Geophysical Research Abstracts
Vol. 13, EGU2011-3592, 2011
EGU General Assembly 2011

Convection, melting and the structure of the inner core and lowermost outer core

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The seismological observation of a stably stratified $\sim$ 200 km thick layer at the base of the outer core is difficult to reconcile with the classical picture of outer core convection, where buoyant liquid is released at the ICB by the progressive crystallization of the inner core. We propose here that this layer has been generated by simultaneous melting and crystallization at the ICB. Melting inner core material produces a dense iron-rich liquid which spreads at the surface of the inner core, while crystallization produces a buoyant liquid which may carry along part of the dense melt as it rises. The stratified layer results from a dynamic equilibrium between production of iron rich melt and entrainement and mixing associated with the release of buoyant liquid. Analogue experiments show that a stratified layer indeed develops if the buoyancy flux associated with the dense melt is larger (in magnitude) than a critical fraction ($\sim$ 80 %) of the buoyancy flux associated with the light liquid.

Melting part of the inner core at a significant rate while the core is cooling and the inner core crystallizing on average is difficult. The most plausible way to do it is to generate dynamically a topography that will bring locally the ICB at a potential temperature lower than that of the adjacent liquid core. The melting rate is then limited by the ability of outer core convection to provide the latent heat absorbed by melting, and only a significant ICB topography can lead to a non-neglible melting rate. We explore here the possibility that thermal convection is at the origin of such topography. The uncertainties on most relevant parameters do not allow for a definitive answer on the likelyhood of inner core thermal convection, but thermal convection appears to be at least as likely as not. In the limit of a large inner core viscosity, the only unstable mode is a translation of the inner core with associated melting in one hemisphere and crystallization in the other. An analytical model including inner core thermal evolution, kinetics of phase change at the ICB, and self-gravitation, shows that such convective translation can induce a melting rate large enough to explain the formation of a dense layer at the base of the outer core. We extended our analysis to allow for finite viscosity with a numerical model of convection which includes phase change at the ICB. The translation mode is dominant if the viscosity is larger than $\sim 10^{18}$ Pa.s. With a smaller viscosity, the convection regime is typical of high Rayleigh number internaly heated convection, with narrow plumes falling down from a thermal boundary layer below the ICB. Phase change associated with the dynamic topography is still significant if the viscosity is not too small, and has a positive feedback on the vigour of convection, with freezing localized above plumes roots and melting occuring above upwellings. We discuss the implications of our model for the internal structure of the inner core, and the seismologicaly observed East/West asymetry.