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## Brevia

## SHORT NOTE

## The effect of crystallographic orientation on pressure solution in quartzite

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By measuring the degree of flattening and the orientation of the c-axis of single quartz grains in a naturally deformed ("cleaved") sandstone, Becker (1995) showed that: "quartz grains with a small angle between c-axis and the Z-axis of shortening exhibit the least amount of pressure solution, whereas grains with c-axes oriented at about 50° to Z manifest the highest degree of pressure solution". I briefly present some experimental results that show exactly the same.

I have experimentally deformed a series of natural quartzites (grain size ~ 150 µm) in the presence of small amounts of added water (up to 1 vol%) at a temperature of 800°C and pressure of ~ 1200 MPa, at constant strain rates ( $\dot{\epsilon}$ ) in the range  $10^{-5}$  to  $10^{-7}$  s<sup>-1</sup> (see Den Brok & Spiers 1991, Den Brok 1992, and Den Brok *et al.* 1994). The aim of the experiments was to study the origin of the mechanical weakening effect of the added water. At  $\dot{\epsilon} = 10^{-6}$  and  $10^{-7}$  s<sup>-1</sup> the quartzite showed behaviour consistent with a power law with a stress exponent  $n \leq 1.3$ , suggesting diffusional creep. Detailed examination showed that the corresponding optical microstructure was characterised by axially oriented intra- and inter-granular microcracks, plus similar arrays of small, new, subehedral quartz grains. These arrays incorporated abundant micro-scale voids and channel structures, and were inferred to be axially oriented microcracks filled with small new grains grown out of solution. Grain boundaries parallel to the shortening direction (Z) often showed sub-ehedral overgrowth features, conspicuously absent on grain boundaries perpendicular to Z. The surface of a single crystal space added in line with the quartzite sample in one experiment showed numerous grain-scale indentation pits, indicative of pressure solution. From the mechanical data and microstructures it was concluded that pressure solution plus micro-cracking were responsible for most of the deformation at  $\dot{\epsilon} = 10^{-6}$  and  $10^{-7}$  s<sup>-1</sup>.

Two samples were axially deformed up to relatively large amounts of bulk finite strain: sample GRU29 was

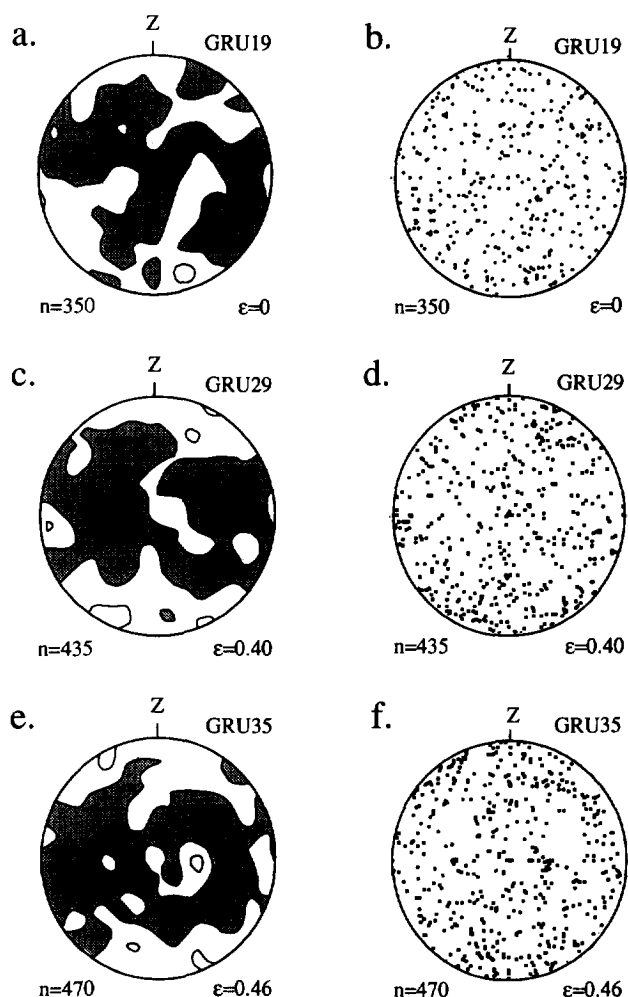


Fig. 1. Reproduced after Den Brok (1992), fig. 4.1. (a) & (b) Crystallographic preferred orientation (CPO) of quartz c-axes of undeformed sample GRU 19 hydrostatically loaded to a temperature (T) of 800°C and a confining pressure (P) of ~ 1200 MPa. (c) & (d) CPO of quartz c-axes of sample GRU29 deformed to ~40% strain with 1 vol% added water at T = 800°C, P = 1200 MPa, and a strain rate ( $\dot{\epsilon}$ ) of  $10^{-6}$  s<sup>-1</sup>. (e) & (f) CPO of quartz c-axes of sample GRU35 deformed to ~46% strain with ~ 1 vol% added water at T = 800°C, P = 1200 MPa, and  $\dot{\epsilon} = 10^{-7}$  s<sup>-1</sup>. Contours in equal area plots are 1 and 2 times uniform. Shortening direction Z is indicated.

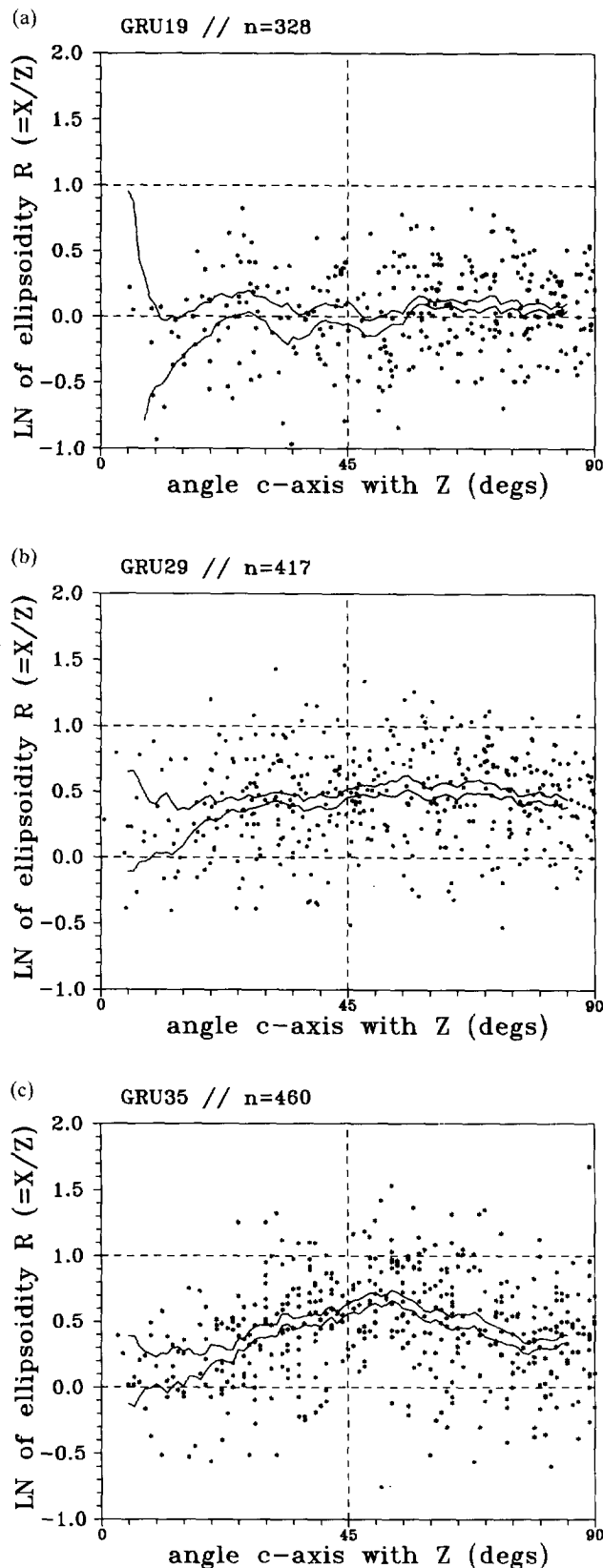


Fig. 2. Slightly modified after Den Brok (1992), fig. 3.15. Natural logarithm of ellipsoidity ( $R = X/Z$ ) versus angle of c-axis with shortening direction Z for (a) undeformed sample GRU19 which was hydrostatically loaded only, (b) sample GRU29, and (c) sample GRU35. Each point refers to one grain. The average ellipsoidity  $\bar{R}$  plots between the two lines through all the points; the upper line is  $\bar{R}$  plus its standard error; the lower line is  $\bar{R}$  minus its standard error. Note that  $\bar{R}$  was determined for  $10^\circ$  intervals of the angle of the c-axis with Z, and that this was done for all integer values in the range 5 to  $85^\circ$ .

deformed at  $\dot{\epsilon} = 10^{-6} \text{ s}^{-1}$  to  $\sim 40\%$  bulk axial strain, and sample GRU35 was deformed at  $\dot{\epsilon} = 10^{-7} \text{ s}^{-1}$  to  $\sim 46\%$  bulk axial strain. These two samples showed only very weak crystallographic preferred orientations of the quartz c-axes, not much more than undeformed samples (Fig. 1). Just as Becker (1995) did, I also determined the dependence of grain flattening on the crystallographic orientation of the grains (Fig. 2). The results are strikingly similar. Grains with c-axes that are oriented at about  $50^\circ$  to Z are most flattened, grains with c-axes at small angles to Z are the least flattened, and grains with c-axes that are oriented nearly perpendicular to Z are intermediately flattened (compare Fig. 2 with fig. 7 of Becker 1995). It should be noticed that this anisotropy in dissolution behaviour seems not to be affected by the fact that the cleaved sandstone that was studied by Becker (1995) (i) was deformed under P-T- $\dot{\epsilon}$  conditions (greenschist facies) very different from those in the experiments, (ii) contained considerably more fine-grained phyllosilicates, and (iii) showed a linear fabric, rather than a planar one such as in my experiments.

Interestingly, the observed anisotropy in dissolution behaviour closely corresponds to the anisotropy in compliance to fracture in quartz (see e.g. Bloss 1957). Fractures in quartz are most easily formed parallel to the rhombic r- and z-planes (i.e. at  $50^\circ$  to the c-axis), they are next easily formed parallel to the c-axis (i.e. parallel to the prism planes), and least easily formed perpendicular to the c-axis (i.e. parallel to the basal plane). This anisotropy is most readily explained as due to anisotropy in interfacial (grain boundary) energy. The higher the interfacial energy, the higher the resistance to fracture parallel to it. The observed anisotropy in dissolution behaviour therefore suggests that (differences in) interfacial energy might play a significant role during pressure solution too. It is to be noted that this is at variance with most of the published pressure solution models (see e.g. Rutter 1976, Lehner 1995) that predict no dependence of the pressure solution rate on crystallographic orientation and/or interfacial energy.

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