Rheology of the fluid oversaturated simulated quartz shear zone at the brittle-ductile transition

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At the plate boundary, large earthquakes as well as slow earthquakes are typically nucleated around the depth limit of the seismogenic zone. At hot subduction zones, below the seismogenic zone, slow earthquakes and high V_p/V_s ratios indicating the presence of aqueous fluid are commonly observed. Thus, it is important to understand how the water content and the pore structure affect the rheology of polycrystalline materials at these conditions.

We conducted deformation experiments on quartz aggregates using a Griggs-type deformation apparatus. Silica gel was used as the starting material; quartz samples synthesized from "as-is" silica gel contain a fluid-filled porosity of ~22%; we prepared samples with lower fluid-filled porosity by pre-drying the gel at 120 degC (~15% porosity), 450 degC (~16%), and 900 deg (~7%). The average grain size is about 12 um, the grain shape is equigranular, and no crystallographic preferred orientation (CPO) is observed.

The measured stress from general shear experiments on porous quartz aggregates at an equivalent strain rate of 1.5 x 10^{-4} 1/s, pressures of 1.1 and 1.5 GPa and temperatures of 800–900 deg is significantly lower than predicted by the wet quartzite flow laws (e.g., Tokle et al., 2019), and shear stress decreases with increasing porosity. The stress exponent n at 800–900 deg is 2.8–5.2, suggesting that the dislocation creep of quartz controls the overall rate-behavior in the quartz shear zone. The stress exponent at 500–700 deg is 4.7–19, indicating a transition to brittle fracture/friction and/or semi-brittle flow.

S-C' mylonitic structures characterized by the CPO and water segregation are observed in recovered samples deformed at 800–900 deg. A-axes of quartz align parallel to the P direction. We also found evidence for strain localization along R_1 riedel shears, structure that are characterized by high porosity. In contrast, deformation experiments on cores of quartzite show homogeneous dislocation creep at this pressure/temperature condition.

The low flow stress and R1 reidel shear zones suggest that a stress enhancement process promoted by the high volume fraction of water, similar to observations on partially molten samples (e.g., Hirth and Kohlstedt, 1995). At low temperature conditions, sample strength may decrease owing to the influence of the effective pressure law in frictional deformation, in which case the effective fluid pressure increases with increasing porosity. The strength of the water-saturated high-porosity quartz shear zones can be explained by the combination of quartz flow law (e.g., Tokle et al., 2019) and the frictional strength of quartzite (Hirth and Tullis, 1994) including the effect of porosity on both the effective pressure law in the brittle regime and plastic strengths (Cooper et al., 1989) and a BPT constitutive law (Shimamoto and Noda, 2014). Our mechanical data is well explained by the combination of those theoretical and empirical equations.

Our result suggests that a few % of porosity causes drastic weakening in the quartz shear zone from a brittle to fully plastic regime. These rheology of fluid oversaturated shear zones could explain the weakness and the spectrum of slip behavior along the plate boundary.

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