Grain Size Evolution, Rheology, and Criticality of Subducted Slabs

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Grain size may affect strongly the rheology of rocks under special conditions, when

(1) the type of rock microstructure is changing from a 'load-bearing framework' to an 'interconnected weak layer' structure (as described by Handy (1994)), where the 'weak layer' is a film of (ultra) fine grains of one mineral phase
(2) this microstructural change happens on a relatively short time scale
(3) the 'load-bearing framework' of the original rock microstructure exhibits a comparably large creep strength (high viscosity) due to low temperature

All three conditions are perfectly met at subduction zones with thick and cold plates of descending oceanic lithosphere. The low temperatures in the coldest cores (the 850 K isotherm may reach 400 km depth) result very likely in a kinetic inhibition of the otherwise fast transformation of olivine to spinel phase, and this metastable delay results finally in an anomalous slab viscosity structure near to the bottom of the transition zone. Karato et al. (2001) suggested that, because of this anomalous slab viscosity structure, slab viscosity may act effectively as a kind of 'rheological filter' for either layered or whole mantle convection between upper and lower mantle, controlled mainly by the subduction velocity (or the slab thermal parameter age$*$velocity, respectively).

Early support for this model came from geophysical observation: A sudden mechanical weakening of subducting slabs in the transition zone would be very likely accompanied by a cutoff of deep seismicity (Castle and Creager, 1998).
The authors argued, that the largest earthquakes, where the seismicity ceases, mark the location where all of the olivine in the metastable wedge has been consumed. The zone of weakness at the seismicity cutoff effectively isolates the deep slab, relieving it of its membrane strength and allowing it to fall nearly vertically into the lower mantle, whereas the upper part of the slab remains stagnant in the upper mantle/transition zone.

A more indirect support to the notion of a 'critical viscous state' of subducting slabs at the bottom of the transition zone comes from recent observations by Tibi et al. (2003): The authors showed that deep-focus earthquakes can dynamicly trigger further deep events at remote distances. Their detailed analysis of the 19 August 2002 Tonga deep earthquake sequences showed evidence for both static and dynamic triggering.
Furthermore, they propose that the triggered events are caused by transient effects in regions near criticality, where earthquakes have otherwise - without external influences - difficulty to nucleate.

In this paper, we analyze the observed remote triggering of deep-focus earthquakes on the basis of a visco-elastic block slider model for ductile instabilities in the subducting lithosphere. It shows, that the proposed triggering effect can be explained by a divergence of the correlation length of the stress transfer function near to 'criticality', i.e. near to an unstable visco-elastic state of the subducting slab.
At this state, nucleation of ductile instabilities of various kinds is prone to occur and can be triggered easily, e.g. by a passing by traveling seismic wave.

The existence of this critical state in the deformed subducting slab is mainly caused by large bending forces in the mantle transition zone and is largely promoted by the unusual slab viscosity structure resulting from a metastable olivine-spinel phase transformation (Karato et al., 2001).