THE ROLE OF A PRESSURE-DEPENDENT RHEOLOGY IN THE DYNAMICS OF MANTLE CIRCULATION

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We have constructed a thermomechanical model for upper mantle convection such that the thickness and the structure of the lithosphere are determined self-consistently by the heat transported by convection. In this study of the interaction between the lithosphere and upper mantle, strongly temperature- and pressure-dependent rheologies for both Newtonian and non-Newtonian creep mechanisms are employed. For a strictly temperature-dependent rheology an insignificant amount of heat, less than $12.5 mW/m^2$, can be transported convectively for an interior viscosity, $0(10^{21} Pas)$, compatible with post-glacial rebound. On the other hand, for similar values of the interior viscosity, steady heat fluxes between 20 and $40 mW/m^2$ are produced by introducing pressure-dependence into the rheology. For the temperature- and pressure-dependent flow law the horizontally averaged interior temperature displays very little variation with the amount of heat evacuated, once all of the rheological parameters are fixed. This finding may have important ramifications for parameterized convection. We employ both the single-mode, mean-field approximation and the complete two-dimensional equations, using finite-elements, to obtain solutions for the various types of rheologies. From evaluating the geophysically relevant observables, such as topography, free-air gravity anomalies, surface heat-flow and stress field in the lithosphere, we find that the lateral variations of these quantities predicted by a non-Newtonian rheology are much smaller than those derived from a linear rheology. These results suggest that surface variations of geophysical observables are more compatible with a non-Newtonian rheology in the upper mantle.

We have also investigated the evolution of the oceanic lithosphere from a thermomechanical approach. The finite-amplitude development of secondary convection cells beneath the oceanic plates is studied by means of the single-mode mean-field equations and the fully two-dimensional convection equations, using finite-element techniques. Both Newtonian and non-Newtonian rheologies with highly temperature- and pressure-dependences, and an activation energy of 100 Kcal/mole have

been employed. The temperature at the base of the convection medium governs the final thickness of the lithosphere. The mean interior temperature varies only slightly during the temporal evolution. Non-Newtonian rheology has the tendency to induce oscillatory time-dependent behavior in the flow structure. Heat flow, topography and gravity are influenced by secondary convection in two ways. Small scale perturbations with wavelengths of around 600 km arise from the lateral thermal differences between the uprising and descending convective limbs; large-scale features are also produced as a consequence of lithospheric growth. The calculated quantities of the heat-flow topography and gravity associated with small-scale convection are typically in the range of O(HFU), $O(10^2 m)$, and O(10mgal). The horizontal mean-temperature profiles from the convection model are used to calculate long wavelength geophysical observables as a function of age. Convective processes are found to reduce the rate of lithospheric thickening. Predictions from our model can fit well the observed data of heat flow, ocean floor topography and geoid off-sets along fracture zones, the last data base exhibiting the most sensitivity to thermal perturbations below the lithosphere. Our calculations show that the oceanic lithosphere is able to grow continuously up to $0\ (10^9 yr)$, long past the flattening of the seafloor. We report here that the thickness of a thermally equlibrated lithosphere could reach about 250 km, which lies within the appropriate range of values for the continental lithosphere, as inferred from studies in seismology, flexure observations, and secular polar motions.

Finally we have proposed a new dynamical mechanism, operative only for a temperature- and pressure-dependent rheology. The idea is based on the formation of small-scale convective instabilities from an ascending flow passing through the low viscosity zone, which exists in virtue of the temperature- and pressure-dependent viscosity. Strong secondary convections results from a local increase of the mantle temperature by a couple of hundred degrees. The vertical velocity increases greatly and assumes a jet-like profile in a low viscosity channel with a minimum of $O(10^{16} Pa\ s)$. This secondary convection model can deliver the proper timescales for the uplift and thinning of the lithosphere, as observed geologically.