Melting properties of the deep Earth's mantle

D. ANDRAULT[1], S. PETITGIRARD [2], M.A. BOUHIFD[1], N. BOLFAN-CASANOVA[1],
G. GARBARINO[2], M. MEZOUAR[2]

[1] Laboratoire Magmas et Volcans, Université Blaise Pascal, Clermont-Ferrand, France
[2] European Synchrotron Radiation Facility, Grenoble, France

A large fraction of our planet has experienced melting in the course of its accretion history as a consequence of large meteoritic impacts. In the Earth today, partial melting is also suggested based on seismic observations of low velocity zones in the lowermost mantle. The occurrence of melting is of primary importance for the dynamic evolution of our planet because it induces major chemical segregation and formation of distinct chemical reservoirs. Three independent parameters must be refined to improve our knowledge on the melting properties at high pressures: (1) the temperature profile in the deep Earth (2) the pressure dependence of the solidus and liquidus melting temperatures of major geological materials (3) the relative buoyancy of melts compared to the solid mantle.

(1) The temperature profiles in the present-day deep mantle and in the primitive Earth can be estimated by geodynamical modeling. However, they remain poorly constrained and potentially controversial. In the modern mantle, extrapolation of an adiabatic gradient from the upper mantle to the core-mantle boundary (CMB) yields temperatures below 3000 K at all mantle depths. However, an adiabatic gradient could be poorly relevant to the Earth mantle if there is an heterogeneous repartition of the radioactive elements as a function of depth; they could be concentrated in deep (primitive) mantle reservoirs, for example. Also, a major temperature increase is expected in the D"-layer (a 200-300 kilometers thick layer sitting just above the CMB) as a consequence of a very hot outer core.

(2) Based on experimental investigations in the laser heated diamond anvil cell coupled with synchrotron radiation, we recently determined the solidus and liquidus melting curves of a chondritic-type mantle up to CMB pressures. We find melting temperatures well above the different models of mantle geotherm, at least for depths up to the D"-layer. In the lowermost mantle, the occurrence of melting depends primarily on the steepness of the temperature gradient in this region. If the mantle reaches more than 4150(+/-100) K at 135 GPa, partial melting could occur. In addition, our measurements evidence a relatively high liquidus melting temperature as well as a large temperature gap between solidus and liquidus temperatures. In the context of the primitive Earth, it suggests that the mantle should not melt completely because an excessively high temperatures would be required at the Earth's surface. Instead, partial melting could have taken place over a large depth interval, with a sustained magma ocean remaining only at the Earth surface.

(3) Then, the fate of the melts depends primarily on their density contrast with solid material. The controlling parameters are -the Fe-partitioning between solid and liquid phases, -the SiO_2/MgO ratio in the liquid and -the volume of melting. The later is of a couple of percents and decreases slightly with increasing pressure. The liquid SiO_2/MgO ratio in the liquid remains poorly constrained. It may decrease with increasing pressure, at least in the upper part of the mantle, which could favor sinking of melts in the deep mantle. The dominant parameter, however, is the Fe-partitioning between the two phases. Our experimental measurements using the X-ray fluorescence technique show that even if Fe remains relatively incompatible with the solid mantle at all mantle depths, it is not sufficiently incompatible to make the melts denser than the solid mantle. This observation is contradictory with a model of basal magma ocean remaining stored in the lowermost mantle at the contact with the CMB for long geological times.