Modeling mantle geochemical (isotopic) and geodynamical evolution

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To investigate dynamical mechanisms that have been proposed to explain geochemical observations, several researchers have used numerical models of mantle convection that include tracking of geochemical species. Here a model is presented that combines a treatment of major and trace-element geochemical evolution with a dynamically-consistent mantle convection-plate tectonics model. Melting is simulated using an experimental solidus and assumed to erupt instantly, forming a crust, thereby generating chemical heterogeneity including the partitioning of trace elements between oceanic crust and residue. Trace elements studied are the U-Th-Pb and Sm-Nd isotope systems, helium and argon. Both olivine and pyroxene-garnet system phase transformations are included. A suite of numerical experiments has been run to systematically investigate the sensitivity of the results to uncertain physical properties such as the density of subducted crust in the deepest mantle and elemental partition coefficients. Different stratifications of the mean major- and trace-element chemistry develop depending on the relative densities of eclogite and pyrolite in the deep mantle. The system self-consistently evolves regions that have a HIMU-like signature. 50-60% outgassing of radiogenic ^{40}Ar occurs for a wide range of parameter combinations. MORB-like $^{3}He/^{4}He$ histograms are produced in erupted material either when the shallow mantle has a high proportion of residue and He is highly incompatible, or when sufficient recycled crust mixes back into the shallow mantle to suitably reduce its $^{3}He/^{4}He$. Different mechanisms are investigated for producing the observed isotopic 'age' of the Pb-Pb isochron, including remelting, stretching, sampling lengthscale and a change in subduction. The results reaffirm the importance of stretching as a key mechanism for effectively deleting older heterogeneities, although a lack of HIMU subduction prior to 2.5 Gyr before present also produces the correct age.

A comparison between lower mantle models from probabilistic tomography and models of thermo-chemical convection

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We combine recent progress in seismic tomography and numerical modelling of thermo-chemical convection to infer robust features on the structure and dynamics of the lower mantle. The technique of probabilistic tomography is able to infer independent probability density functions for long wavelength models of bulk-sound and shear wave speed, density and boundary topography in the mantle. Using appropriate depth-dependent sensitivities, likelihood of density and seismic velocities anomalies can be converted into likelihoods of variations in temperature, perovskite and iron content throughout the mantle (Trampert et al., 2004). Sensitivities are obtained following a Monte-Carlo search that accounts for uncertainties in mineral physics data and in the thermo-chemical reference state of the mantle. Throughout the mantle, bulk-sound speed (density) is an excellent proxy for perovskite (iron), but surprisingly shear-wave speed is not highly correlated to temperature. Compositional variations are essential to explain the seismic data. In particular, the regions of low shear-wave velocity in the deep mantle ($\leq$2000 km) beneath Africa and the Pacific, usually referred to as 'superplumes', are due to an enrichment in iron (and to a lesser extent, in perovskite), which makes them denser than the surrounding mantle. The thermo-chemical distributions can be used to identify the thermal and chemical contributions to the observed density anomalies. We performed statistical comparisons between these contributions and some chosen models of thermo-chemical convection that include the anelastic approximation (Tackley 2002). We find that a stable and ubiquitous layer of dense material is unlikely to be present at the bottom of the mantle. Models of piles entrained upwards explain the observation significantly better, but discrepancies remain at the top of the lower mantle. These discrepancies could be linked to the deflection of slabs around 1000 km, or to the phase transformation at 670 km, not included yet in the thermo-chemical calculations.

References

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