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Intermediate-depth earthquakes: Role of geofluids and stresses

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Generation of intermediate-depth earthquakes is an ongoing enigma because high lithostatic pressures render ordinary dry frictional failure unlikely. Earthquakes in oceanic crust have been linked to the transformation of basalt to eclogite and concomitant dehydration (e.g., Kirby et al., 1996), and earthquakes in the oceanic mantle have been discussed in terms of dehydration of serpentine minerals (e.g., Yamasaki and Seno, 1996). Here we perform waveform analyses of two small seismic clusters in the crust and mantle of the downgoing oceanic lithosphere and show seismic evidence for fluid-related embrittlement for both crustal and mantle earthquakes. The observations presented in this study show the role of volume-change related stresses and fluid-related embrittlement as viable processes for nucleating earthquakes in downgoing oceanic lithosphere.

Eclogitization of the basaltic and gabbroic layer in the oceanic crust involves a volume reduction of 10%?15%. One consequence of the negative volume change is the formation of a paired stress field as a result of strain compatibility across the reaction front. Waveform analysis of an isolated seismic cluster reveals that tensional earthquakes lie 1 km above compressional earthquakes, and earthquakes with highly similar waveforms lie on well-defined planes with complementary rupture areas. The tensional stress is probably caused by the dimensional mismatch between crust transformed to eclogite and underlying untransformed crust, and the earthquakes are probably facilitated by reactivation of fossil faults extant in the subducting plate (Nakajima et al., Geology, 2013).

For mantle earthquakes, we focus on a seismic cluster that was activated in the Philippine Sea slab, 8 months after the megathrust Tohoku-oki earthquake (Mw9.0) on March 11, 2011. The seismic sequence started with an M 4.1 normal-fault event at the deepest part of the cluster, and subsequent earthquakes migrated upward along a conduit-like zone that dips northward. The tensional stress due to the co-seismic slip promoted the efficient upward migration of fluids from the underlying Pacific plate, producing overpressurized conditions at the tip of the fluid migration paths. The enhanced pore-fluid pressures and the resultant reduced effective normal stress weakened the strength of the faults sufficiently to bring the system into the brittle regime under the enhanced deviatoric stress. The gap of 8 months may represent the time needed for the increases in pore-fluid pressures to become sufficient to overcome the lithostatic pressure.

Keywords: Intraslab earthquakes, fluids, dehydration