Rapid Core Formation through Diapirism from High-Pressure X-ray Radiography: J. Li[1], B. Chen[2], Kurt Leinenweber[3] and Yanbin Wang[4], [1]Department of Geological Sciences, University of Michigan, 1100 N. University Ave, Ann Arbor MI 48109, USA. jackieli@umich.edu, [2]Division of Geological and Planetary Sciences, California Institute of Technology, [3]Department of Chemistry, Arizona State University, [4]Center for Advanced Radiation Sources, The University of Chicago

Introduction: Geochemical observations based on Hf/W isotopic measurements suggest that the Earth's core formed in less than 30 Ma after the birth of the solar system [1]. Rapid core-mantle differentiation requires an efficient mechanism. To date the physical process of core segregation during the "dark age" of the Earth's history remains poorly understood [2].

One group of models postulates that core formation took place in a deep magma ocean (Fig. 1), first through quick settling of iron-rich droplets at the bottom of a thick layer of molten silicate, and then by sinking of large iron-rich diapirs through a viscous silicate mantle [3]. Recent numeric simulations examined rheological controls on core-formation mechanisms and found that diapirism can contribute significantly to metal-silicate equilibration during core formation [4]. Experimental studies under controlled pressure and temperature conditions are needed to test these models.

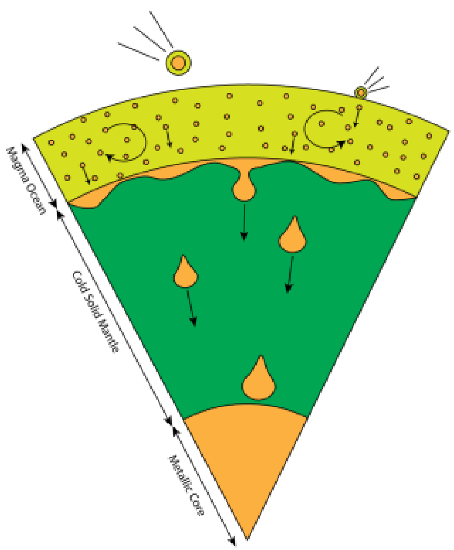

Figure 1 Cartoon illustration of core formation in a deep magma ocean.

In this study we investigate the process of diapiric core segregation using high-pressure X-ray radiography and X-ray computed microtomography (CMT) techniques. We aim to observe stress-induced melt channeling and drainage process and to determine the Stokes velocity of iron-rich diapirs sinking through solid silicate under high pressure and high temperature. Our results are compared with numerical models in order to shed new light on diapirism as a mechanism to transport core alloys to the center of the Earth.

Experimental Method: Experiments were carried out at the Sector 13 (GSECARS) of the Advanced Photon Source, Argonne National Laboratory. A 1000-ton press with a T-25 multi-anvil module was used to generate high pressure and high temperature. Two cell assemblies were designed to reduce absorption of X-rays by materials surrounding the sample, thus allowing *in situ* radiographic observations: The 14/8 assembly used a boron-nitride sample container and a rectangular-shaped graphite window inserted into the rhenium heater (Fig. 2); In the 10/5 equatorial assembly, we used graphite or titanium-boride/boron-nitride heater and replaced the center portion of the zirconia insulating sleeve with an MgO ring.

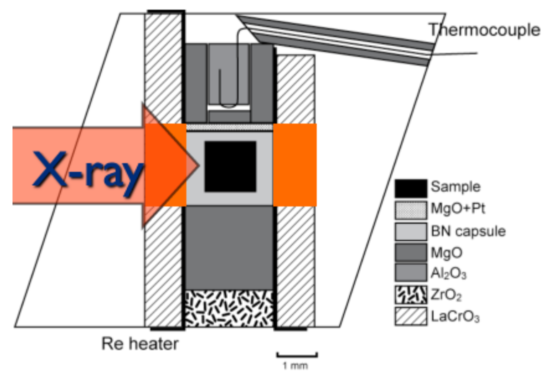

Figure 2 Multi-anvil 10/5 cell assembly for in situ X-ray radiography experiments.

The X-ray radiographic imaging system at 13-ID-D includes a Ce-dopedYAG fluorescent screen and a CoolSNAP CCD camera that records two-dimensional intensity data. The beamline is also equipped with an energy dispersive X-ray diffraction (EDXD) setup that allows *in situ* pressure determination and phase identification.

The sample consisted of a layer of San Carlos olivine (Fo90) containing a Fe-S "diapir" and sandwiched between two layers of Fe-S powder (Fig. 3). In each run, the sample was first compressed to the target pressure, and then heated to the target temperature, above the liquidus of the Fe-S starting composition. Radiographs were collected at 5 s time intervals, until the upper Fe-S layer sank through the olivine layer and merged completely with the thin Fe-S layer below.

X-ray computed microtomography (CMT) measurements were conducted on the recovered samples at Sector 13-BM-D. A series of images were collected while the sample was rotated with respect to the axis perpendicular to the incident beam. These images were then combined to produce 3-D microtomography images.

Results and Discussion: We conducted one experiment at 10 GPa and up to 1900 K (T1031) and another at 14 GPa and up to 1873 K (T1034). In Run T1031, the X-ray radiograph taken at the beginning of the series (Fig. 3) showed two layers of dense Fe-S powder (dark bands) and an Fe-S "diapir" (gray) embedded in a lighter olivine layer (light band). With time, the Fe-S layer melted gradually. The diapir grew larger and moved downwards to connect with the lower reference layer. The sinking of molten Fe-S proceeded dynamically for nearly 40 min, before forming a single Fe-S domain beneath the olivine layer.

In Run T1034, olivine transformed to its high-pressure polymorph wadsleyite. It took about 30 min for the Fe-S diapir to sink through the wadsleyite layer and merge with the lower layer.

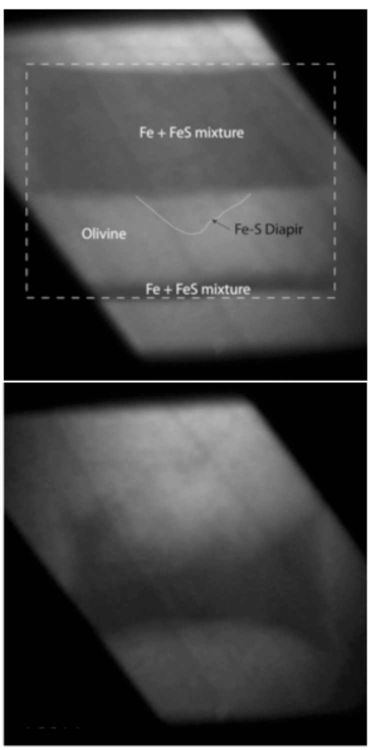

Figure 3 Radiographs of Run T1031 at 10 GPa and 1900 K. Upper: Before melting of Fe-S alloy; Lower: 40 min after melting. Dashed lines enclose an area of 1.2 mm x 1.0 mm.

X-ray computed microtomographs of the recovered samples (Fig. 4) confirmed that the molten Fe-S had sunk through the silicate layer to reach the bottom of the sample chamber. They also revealed significant grain growth in olivine/wadsleyite and leaking of molten Fe-S into the boron-nitride sample container.

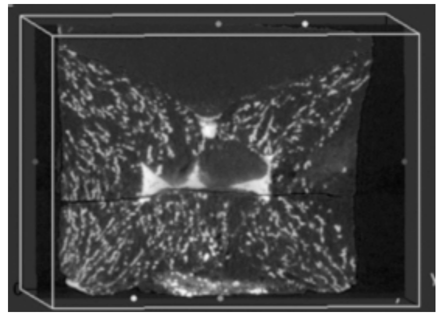

Figure 4 X-ray computed microtomograph of the recovered sample from Run T1031 at ambient condition, showing two large olivine grains (dark) inside quenched Fe-S melt (bright).

We observed that at 10 and 14 GPa sub-millimeter sized Fe-S diapir sank through underlying solid olivine/wadsleyite layer in less than one hour, equivalent to a rate of thousands of km per million years. Diapirism appears to be an efficient mechanism for core segregate through partially molten or solid mantle. By applying the general scaling laws for diapir sinking velocities $V_0 = 1/3 \cdot \Delta\rho \cdot g \cdot r^2/\eta$, new constraints can be placed on the timing of the core formation [4].

The rate of core segregation through diapirism may be affected by the grain size and melt content of the silicate, the composition of the iron-alloy, the sizes of the diapirs, and the pressure and temperature conditions. Quantifying these effects will improve our understanding of the role of diapirism in the early differentiation of Earth-like planets.

References: [1] Yin et al. (2002) *Nature* 418, 949-952; Kleine et al. (2002) *Nature* 418, 952-955. [2] Rubie et al. (2007) *Treaty of Geophysics* 9, 51-90. [3] Stevenson, D. (1981) *Science* 214, 611-619; Li, J. and Agee C. (1996) *Nature* 381, 686-689. [4] Samuel, H. and Tackley P. J. (2008) G^3, 9(6), Q06011; Golabek G. J. et al. (2008) *Earth. Planet. Sci. Lett.* 271, 24-33; Golabek et al. (2009) G^3, 10(11), Q11007.

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