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The effect of fluids on the mechanical and seismic behavior of the 'ductile' lithospheric mantle

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Recent seismological studies have found along-strike variations in mantle mechanical behavior on oceanic transform faults (OTFs). At similar pressure and temperature conditions (~600-1100°C), plate motion on some sections of the fault is accommodated by aseismic slip only (ductile deformation), whereas motion on other sections is by slip and deep microearthquakes (semi-brittle deformation) of mantle rocks (McGuire et al., 2012). To explore the possible role of fluids for lateral variations in mantle mechanical behavior and the occurrence of deep mantle microseismicity, we carried out an integrated study on peridotite mylonites dredged from two OTFs on the Southwest Indian Ridge.
The samples show variable degrees of deformation, ranging from proto- to ultra-mylonitic textures. The most deformed zones of the mylonites are characterized by an increase in the proportion of fine grained (<10 micron) mylonitic shear bands compared to coarse grained (millimetre) porphyroclasts.
Shear bands are composed of polymineralic mixtures of olivine, pyroxene, spinel and high temperature amphibole (Mg-hornblende to pargasite). The textural characteristics of amphibole indicate that they crystallized during shear band development, while their high chlorine concentrations indicate seawater-peridotite interaction during mylonite formation. Olivine has a weak to random crystallographic preferred orientation, indicating deformation through a grain size sensitive creep mechanism. Some olivine grain boundaries are irregular, displaying triangular or pyramidal etch pits that are filled with nano- to micro-metric amphibole, pyroxene and spinel grains. This suggests that dissolution/precipitation occurred during deformation due to fluid percolation along grain boundaries.
Porphyroclasts from proto- to ultra-mylonites contain evidence for cycles of ductile and brittle deformation. The presence of subgrains, high aspect ratios, and internal misorientations crosscut by fractures imply that olivine and pyroxene were deforming through dislocation creep before brittle deformation. Fracture are then sealed by the fine-grained shear bands. This suggests that permeability enhancement and fluid pumping during brittle deformation were responsible for grain size reduction and phase mixing, leading to ductile weakening of the peridotite.
Empirical thermometers indicate that shear band creep and coarse grain fracturing occurred from 700°C to ~1000°C, beyond the 600°C peridotite long-term (i.e. at geological strain rates) brittle-ductile transition. We evidence that this fracturing of coarse grains was due to high stress accumulation generated during ductile flow of surrounding weak and hydrated mylonitic shear bands.
From these results we propose that the seismically observed lateral variations in mantle seismic behavior on OTFs originate from lateral variations in fluid-mantle interaction and mantle grain size. Mantle below rupture zones is more evolved, with >50% of weaker, hydrated mylonitic shear zones, while less evolved mantle (>50 % lenses of coarse grained peridotites) occurs below barrier zones that produce microearthquakes.