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Combined Geophysical-Petrological Modelling of the Lithosphere

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The density and seismological structure of the lithospheric and sublithospheric mantle, and their relationship with geophysical observables, are assessed with a model that integrates mineral physics, geochemical, petrological, and geophysical data. Compressibility, partial melting, and compositional heterogeneities are considered in addition to standard thermal modelling. Elevation is estimated self-consistently with a new approach that permits us to distinguish between lithospheric and sublithospheric buoyancy contributions, assuming that individual columns are locally compensated within the upper mantle. Results are presented for representative sections of oceanic (OL) and continental (CL) lithosphere of different ages. Predictions of surface heat flow, potential fields, seismic velocities, and elevation are used to control the reliability of the models.

In both oceanic and continental sublithospheric mantle, where the thermal gradient becomes adiabatic, density increases downwards with a depth derivative $\delta\rho/\delta z \sim 8.7\times10^{-4}$ kg m^{-4} between 100 and 320 km depth, where it reaches maximum values of 3510 – 3520 kg m^{-3}. In OL, density decreases with depth until the base of the lithosphere with averaged depth derivatives $\delta\rho/\delta z \sim -1.7\times10^{-3}$ and -3.7×10^{-4} kg m^{-4} for 25 and 100 Ma old OL, respectively. When chemical differentiation is included, the resulting average density of a 100 km thick OL ($\sim$ 3280 kg m^{-3}, including the crust) is less than the density of the sublithospheric mantle at the bottom of the OL. In CL, density increases systematically with depth in all continental domains thicker than $\sim$ 140 km, with mean density values being dependent on its compositional and thermal structure (i.e. age). In thinner CL the temperature effect is dominant and hence the density variation with depth is inverted. Simulations in Archean cratons suggest

that the high degree of depletion usually assumed for these domains cannot be representative of the whole lithosphere, in agreement with petrological evidence.

Predicted seismic velocities show that a low-velocity zone (LVZ) is always present in OL, even without partial melting. In contrast, a clear LVZ is present only in CL < 150 km thick for isotropic velocities. These predictions are in agreement with available seismological models.

These results have strong implications for the stability of the lithosphere, and the triggering of dynamic processes such as convective thinning or subduction initiation.

In particular, our results suggest that: a) the density contrast between mature OL and the underlying mantle might have been overestimated by as much as ~ 45 kg m^{-3}in previous studies; b) the roots of Archean cratons can be positively/neutrally buoyant down to ~ 300 km depth, making them more resistant to convective thinning.