Plastic Instabilities as a Possible Physical Mechanism Causing Intermediate-Depth and Deep-Focus Earthquakes

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The physical mechanism causing deep-focus earthquakes is one of the outstanding problems of solid-Earth geophysics for almost 70 years. The recently formulated transformational faulting hypothesis assumes that the mechanism of failure for deep earthquakes is related to the formation of thin shear zones along planes of maximum shear stress in the cold interior of subducting slabs.
One problem of this theory, however, is that the predicted size (area) of the seismogenic fault zone is much smaller than the value derived from observation.
We suggest instead that the occurence of plastic instability in the deeper portion of a slab is the responsible mechanism for the generation of deep-focus earthquakes. We calculate the stability of the dominating mineral phases of the subducting lithosphere, olivine resp. spinel, against viscous deformation. On the basis of a moment balance equation including temperature-, grain-size- and stress-dependent creep mechanisms for all relevant mineral phases, we apply an instability criterion originally derived by Hobbs et al. (1986) to the stress-strain relationship for a bended, highly inhomogeneous plate. We find that, under certain conditions, the instability criterion can be met for nonlinear power-law creep (dislocation creep) of olivine resp. spinel (below 410 km discontinuity), so that the existence of metastable olivine in the deeper portion of a slab (below 500 km) is not a necessary condition for the generation of deep-focus earthquakes.
A similar mechanism, i.e. heat generation during viscous deformation providing a positive feedback to creep and eventually faulting under high pressures, could also be responsible for the occurence of intermediate-depth earthquakes within the mantle lithosphere, for which mechanisms involving dehydration or phase transformations do not apply.
Recent detailed receiver function images of the structure of the Japan subduction zone seem to provide support for this notion. First, there is no indication of an existing metastable olivine wedge. Second, the intermediate-depth seismicity seems to be located in the strong and colder portions of the downgoing slab, about 30 km below the oceanic Moho. This suggests that instead of dehydration or phase transformation triggered events, ductile faulting is its predominating cause.

References

B. E. Hobbs, A. Ord, and C. Teyssier, "Earthquakes in the Ductile Regime ?" Pageoph 124, 309-336 (1986)