# Brittle-to-viscous behaviour of quartz gouge in shear experiments

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In order to study the microstructure development across the brittle-viscous transition and to derive the corresponding flow laws, we performed shear experiments on quartz gouge in a Griggs-type deformation apparatus. The starting material is a crushed quartz single crystal (sieved grain size $<100$ $\mu$m) with 0.2 wt% water added. The experiments were conducted at temperatures between 500 ˚C and 1000 ˚C at confining pressures of 0.5 GPa, 1.0 GPa or 1.5 GPa. Four strain-rate-stepping experiments were conducted at strain rates between $\sim$2.5 x $10^{-6}$ s$^{-1}$ and $\sim$2.5 x $10^{-4}$ s$^{-1}$. Other experiments were conducted at constant strain rates of $\sim$2.5 x $10^{-6}$ s$^{-1}$, $\sim$2.5 x $10^{-5}$ s$^{-1}$, $\sim$2.5 x $10^{-4}$ s$^{-1}$ and $\sim$2.5 x $10^{-3}$ s$^{-1}$.

At high confining pressure, the strength of the samples decreases with increasing temperature for all strain rates. The largest decrease occurred between 650 ˚C and 700 ˚C at shear strain rates of $\sim$2.5 x $10^{-5}$ s$^{-1}$. At the same time, the pressure dependence of strength is positive for T $\leq$ 650 ˚C while an inverse pressure dependence is observed at T $>$ 650 ˚C. For T $<$ 700 ˚C, the friction coefficient decreases slightly with increasing temperature, from 700-1000 ˚C it shows a strong temperature dependence.

Between 650 ˚C and 700 ˚C at shear strain rates of $\sim$2.5 x $10^{-5}$ s$^{-1}$ a change in the deformation process occurs from one dominated by cataclastic flow to one dominated by crystal plasticity. The microstructure reveals a less abrupt transition in terms of operating processes, because brittle and viscous processes are equally active around 650 ˚C. With increasing temperature the volume fraction of recrystallised grains increases, and at 900 ˚C - 1000 ˚C recrystallisation is nearly complete at strains of $\gamma \sim 3$. The crystallographic preferred orientation of the c-axis evolves from a random distribution at low temperatures towards two peripheral maxima at intermediate temperatures. At high temperatures the c-axis show a single Y-maximum.

At high temperature, the stress exponent is n = 2.1 $\pm$ 0.2. The activation energy Q is 193 $\pm$ 12 kJ/mol at strain rates of $10^{-5}$ s$^{-1}$, at faster strain rates the activation energy drops down to Q = 119 $\pm$ 12 kJ/mol. This small stress exponent at high temperatures indicates a combination of deformation processes (diffusion in very fine grained material and dislocation creep in coarser grained material). At lower temperatures the n-value is significantly higher (n $\sim$ 8) indicating the beginning of the power-law-breakdown.

Interestingly, the mechanical data indicate a sharp transition between brittle- and viscous-dominated regimes around 650 ˚C to 700 ˚C, while the microstructure reveals a smoother transition over a wider temperature range. The relatively low stress exponent of n $\sim$ 2 clearly suggests the activation of diffusion creep deformation processes.