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Experience melting through the Earth's lower mantle via LH-DAC experiments on MgO-SiO_2 and CaO-MgO-SiO_2 systems

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The large low shear-wave velocity provinces (LLSVPs) and ultra-low velocity zones (ULVZs) of the lowermost mantle [1] are likely characterized by distinct chemical compositions, combined with temperature anomalies. The heterogeneities may have originated by fractional crystallization of the magma ocean during the earliest history of the Earth [2,3] and/or the continued accretion at the CMB of subducted basaltic oceanic crust [4,5]. These structures and their properties control the distribution and magnitude of the heat flow at the CMB and therefore the convective dynamics and evolution of the whole Earth. To determine the properties of these structures and thus interpret the seismic results, a good understanding of the melting phase relations of relevant basaltic and peridotitic compositions are required throughout the mantle pressure range.

The melting phase relations of lower mantle materials are only crudely known. Recent experiments on various natural peridotitic and basaltic compositions [6-8] have given wide ranges of solidus and liquidus temperatures at lower mantle pressures. The melting relations for MgO, $MgSiO_3$ and compositions along the MgO-SiO_2 join from ab initio theory [e.g. 9,10] is broadly consistent with a thermodynamic model for eutectic melt compositions through the lower mantle based on melting experiments in the MgO-SiO_2 system at 16-26 GPa [3]. We have performed a systematic study of the melting phase relations of analogues for peridotitic mantle and subducted basaltic crust in simple binary and ternary systems that capture the major mineralogy of Earth's lower mantle, using the laser-heated diamond anvil cell (LH-DAC) technique at 25-100 GPa.

We determined the eutectic melting temperatures involving the following liquidus mineral assemblages:

1. bridgmanite (bm) + periclase (pc) and bm + silica in the system MgO-SiO_2 (MS), corresponding to model peridotite and basalt compositions

2. bm + pc + Ca-perovskite (cpv) and bm + silica + cpv in the system CaO-MgO-SiO_2 (CMS).

The eutectic melting temperatures (T_e) were determined by multi-chamber DAC-experiments on near-eutectic compositions [3,9]. Ultra-fine W-powder mixed into the samples absorbed the laser energy. The samples were heated at a rate of 500-1500 K/min by increasing the laser power. More than 75-90% eutectic melt is produced at the the solidus, resulting in rapid aggregation of the W-powder and inefficient laser energy absorption. The resulting plateau in the temperature versus power curve is interpreted as T_e.

Our preliminary results show an expected positive p-T_e correlation, with lower T_e for the CMS-system. The dT_e/dp slope for the bm-silica eutectic is lower than for the bm-pc eutectic in the MS-system. The experimental results agree with the DFT-studies and thermodynamic models.

We have also developed a novel technique for micro-fabrication of metal-encapsulated samples (Re, W, Mo), to investigate more precisely the melting phase relations in the lower mantle pressure range. The metal-covered, 20 μm thick sample disc, placed between thermal insulation layers in the DAC, will be laser-heated at the two flat surfaces, providing low thermal gradients and preventing reaction between the sample and the pressure medium.

[1] Lay and Garnero (2007, AGU Monograph); [2] Labrosse et al (2007, Nature); [3] Liebske and Frost (2012, EPSL); [4] Elkins-Tanton (2012, Ann Rev Earth Planet Sci); [5] Hirose et al (1999, Nature); [6] Fiquet et al (2010, Science); [7] Andrault et al (2011, EPSL); [8] Andrault et al (2014, Science); [9] de Koker et al (2013, EPSL); [10] de Koker and Strixrude (2009, Geophys J Int).