last Pleistocene glaciation is simulated using two different scenarios, with different glaciation histories followed by the deglaciation history of the global ice model ICE-3G (Tushingham & Peltier, 1991). We investigate the influence of variable earth rotation on sea level and the influence of different viscosity models and glaciation histories on earth rotation.

References:

— INVITED —

The fluid dynamics of plumes

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In geodynamics plumes play an important role for phenomena on different scales, ranging from local hot-spots to large scale features like superswells. Plumes evolve from thermal boundary layers if a critical parameter (similar to a local Rayleigh number) exceeds a critical value. In that sense plumes can be viewed as threshold phenomena. By means of numerical experiments various aspects of plume structure and evolution will be demonstrated in this presentation.

The shape and the evolution of plumes is strongly influenced by the viscosity of the material. Especially a strong temperature dependence of the viscosity leads to episodic bursts of hot material from the thermal boundary layer following a previously established path of low viscosity. Episodicity is a common feature of plumes in fluids with temperature dependent viscosity, even if the forcing is not varying with time. If plumes are evolving self-consistently from a thermal boundary layer they hardly entrain material during ascent, i.e. material reaching the top is very similar to the material of the source region. Besides the temperature dependence also the pressure dependence of the viscosity significantly influences the behavior of plumes. The symmetry, between the upwelling and downgoing currents is destroyed by pressure dependence of the viscosity. Strong upwellings exist while the downwellings are weakened. The effect of the viscosity increasing with pressure on the flow dynamics is further enhanced by the decrease of the thermal expansion coefficient with pressure. Both, act to increase the strength of upwelling plumes, thus leading to flows of large horizontal scales. In two dimensions, flows with aspect ratios greater than 30 have been observed.

Under appropriate conditions (combinations of pressure and depth dependence) small plumes from the thermal boundary layer gather to form massive upwellings. This is a possible scenario relevant for the formation of superplumes. Under the same condition the net viscosity profile exhibits a local maximum in the lower mantle, as indicated by recent studies.

Viscous Heating in the Mantle Induced by Glacial Forcing

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We have studied the possibility of energy transfer from glacial forcing to the Earth’s interior via viscous dissipation of the transient flow. We applied our initial-value approach to the modelling of viscoelastic relaxation of spherical compressible self-gravitating Earth models with a linear viscoelastic Maxwellian rheology. We have focussed on the magnitude of deformations, stress tensor components and corresponding dissipative heating for glaciers of Laurentide extent and cyclic loading with a fast unloading phase of various lengths.

We have surprisingly found that this kind of heating can represent a non-negligible internal energy source with exogenic origin. The volumetric heating by fast deformation can be locally higher than the chondritic radiogenic heating during peak events. In the presence of an abrupt change in the ice-loading, its time average of the integral over the depth corresponds to equivalent mantle heat flow of milliwatts per m² below the periphery of ancient glaciers or below their central areas. However, peak heat-flow values in time are by about two orders of magnitude higher. Note that nonlinear rheological models can potentially increase the magnitude of localized viscous heating.
To illustrate the spatial distribution of the viscous heating for various Earth and glacier models, we have invoked the 3-D visualization system Amira (http://www.amiravis.com). Our file format allows to animate effectively time evolution of data fields on a moving curvilinear mesh, which spreads over outer and inner mantle boundaries and vertical mantle cross-sections. Two attached snapshots of the Amira movies show examples of normalized dissipative heating of the PREM model with a lower-mantle viscosity hill at the end of the instantaneous unloading of glaciers with rectangular (Fig. 1a) and parabolic (Fig. 1b) cross-sections.

Small-Scale Asthenospheric Convection and Cenozoic Extensional Tectonics of the Basin and Range Province, Western U.S.A.

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Cenozoic extension in the Western U.S. is broadly associated with widespread volcanism, high heat flow, extensive thinning or removal of mantle lithosphere, and uplift. While there is no universally straightforward temporal relation between the onset times of extension and volcanism in the basin and range province, these phenomena appear to be related to, or at least partly controlled by, dynamic processes occurring in the upper mantle. Because the mantle lithosphere is denser than the underlying asthenosphere, it is gravitationally unstable and may give rise to small-scale convective motions that result in lithospheric thinning, voluminous melt production, and high heat flow. Numerical simulations of this process, including the effects of melting, indicate that the occurrence of partial melting dramatically increases the propensity for small-scale convection. Two distinct styles of small-scale convection are observed in these models: 1) large amplitude (up to \( \sim 300 \text{ K} \)) sluggish convection that results in substantial convective removal of mantle lithosphere (the "drippy" mode), and 2) small amplitude (\( \sim 100 \text{ K} \)) rapid convection which tends to leave the lithosphere largely intact (the "compact" mode). The occurrence of these two styles is regulated by the viscosity contrast between asthenosphere and lithosphere. The drippy mode occurs when the viscosity contrast is low (i.e. a soft mantle lithosphere), while the compact mode occurs when the viscosity contrast between lithosphere and asthenosphere is large (i.e. a stiff mantle lithosphere). Thus a drippy style of small-scale convection, producing silicic volcanism at the surface and resulting in substantial thinning of mantle lithosphere, is expected to accompany a "wet" mantle. A hot and "dry" mantle, on the other hand, would give rise to a compact mode of small-scale convection that will most likely produce effusive basaltic volcanism at the surface. A temporal transition from drippy mode small-scale convection associated with the mid-Tertiary ignimbrite flare-up and removal of the wet Farallon flat slab to a compact mode beginning at roughly mid-Miocene times appears to be a viable mechanism for unifying Cenozoic mantle and crustal dynamics in the Western U.S.

Small scale convection under the island arc?

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Recently Billen and colleagues (e.g. Billen et al. (2003)) extensively studied the subduction zones based on the dynamic modeling of subduction zones and proposed the existence of the low viscosity wedge (LVW), which may be produced by the water dehydrated from subducting slabs. Meanwhile, in northeast Japan, Tamura et al. (2002) found along-arc variations of distribution of volcanoes, low velocity anomalies and Bouger anomalies. They can be grouped 10 lineaments with a wavelength of \( \sim 80 \text{ km} \), which are perpendicular to the trend of trench. They called these "Hot Fingers", since those features are suggestive of high temperature in the upper mantle. The morphology akin to this has previously been expected for small-scale convection beneath moving oceanic plates. We might expect such a small-scale convection under the back-arc, if the wedge mantle viscosity is low enough. This small-scale convection may be a possible origin of Hot Fingers. We explore this possibility using both 2-D and 3-D modeling with/without pressure and temperature dependent viscosity of wedge mantle. 2-D models without pressure and temperature dependence of viscosity show that, with a reasonable geometry of the LVW and subduction speed, the small-scale convection is likely to occur, when the viscosity of the LVW is less than 1019 Pa sec. Corresponding 3-D model studies reveal that the wavelength of rolls depend on the depth of the LVW. An inclusion of temperature dependent viscosity requires an existence of further low viscosity in the LVW, since temperature dependence suppresses the instability of cold thermal boundary layer. A pressure (i.e. depth) dependence combined with a temperature dependence of the viscosity produces a low-viscosity zone, and, thus, it promotes short wavelength instabilities. The model, which shows a relatively moderate viscosity decrease in the LVW (most of the LVW viscosity is 1018 - 1019 Pa sec) and the wavelength of roll \( \sim 80 \text{ km} \), has a rather small activation energy and volume (\( \sim 130 \text{ kJ/mol} \) and \( \sim 4 \text{ cm}^3/\text{mol} \)) of the viscosity. This small activation energy and volume may be possible, if we regard them as an effective viscosity of non-linear rheology.

References:


Mantle melting during continental breakup

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