The effect of water, temperature and strain rate on the dislocation creep microstructure, recrystallized grain size and flow stress of quartz

Vortrag

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Since the work of Griggs & Blacic (1965) it is well known that the crystal plastic flow strength of 'wet' quartz samples is much lower than that of 'dry' samples deformed at the same conditions, and the general effect of water on dislocation creep microstructures has been documented (e.g. Hirth & Tullis 1992), but its effect on the recrystallized grain size has not been quantified. The recrystallized grain size is the most reliable and most easily measurable microstructural feature to derive flow stresses from natural mylonites (e.g. White 1979, Kohlstedt et al. 1980). In a recent experimental study, a well-constrained recrystallized grain size piezometer for quartz (Stipp & Tullis 2003) was calibrated using natural as-is quartzites; the use of a molten salt cell at high confining pressure (1.5 GPa) in a Griggs-type apparatus allowed good stress resolution (Green & Borch 1989). There has been some debate as to whether there is any independent effect of water on the recrystallized grain size piezometer. Two laboratory studies on olivine aggregates (at different pressures) report contradictory results; van der Wal et al. (1993) found that the recrystallized grain size piezometer is independent of the water content, whereas Jung & Karato (2001) observed a water-dependence of the piezometer.

In this study, we have investigated changes in the recrystallized grain size and other deformation microstructures of quartz within dislocation creep regimes 2 and 3 of Hirth & Tullis (1992). Deformation experiments on Black Hills quartzite with three different initial water contents (as-is, water-added and vacuum-dried) were carried out in order to evaluate the effect of water on the recrystallized grain size / flow stress piezometer. Samples were deformed in axial compression at temperatures of 750° to 1100°C, strain rates between $2 \times 10^{-7}\,\mathrm{s}^{-1}$ and $2 \times 10^{-4}\,\mathrm{s}^{-1}$ and strains up to 46% using a molten salt assembly in a Griggs apparatus. An increase of the initial water content at otherwise constant deformation conditions caused a decrease in flow stress, an effect known as hydrolytic weakening. The total water content of the starting material was analyzed by Karl Fischer Titration (KFT) and Fourier Transform Infrared (IR) spectroscopy, and quenched samples were analyzed microstructurally and by IR. Changes in the dynamic recrystallization microstructure correlate with changes in flow stress, but there is no independent effect of temperature, strain rate or water content. IR absorption spectra of the deformed samples indicate that different water contents were maintained in the three sample sets throughout the experiments. For quantitative determination of the water content in the deformed samples a new IR calibration was developed, based on KFT analysis of the starting material.

A comparison with previously used

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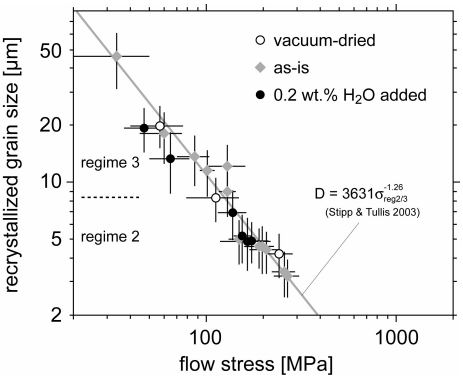

Figure 1: Recrystallized grain size/flow stress data from the water-added, as-is and vacuum-dried samples plotted together with the least squares fit calibration of the recrystallized grain size piezometer of dislocation creep regimes 2 and 3 (Stipp & Tullis 2003, equation is indicated).

IR calibrations (e.g. Paterson 1982) demonstrates that the latter systematically underestimate the water content of Black Hills quartzite. Only relative differences in water content within a sample set are reliable when solely using these previous IR calibrations. However, relative differences within the sample set indicate that the amounts of water measured within the vacuum-dried ($\sim$260$\pm$40 ppm H_2O), the as-is ($\sim$340$\pm$50 ppm H_2O) and the water-added ($\sim$430$\pm$110 ppm H_2O) samples are significantly smaller than the initial content of the quartzite ($\sim$640$\pm$50 ppm H_2O, each with our IR calibration). We assume that this initially puzzling result was caused by a redistribution of the water content during experimental deformation and/or during IR sample preparation. Decrepitation of aqueous fluid inclusions and transport of the water via microcracking or dislocation pipe diffusion are presumed to produce an increase of the free fluid phase along the grain boundaries, which probably controls water fugacity and flow stress during the experiments. The differences in water content before and after the experiments can largely be explained by loss of water during IR sample preparation. Initial differences in water content between the three sample sets were maintained during experimental deformation. A comparison of the three sample sets shows that vacuum-dried as well as water-added samples have the same recrystallized grain size/flow stress relationship as the piezometer determined for as-is samples by Stipp & Tullis (2003). Hence, no independent effect of water on the piezometric relationship has been detected (Fig. 1; Stipp et al., in press), and paleostress estimates on natural mylonites need not consider differences in water content when applying the recrystallized grain size piezometer of quartz.

References

Green HW II & Borch RS (1989) A new molten-salt cell for precision stress measurement at high pressure. Eur. J. Mineral. 1, 213–219

Griggs DT & Blacic JD (1965) Quartz: Anomalous weakness of synthetic crystals. Science 147, 292–295

Hirth G & Tullis J (1992) Dislocation creep regimes in quartz aggregates. J. Struct. Geol. 14, 145–159

Jung H & Karato S-I (2001) Effects of water on dynamically recrystallized grain-size of olivine. J. Struct. Geol. 23, 1337–1344

Kohlstedt DL & Weathers MS (1980) Deformation induced microstructures, paleopiezometers and differential stresses in deeply eroded fault zones. J. Geophys. Res. 85, 6269–6285

Paterson MS (1982) The determination of hydroxyl by infrared-absorption in quartz, silicate-glasses and similar materials. Bull. Mineral. 105, 20–29

Stipp M & Tullis J (2003) The recrystallized grain size piezometer for quartz. Geophys. Res. Lett. 30(21), 2088, doi:10.1029/2003GL018444

Stipp M, Tullis J & Behrens H (in press) The effect of water on the dislocation creep microstructure and flow stress of quartz, and implications for the recrystallized grain size piezometer. J. Geophys. Res.

van der Wal D, Chopra P, Drury M & Fitz Gerald J (1993) Relationship between dynamically recrystallized grain size and deformation conditions in experimentally deformed olivine rocks. Geophys. Res. Lett. 20, 1479–1482

White S (1979) Grain and sub-grain size variations across a mylonite zone. Contrib. Mineral. Petrol. 70, 193–202