

Rheology of quartz at high-temperature: an example from Rundvagshetta, Antarctica

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Quartz is one of the most common minerals in the continental crust and has a relatively low yield strength. The rheological behaviour of this mineral therefore has an important influence on the mechanical behaviour of the crust as a whole. High-temperature crystal plastic deformation is dominantly achieved by dislocation creep and diffusion creep. Dislocation creep is due to the movement and climb of line dislocations within crystals and shows power law stress-strain relationship with the stress exponent usually between 3 and 6. This represents non-Newtonian behaviour where the apparent viscosity depends on the differential stress: high stress domains have a low apparent viscosity. In contrast, diffusion creep is caused by the movement of point defects including vacancies and interstitial atoms and is characterized by a linear relationship between stress and strain representing a Newtonian rheology. The strain rate and temperature also affect the dominant deformation mechanism. To assess the bulk rheology to be used in tectonic studies it is important to assess the affects of these different parameters and to decide the dominant deformation mechanism. Laboratory experiments on quartz shows that that diffusion creep is dominant at relatively high T and small grain sizes (>900K, <1micro m). Plastic deformation at lower T and for larger grain sizes is expected to take place by dislocation creep. However, natural examples of diffusion creep taking place at temperatures of around <500°C in quartz-rich metacherts with a grain size of about 10-20micro m have recently been reported. Such examples suggest that diffusion creep may occur more commonly in natural examples than generally thought. To investigate this possibility, it is important to examine natural examples of deformation at higher temperatures. Two quartz-rich deformed samples collected from the ultra high temperature metamorphic region of Rundvagshetta (RH-112-20A, RH-112-20B) were studied to examine evidence for the dominant deformation mechanism. Both samples show a strong foliation and stretching lineation that are assumed to reflect the X-Y plane and X directions of the finite strain (X>Y>Z).

RH-112-20A has a grain size of 2.9+/-1.2mm, and a strong quartz c-axis preferred orientation with concentrations in three separate directions. The presence of a strong CPO is strong evidence for deformation by dislocation creep. The orientations of the c-axis concentrations are similar to those reported in other high temperature tectonites. RH-112-20B has a grain size of 0.93+/-0.03mm and the c-axes show no clear preferred orientation. The lack of a CPO is not compatible with dislocation creep, but can be readily explained if the deformation is by diffusion creep. Measurements of the Ti content of quartz can be used as an indication of the P-T conditions of deformation. A combination of these results with microstructural observations and the P-T path of this area allows the temperature of deformation to be estimated at around 600~700°C, 4~6kbar. The two samples come from the same outcrop and hence have undergone very similar physical conditions of deformation. However, they show contrasting deformation mechanisms. This can be used to investigate the applicability of published rheological models for quartz. A construction of deformation maps using flow laws derived from mainly from experimental work and those derived mainly from theoretical considerations shows that the results of this study are not compatible with extrapolation of experimental work. In theoretically focused flow laws can explain the observed change of dominant deformation mechanism at strain rates of around 10^{-15} s^{-1} .

This study implies deformation in the Rundvagshetta region was as geologically normal strain rates despite the very high temperatures. This study also implies that diffusion creep may be more widespread than generally thought by extrapolation of deformation experimental work.

Keywords: Quartz, Deformation mechanism, Crystal Preferred Orientation, Diffusion creep, Dislocation creep