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Viscous Dissipation and Criticality of Subducting Slabs

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Rheology of subducting lithosphere appears to be complicated. In the shallow part, deformation is largely accomodated by brittle failure, whereas at greater depth, at higher confining pressures, ductile creep is expected to control slab strength.

The amount of viscous dissipation ΔQ during subduction at greater depth, as constrained by experimental rock mechanics, can be estimated on the basis of a simple bending moment equation [1,2]

$$M(z) = \frac{2\dot{\epsilon}_0(z)}{h} \cdot \int_{-h/2}^{+h/2} 4\mu(y,z)\, y^2 dy \quad , \tag{1}$$

for a complex multi-phase rheology in the mantle transition zone, including the effects of a metastable phase transition as well as the pressure, temperature, grain-size and stress dependency of the relevant creep mechanisms; μ is here the effective viscosity and $\dot{\epsilon}_0(z)$ is a (reference) strain rate.

Numerical analysis shows that the maximum bending moment, M_{crit}, that can be sustained by a slab is of the order of 10^{19} Nm per m according to $M_{crit} \cong \sigma_p * h^2/4$, where σ_p is the Peierl's stress limit of slab materials and h is the slab thickness. Near M_{crit}, the amount of viscous dissipation grows strongly as a consequence of a lattice instability of mantle minerals (dislocation glide in olivine), suggesting that thermo-mechanical instabilities become prone to occur at places where a critical shear-heating rate is exceeded, see figure. This implies that the lithosphere behaves in such cases like a perfectly plastic solid [3].

Recently available detailed data related to deep seismicity [4,5] seems to provide support to our conclusion. It shows, e.g., that thermal shear instabilities, and not transformational faulting, is likely the dominating mechanism for deep-focus earthquakes at the bottom of the transition zone, in accordance with this suggested “deep criticality” model. These new findings are therefore briefly outlined and possible implications are discussed.

References

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