 1130 and 1156 K, a new boundary appeared in the sample, and the top edge of the sample turned fuzzy and irregular. Upon further heating, the newly formed boundary migrated downwards continuously and the top edge became concave shaped. After the temperature was raised to 1573 K, the boundary in the sample disappeared and the edges of the sample faded. Upon further heating up to 1673 K, the image did not change significantly.

We interpret the appearance of the new boundary and loss of a sharp and straight top edge as the onset of melting. On the iron-rich side of the Fe-S system, this corresponds to the eutectic temperature. This interpretation is supported by existing results from quench experiments (Fig. 1b). Using the same criterion, we determined the eutectic temperatures in experiments T0899 and T0901 (Fig. 2). Although the three experiments were conducted at the same ram load, the sample pressures may differ by as much as 2 GPa. Our radiographic observations are consistent with existing data showing a minimum eutectic temperature near 14 GPa.

In the radiographs, the downward migration of the liquid/solid boundary is consistent with the increasing volume fraction of liquid during heating. Assuming that the solid phase is nearly pure iron within our experimental pressure range, we estimated the eutectic and liquidus composition from the radiographs (Fig. 1). Qualitatively, the radiograph results reproduced the steep slope of the liquidus curve between the eutectic temperature and about 1600 K, and the relatively flat slope near 1600 K. There is also a qualitative agreement between the radiographic results and quench data in experiments T0899 and T0901.

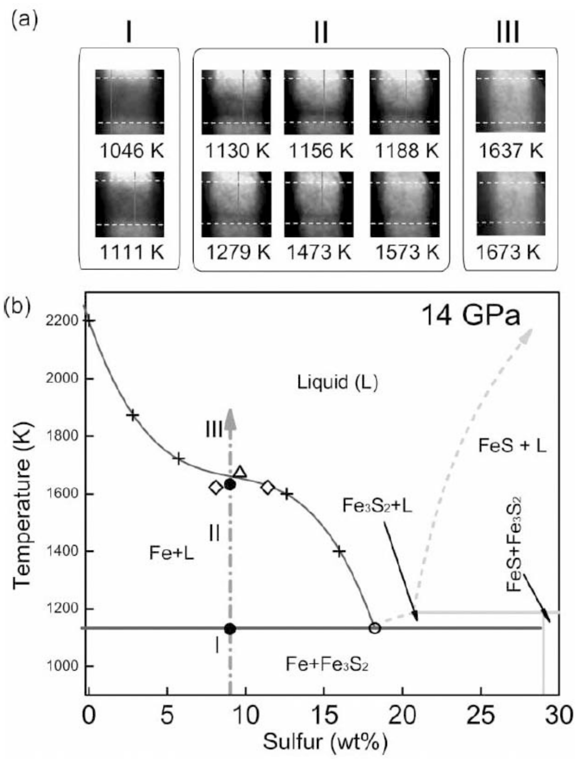

Figure 1 X-ray radiographs and the melting behavior of the Fe-S system at 14 GPa (a) Radiographic images of the upper sample chamber in Run T0898. The sample contains 9 wt% sulfur. The three groups of images correspond to the subsolidus (I), partially molten (II), and super-liquidus (III) regions of the phase diagram, respectively. White dashed lines mark the interface between the sample and BN capsule. The height of the sample is about 200 μm. (b) Comparison between our experimental data and the existing Fe-S phase diagram [3]. The dash-dotted line with an arrow head indicates the heating path. The eutectic and liquidus temperatures inferred from the radiographs (circles) match the quench results. Electron probe analyses of the recovered product from Run T0898 (triangle) and a quench experiment using the same cell assembly (diamonds) provide further confirmation of the liquidus curve constructed by Chen et al. [3].

The sample is considered totally molten when the liquid/solid boundary in the radiograph disappears. In T0898, the liquidus temperature at 14 GPa is located between 1573 K and 1637 K (Fig. 1). This result was reproduced in experiment T0899 and agrees with the quench data (Fig. 1b). In experiment T0901, we obtained a lower limit of 1723 K for the liquidus temperature at 16 GPa, which is consistent with the expected increase of liquidus temperature with increasing pressure.

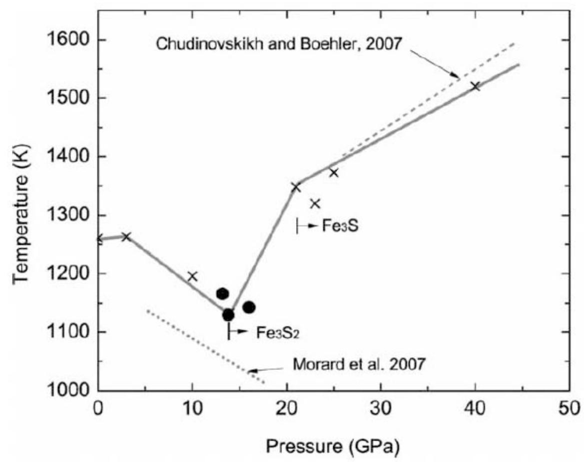

Figure 2 Comparison between the eutectic temperatures determined in this study (open circles) and existing data from quench experiments (crosses) and in situ experiments (lines) by Morard et al. 2007 [4] and Chudinovskikh and Boehler, 2007 [5]. Sources of quench data are found in [3].

Our results demonstrate that the synchrotron radiographic method is effective and efficient for investigating the partial melting behavior of Fe-S binary system under moderate pressures, where liquid and solid coexist over a wide pressure/temperature field and have relatively large absorption contrast. Aside from its application to the melting behavior of binary systems, the radiographic method is also promising for investigating melt immiscibility in systems containing iron and several light elements such as Fe-O-S ternary or Fe-O-S-C quaternary systems.

References: [1] Wang Y. et al. (2008) *Phys. Earth Planet. Inter.* DOI: 10.1016/j.pepi.2008.06.017. [2] Leinenweber K. et al. (2006) *High Pressure Res.* 26, 283-292. [3] Chen B. et al. (2008) *High Pressure Res.* 28, 315-326. [4] Morard G. et al. (2007) *Earth Planet. Sci. Lett.* 263, 128-139. [5] Chudinovskikh L. and Boehler R. (2007) *Earth Planet. Sci. Lett.* 257, 97-103.

Acknowledgements: We thank L. Gao, K. Leinenweber, Y. Wang, and T. Sanehira for their contributions to the synchrotron experiments, and thank Y. Fei and C. Hadidiacos for their help with the electron microprobe analysis. This work is partially supported by National Science Foundation Grants EAR-0337612, EAR-0609639, and EAR-0738973.