CONSTRAINING THE BULK MAJOR ELEMENT COMPOSITION OF THE EARTH'S LOWER MANTLE - A GEOPHYSICAL PERSPECTIVE.
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Introduction. Knowledge of the internal constitution of the planets is crucial to our understanding of the origin and evolution of our solar system. The pyrolite model of Ringwood [e.g. 1] has become widely acknowledged as being representative of the Earth's average upper mantle composition, because of its ability to satisfy a large range of geochemical and geophysical data, such as the 1D seismic reference models PREM [2] and AK135 [3]. In spite of the pyrolite models overall good fit to data, a number of issues are as yet unresolved. For example, can we explain the observed seismic discontinuities, notably the 660, as being due to a change of phase in an isochemical mantle or is a chemical change called for, implying dissimilar bulk upper and lower mantle compositions. The composition of peridotites have been used to estimate the composition of the primitive upper mantle, that is, the composition of the mantle prior to extraction of basaltic crust, but postdating core formation [4, 5, 6] and are found to be depleted in Si relative to chondrites, traditionally thought of as the building blocks of the terrestrial planets. A possible solution to the conundrum of Si depletion would be to sequester it into the core and/or lower mantle. However, as the core contains at most ∼10 wt% [e.g. 7, 8] of low-mass elements, some of the Si would have to be in the lower mantle. This effectively calls for a chemical distinction between the upper and lower mantle contrary to what has been argued by [9]. The resolution of the lower mantle Si content thus not only holds the potential of providing insight into the nature of the material from which the Earth assembled, but also provides evidence for possible mantle compositional stratification.

Purpose. It is the purpose here to address the above issues from a purely geophysical perspective by inverting a set of different geophysical data jointly for Earth's lower mantle composition and thermal state. Specifically, the data considered include seismic data (global ISC P and S wave travel times [10]), electromagnetic sounding data (long-period inductive responses [11]) and gravity data (mean mass and moment of inertia [12]). The inversion, as described in [13, 14], combines the thermodynamic phase equilibrium calculation of [15] with a fully non-linear stochastic inverse algorithm, based on a stochastic sampling method (Markov chain Monte Carlo), to explore the range of model parameters consistent with the observations, i.e. Earth's mantle geotherm and composition.

Method of Analysis. Our model of the Earth is assumed spherically symmetric and divided into four layers of variable thickness, corresponding to crust, upper and lower mantle as well as core. Crust and mantle layers are parameterized using composition c (upper mantle composition is held fixed using the pyrolite composition of [5]), thickness d and temperature T, whereas the core is modeled using the parameters radius, density and electrical conductivity. The Earth's chemical composition is modeled using the model system CaO-FeO-MgO-Al_2O_3-SiO_2. For a given model configuration that specifies mantle composition and thermal state, the inversion procedure consists of the following steps:

- Gibbs free energy minimization is used to compute equilibrium mineral modes at the pressure and temperature conditions of interest.
- Physical properties in the form of density, P and S-wave velocity are then estimated from the computed mineralogy as function of depth.
- The mineral modes are combined with laboratory-based models for the conductivity of individual minerals to estimate the bulk Earth electrical conductivity structure (σ).
- From these radial profiles, seismic travel times, mean mass, mean moment of inertia and electromagnetic responses at the surface of the Earth are calculated.

Results. Our derived lower mantle compositions suggest a compositional difference between the upper and lower mantle. This is seen in figure 1a, which shows a higher SiO_2 content (∼50 wt%) in the lower mantle, in comparison to the pyrolite estimate of 44.4 wt% [5]. This is further highlighted in figure 1b, which shows sampled molar lower mantle Mg/Si and Fe/Si ratios. The former is seen to peak at ∼1.15, whereas the value for pyrolite quoted by [5] is 1.27. The Si-rich lower mantle thus provides a means for explaining the Si depletion of the upper mantle relative to chondrites, without having to invoke a scenario where all the Si is in the core. A lower Mg/Si ratio in the lower mantle also makes it possible to derive the Earth from chondrites, without having to invoke the existence of as yet unsampled material from which the Earth assembled, as suggested by [9]. Temperatures in the transition zone were found to agree well with experimental determinations, if the reactions Ol→ β-Sp and β-Sp→Mw+Pv are related to the 410 and 660 km seismic discontinuities. The geothermal gradient in the lower mantle was found to be superadiabatic in agreement with some other recent investigations, resulting in a relatively hot lower mantle with CMB temperatures around 2900 °C. The physical properties (density, seismic wave velocities and electrical conductivity) derived from our sampled compositions and geotherms, are found to agree with purely geophysically-derived models such as PREM, AK135 and the electromagnetic conductivity models obtained by previous workers [e.g. 10] (figure 3).

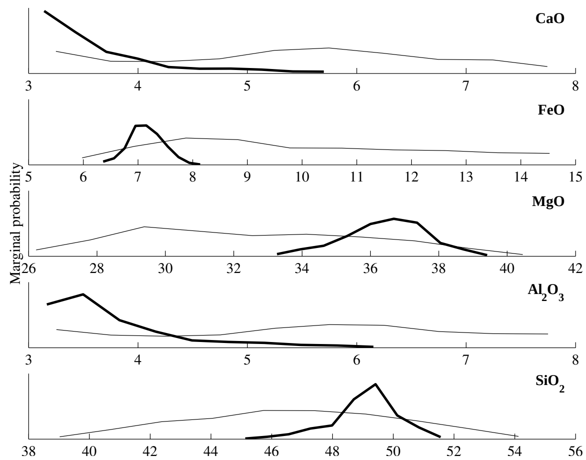

Figure 1a: Sampled lower mantle major element compositions. Thin lines denote prior probability density functions (before inversion), while heavy lines depict the posterior density functions (after inversion).

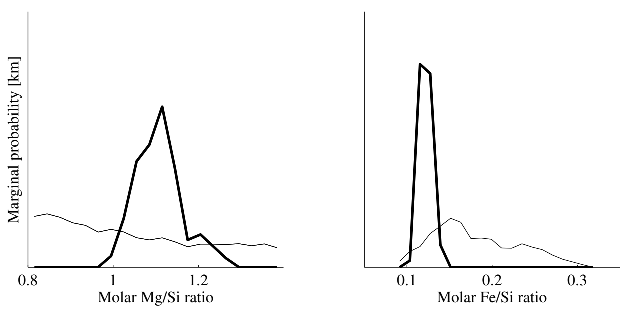

Figure 1b: Sampled lower mantle molar Mg/Si and Fe/Si ratios. Thin lines denote prior probability density functions (before inversion), while heavy lines depict the posterior density functions (after inversion).

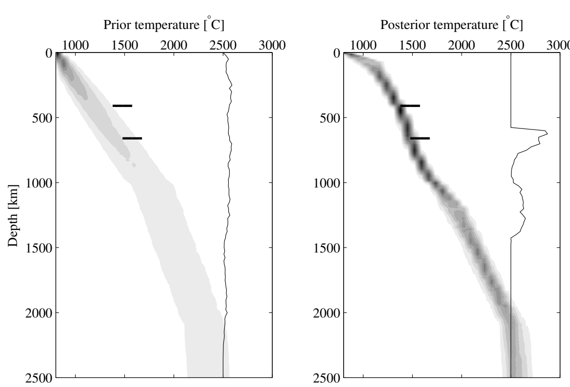

Figure 2: Sampled prior and posterior thermal profiles. The contours directly reflect the probability of occurence of the temperature at a given depth, with white corresponding to least probable and black to most probable. White line denotes maximum likelihood model. Horizontal bars denote experimentally determined mantle phase transition temperatures, while the vertical line shows the depth to the upper/lower mantle transition.

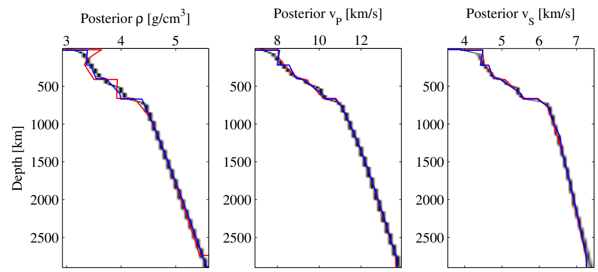

Figure 3: Calculated physical properties and their comparison to previous purely geophysically-derived profiles PREM (blue) and AK135 (red).

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