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Fluid pumping induced by strain localization during high-pressure experiment

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Strain localization commonly affects naturally deformed rocks of the crust and mantle. In the ductile regime, this gives rise to shear zones where the deformation of fine-grained phases involves creep cavitation to occur with possible fluid pumping (Ref. 1). As recently highlighted in mantle shear zones (Ref. 2), this latter process may have strong implications for ores deposits, partial melting or rock rheology. However, as creep cavitation potentially involves some dilatancy, it remains challenging for this mechanism to be relevant at high pressure, typically when differential stresses are far below the lithostatic pressure, i.e. below the Goetze criterion. Based on ion probe analyzes, we here document the water content of a fine-grained (1-2 μm) olivine matrix deformed experimentally in presence of water added (1300 ppm) and coarse-grained (> 100 μm) diopside (30 %). The experiments were carried out at a pressure of 1.2 GPa, a temperature of 900 °C, and the differential stress never exceeded 0.9 GPa. The development of a narrow shear zone (50 μm thick) also gave rise to pronounced sample-scale strain localization. The olivine matrix has been then probed post-mortem across the resulting strain gradient, each spot (10*10*4 μm) including several grain boundaries. Through data interpolation, our ion probe dataset reveals high water concentration – higher than initially added (> 2000 ppm) – where strain has been localized. Furthermore, using high-resolution EBSD maps to precisely measure the olivine grain size, we show that water content does not follow the trend of the expected porosity related to grain size reduction. Instead, we document a deficit of water in the low-strain region and an excess of water in the high-strain zone. Together with TEM observations of some micro-cracks in the shear zone, these features indicate the presence of strain-induced cavities where water has been pumped and trapped as fluid inclusions. Our findings therefore provide evidence of experimental creep cavitation at high pressure and below the Goetze criterion, suggesting that related fluid pumping may persist at great depths despite increasing pressure.

Ref. 1: Fusseis, F., Regenauer-Lieb, K., Liu, J., Hough, R. M., and De Carlo, F. (2009) Creep cavitation can establish a dynamic granular fluid pump in ductile shear zones. Nature 459: 974-977
Ref. 2: Précigout, J., Prigent, C., Palasse, L., and Pochon A. (2017) Water pumping in mantle shear zones. Nature communications 8: 15736