Geophysical Research Abstracts
Vol. 16, EGU2014-7168, 2014
EGU General Assembly 2014

Deep focus earthquakes in the laboratory

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While the existence of deep earthquakes have been known since the 1920's, the essential mechanical process responsible for them is still poorly understood and remained one of the outstanding unsolved problems of geophysics and rock mechanics. Indeed, deep focus earthquake occur in an environment fundamentally different from that of shallow (<100 km) earthquakes. As pressure and temperature increase with depth however, intra-crystalline plasticity starts to dominate the deformation regime so that rocks yield by plastic flow rather than by brittle fracturing. Olivine phase transitions have provided an attractive alternative mechanism for deep focus earthquakes. Indeed, the Earth mantle transition zone (410-700km) is the locus of the two successive polymorphic transitions of olivine. Such scenario, however, runs into the conceptual barrier of initiating failure in a pressure (P) and temperature (T) regime where deviatoric stress relaxation is expected to be achieved through plastic flow.

Here, we performed laboratory deformation experiments on Germanium olivine (Mg_2GeO_4) under differential stress at high pressure (P=2-5GPa) and within a narrow temperature range (T=1000-1250K). We find that fractures nucleate at the onset of the olivine to spinel transition. These fractures propagate dynamically (i.e. at a non-negligible fraction of the shear wave velocity) so that intense acoustic emissions are generated. Similar to deep-focus earthquakes, these acoustic emissions arise from pure shear sources, and obey the Gutenberg-Richter law without following Omori's law. Microstructural observations prove that dynamic weakening likely involves superplasticity of the nanocrystalline spinel reaction product at seismic strain rates.

Although in our experiments the absolute stress value remains high compared to stresses expected within the cold core of subducted slabs, the observed stress drops are broadly consistent with those calculated for deep earthquakes. Constant differential stress conditions at failure over a wide range of confinement (2-5GPa) strongly suggest that transformational faulting is largely independent of normal stress and thus involves non-frictional processes. We suggest that rupture nucleation is controlled by dislocation density and spinel nucleation kinetics, while propagation is controlled by superplastic flow. High stress and high dislocation density conditions can be met in a cold subducting slab full of metastable olivine, due to stress concentrations at the micro and mesoscopic scales because of buckling, folding, and/or inherited fractures. This is particularly true in the Tonga-Kermadec region for instance, for which the largest catalog of deep focus earthquake is available.