Geophysical Research Abstracts
Vol. 13, EGU2011-4850, 2011
EGU General Assembly 2011

Composition, mineral physics and origin of thermochemical piles in the D'' zone

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The D'' zone is laterally heterogeneous with two comparable Large Low Shear Velocity Provinces (LLSVPs) under the Pacific and Africa. Large vertical velocity gradients and distinct seismic discontinuities are also observed in most areas. An upper and a lower, reverse discontinuity observed primarily outside, but also within, the LLSVPs have been ascribed to double crossing of the perovskite (pv) to post-perovskite (ppv) phase boundary (e.g. Hernlund et al. 2005, Nature). The main upper and lower D''-discontinuities are commonly located at 200-300 km and 10-100 km above the CMB. Thin ultra-low velocity zones (5-40 km thickness) of limited areal extent located directly above CMB seem to be concentrated within or near the margins of the LLSVPs.

Seismic tomography demonstrates that the LLSVPs have locally sharp and steep margins (Garnero and MacNamara 2008, Science) and paleogeographic relocation of large igneous provinces of variable ages in a global reference frame shows clustering above the LLSVP margins (e.g. Burke and Torsvik 2004, EPSL; Torsvik et al. 2006, GJI). Repeated large-scale plume generation at stationary LLSVP margins indicate that they may be thermochemical piles of long-term (>300 Ma) stability. Steep margins of 200-400 km thick and stable piles require that they comprise material with a moderate density contrast (2-5%) and higher bulk modulus than the ambient peridotite-dominated mantle. Both of these requirements are probably met by material enriched in meta-basalt with high Fe/Mg ratio in perovskite and post-perovskite and high bulk modulus of the silica-dominated phases (e.g. Hirose et al. 2005, EPSL; Irifune and Tsuchiya 2007, Treatise Geophys). Peridotitic and komatiitic material with elevated Fe/Mg ratio may also fulfill the requirements. The age and evolution of the LLSVPs are probably closely linked to the nature of the material. Enrichment of basaltic material could occur slowly over 4 Ga by separation from subducted lithoshere (e.g Trønnes 2010, MP). Emplacement of komatiitic or peridotitic material with elevated Fe/Mg ratios, however, would occur very early in Earth's history, either by the final solidification of a lowermost mantle magma ocean (Labrosse et al 2007, Nature; Stixrude et al. 2009, EPSL) or by sinking of solidified magma material from about 400 km depth (Lee et al. 2010, Nature). The upper boundary region of the transition zone is potentially a feeding zone for deep melts formed at 10-25 GPa in hot plumes during the earliest history of the Earth. Melting might have been especially extensive at 20-25 GPa where the largest downward inflection of the mantle solidus occurs (e.g. Trønnes and Frost, 2002, EPSL, Stixrude et al. 2009, EPSL). Because ferropericlase is the liquidus phase in part of this range, the accumulated melt composition may be relatively Si-rich, e.g. komatiitic or even basaltic.

The merits of each of the alternatives above may be evaluated by further refined mineral physical studies. Recent experimental investigations by Catalli et al (2009, Nature) and Andrault et al. (2010, EPSL) indicate that the pv-ppv-transition cannot easily explain the two seismic discontinuities in basaltic or komatiitic material with high Fe/Mg ratios and elevated Al-contents. Double crossing of the transition from $CaCl_2$- to PbO_2-structured silica-rich phase may be an alternative. The formation of komatiitic or peridotitic material with high Fe/Mg ratio in a deep mantle magma ocean or by melting in early hot plumes can be studied by further melting experiments at lower mantle pressure conditions (e.g. Fiquet et al. 2010, Science). A planned investigation of pseudo-invariant or pseudo-univariant melt compositions of peridotite at 20-24 GPa may also clarify deep melting in hot mantle plumes.