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Two types of asthenospheric layers and their evolution

Leszek Czechowski and Marek Grad
University of Warsaw, Institute of Geophysics, Faculty of Physics, Warsaw, Poland (lczech@op.pl)

Basic assumptions

The plate tectonics theory describes some basic global tectonic processes in terms of motion of lithospheric plates. The boundary between lithosphere and asthenosphere (LAB) is defined by a difference in response to stress. A few factors determine viscosity of the mantle. The generalized viscosity relation valid for both diffusion and dislocation creeps is:

$$\eta = C\left(\frac{\sigma}{G}\right)^{1-n} \exp\left(\frac{E_a + pV_a}{RT}\right),$$

where η is the viscosity [Pa s], σ is the differential stress [Pa] (in fact: an invariant of the stress tensor), E_a is the energy activation [J], p is the pressure [Pa], and V_a is the volume activation [m^3]. C (G, h, f_{H2O},f_{melts}) is the function of rigidity G [Pa], the grain size h [m], $f_{OH}$is the hydrogen and hydroxyl concentration,f_{melts} is the melt fraction.

The expression E_a+pV_a is proportional to the temperature of melting T_m. In a typical approach, the asthenosphere is believed to be determined by the ratio of $T_m$to the actual temperature T, i.e. by q. The $T_m$is a function of pressure p. Therefore, the basic differences of lithosphere and asthenosphere properties are often explained as a result of the $T - p$ conditions.

Note however that the above equation indicates that the effective viscosity depends also on other factors, e.g. chemical composition, size of grains, etc. In our consideration we choose to investigate the role of σ. Generally, viscosity is proportional to σ^{1-n}. For n=1 the viscosity does not depend on the stress. For true mantle:n is probably in the range from 3 to 5.

Observations

Using results from deep seismic sounding and surface wave tomography we have found that below some regions there are structures in the mantle that could be a forming/vanishing low viscosity layers. Reflectors in the lower lithosphere are observed beneath Trans-European suture zone between Precambrian and Palaeozoic platforms. In a thick Baltic shield lithosphere (200 km or more) low velocity zones and seismic reflectors are observed in the depth range 60-100 km, which could be interpreted as mechanical low Vp velocity zones, in contrast to thermal velocity zone in deeper asthenosphere.

Conclusions

1. In general, two kinds of asthenospheres could exist: mainly of mechanical origin (or shear stress origin) and mainly of thermal origin. In our calculations the role of shear stresses and thermal effects is of the same order.

2. The evolution of σ could be very fast, so the asthenosphere of shear stress origin could be a transient, time-dependent feature.

3. The evolution of the system of two asthenospheres leads usually to origin of a thick lithosphere with characteristic two low S-wave velocity layers. We suggest that at least some of the observed thick continental lithospheres are of this origin.

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