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Stability of the Large Low Shear Velocity Provinces: Thermomechanical modeling

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The focus of this project is to develop a numerical tool to study processes that take place in the deeper mantle. The geodynamic model is constrained by interpretations of the surface measurements done by other geophysical studies, including seismology and experimental mineral physics. One of the most robust results from tomographic studies is the existence of two antipodally located Large Low Shear Velocity Provinces (LLSVPs) at the base of the mantle. Reconstruction of the eruption sites of Large Igneous Provinces and hotspot volcanoes of the last 200 Ma has shown that these project radially downward to the margins of the LLSVPs (Torsvik et al., 2006). This has led to inferences that plumes of arguably deep origin are generated from the margins of the LLSVPs, and that the LLSVPs are stable, long-lived and impose the planform of flow in the mantle and of plate tectonics at the surface (Dziewonski et al., 2010). The negative correlation between the bulk sound velocity and the shear velocity within the LLSVPs, as well as the sharp boundaries between the LLSVPs and surrounding mantle, suggest that these anomalies are not of purely thermal origin. One of the objectives of this project is to study the inferred gravitational stability of the LLSVPs and their relation to generation of plumes.

A thermomechanical Finite Element Method (FEM) code is developed to model convection of a fluid in a rectangular domain. The fluid is confined in an impermeable box and is heated from below, with no internal heating. It is assumed that the fluid is of infinite Prandtl number, with Newtonian rheology and that the Boussinesq approximation applies. The fluid is comprised by two chemically distinct materials: a dense layer along the bottom boundary overlain by a material of lower density and higher viscosity. Density and viscosity of the entire fluid are both temperature- and chemistry-dependent.

The governing equations include the temperature-dependence of viscosity, as well as the conservation laws of mass, energy, and momentum. Operator splitting is used to model the conductive and convective heat transport mechanisms separately. Conductive heat transport is modeled by solving the heat diffusion equation, using the FEM diffusion solver. Convective heat transport is modeled by solving the advection equation, using the method of shooting back characteristics, together with the fourth-order Runge-Kutta method. The diffusion and advection solvers are benchmarked by applying them to problems with known analytical solutions. The mechanical solver MILAMIN (Dabrowski et al., 2008) is utilized for solving the Stokes equation. Two independent grids are used for spatial discretization of the temperature and velocity fields. Different materials in the model are represented by markers, and material transport associated with convection is modeled using marker-in-cell technique. Temporal evolution of the temperature field and distribution of the dense layer are studied.

The results are obtained for different density and viscosity ratios due to chemical variations between the two materials, and different viscosity ratios due to temperature variations. Modeling results show that a relative density difference of at least 1.70% between the dense layer and the ambient material is required in order to achieve gravitational stability of the dense layer for times up to a billion of years. Decreasing the viscosity of the dense layer, or introducing temperature dependence of the viscosity, enhances the entrainment of the dense layer into the ambient material. The results show that the topography of the thermochemical piles that are formed is dynamically supported by the convective motion within the piles. Their shape is also significantly influenced by the sweeping of the piles by the cold downwellings of the ambient material. Plumes of denser material are observed to form both on the top and on the sides of the piles.

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