Shear localization in peridotites and the occurrence of intermediate-depth earthquakes

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The subduction zone produces a major fraction of the Earth' s seismic activity. The mechanisms of intermediate-depth and deep-focus earthquakes are fundamentally different from those of shallow earthquakes. This is because the frictional strength (and also fracture strength) of rocks exceeds the upper limit of the stress level in the upper mantle (< 600 MPa: Obata and Karato, 1995) at depths greater than 30 km. The cause of intermediate-depth intraslab seismicity have been attributed to dehydration of antigorite (Peakock, 2001) and lawsonite (Okazaki and Hirth, 2016), because the location of the double seismic zone in a slab corresponds to the pressure-temperature conditions for breakdown of these hydrous minerals (Omori et al., 2002). However, dehydration embrittlement has been reported at a unrealistically high stress (> 1 GPa) and does not account for the origin of earthquakes in the hydrous-mineral absent regions, such as ~40 km depth below the palaeo-sea floor and the lower seismic plane (Reynard et al., 2010). The effect of hydrous mineral breakdown on failure is questionable because microcracking does not occur through the dehydration of antigorite (Gasc et al., 2011). Therefore, we focus on the hypothesis of intermediate-depth earthquakes triggered by localized heating (Kelemen and Hirth, 2007).
To investigate the origin of intraslab earthquakes at intermediate depths, we conducted uniaxial deformation experiments on dry dunite and wet harzburgite at pressures from 1.0–2.6 GPa and temperatures from 860–1350 K with a constant displacement rate using a deformation-DIA apparatus. The dry dunite and wet harzburgite correspond to the strongest and the weakest peridotites, respectively. Wet harzburgite is the final form of the dehydration product of antigorite and the main constituent of the double seismic zone. Pressure, stress, and strain were measured in situ by using x-ray diffraction patterns and radiographies. Acoustic emissions (AEs) were also recorded continuously on six sensors, and three-dimensional AE source location were determined.
We observed the proceeding of plastic deformation followed by faulting accompanied by significant increments of AEs at temperatures lower than 950 degC. Flow strength was higher than 1 GPa in dry dunite but that was significantly low (down to 0.3 GPa). A sudden stress drop (up to 2 GPa) associated with faulting was observed. The throughgoing faults associated ultrafine-grained (10 nm) gouge layers in dunite and harzburgite samples. In the regions away from faults, formation of subgrain boundaries and recrystallized grains are frequently observed, showing the dislocation-creep controlled flow. AEs were recorded during sampled deformation at strains higher than 1E-4 s^{-1} and at temperatures below 1000 degC. Strain weakening was commonly observed due to grain size reduction, and strain weakening caused strain localization. The b-value was around 1 at the primary phase and it decreased to < 1 just before a mainshock (at < 950 degC). The b-values were anomalously high (between 3 and 6) at 1000 degC, and any AE ceased at temperatures higher than 1100 degC. Our results suggests that the seismicity is strongly related with temperature in the subducting slabs.

Keywords: intermediate-depth earthquake, harzburgite, shear localization, faulting

