Microstructural evidence of impact-induced crystal-plastic deformation and post-shock annealing of quartz

Vortrag

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Introduction

During impact, rocks at the surface and accessible depths encounter extreme conditions. The hydrostatic component of the shock wave-associated stress, the so-called shock pressure, can reach several tens of GPa in the central part of the structure. The shock pressure can cause the transformation of target minerals into their high pressure modifications or amorphous phases. The role of the deviatoric component of the shock wave-associated stress during shock-metamorphism is only poorly understood. Shock effects in quartz are particularly useful for providing information on the conditions during deformation, given the widespread occurrence of this mineral in the Earth's crust and its comprehensive experimental calibration. Two distinct types of quartz microstructure in charnockitic target rocks and quartz veins of the Charlevoix impact structure are compared and contrasted in order to distinguish shock-induced microstructures that indicate a high hydrostatic stress component of the shock wave-associated stress from those that indicate a high deviatoric component, as well as associated microstructures that were generated during post-shock relaxation.

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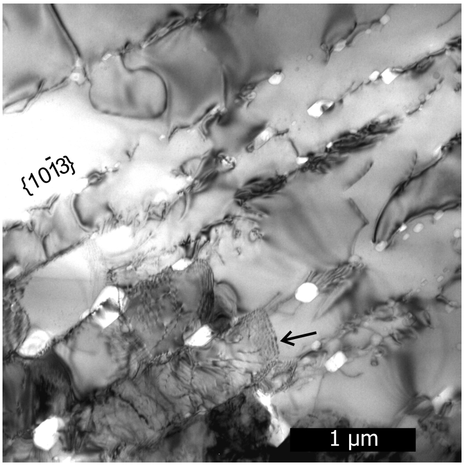

Figure 1: Bright field TEM micrograph showing rhombohedral PDFs that comprise dislocations and fluid inclusions.

Type 1 microstructure

The dominant shock effects in the type 1 microstructure in charnockites at ca. 2–4 km from the centre of the structure are planar deformation features (PDFs) parallel to rhombohedral planes of quartz. The rhombohedral PDFs comprise a high density of dislocations and fluid inclusions, as revealed by transmission electron microscopy (TEM) (Fig. 1). They have been interpreted as the result of water-assisted, post-shock crystallisation of the amorphous phase along rhombohedral planes, initially generated during shock compression (e.g. Goltrant et al. 1992, Leroux et al. 1994, Leroux & Doukhan 1996). The abundance of different sets of these PDFs indicates a high hydrostatic component of the shock wave-associated stress (ca. 10–15 GPa). Evidence of crystal-plastic de-

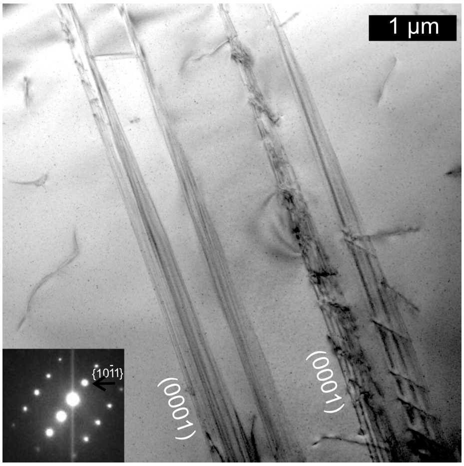

Figure 2: Bright field TEM micrographs showing inclined Brazil twin boundaries in (0001) representing basal PDFs. Note partial dislocations within the boundaries.

formation due to high deviatoric stresses is absent. Post-shock recovery is indicated by the actual microstructure of rhombohedral PDFs, dislocations in climb configuration and well-ordered low angle grain boundaries.

Type 2 microstructure

In contrast, PDFs parallel to the basal plane are predominant in the type 2 microstructure developed in rocks at ca. 4–9 km from the centre of the structure, whereas rhombohedral PDFs are rare. This indicates a lower hydrostatic stress component (ca. 7–8 GPa) compared to the type 1 microstructure, which correlates with a radial decrease in recorded peak shock pressure. The basal PDFs are revealed by TEM to represent mechanical Brazil twins (Fig. 2), which give evidence for crystal-plastic deformation at high deviatoric stresses. In the type 2 microstructure, numerous deformation bands, strong undulose extinction and cataclastic zones at the optical scale, as well as glide-dislocations and microcracks at the TEM scale, occur in association with basal PDFs, and are therefore also interpreted to be shock-induced. Post-shock recovery is indicated by the occurrence of small elongate subgrains with low angle grain boundaries paralleling low-index planes.

Conclusions

Although mechanical Brazil twins in the basal plane are common in naturally-shocked quartz (e.g. Goltrant et al. 1991, Leroux et al. 1994), shock-induced crystal-plastic deformation of quartz is generally considered to be ineffective due to the high rates of loading during shock (e.g. Langenhorst 1994). However, the type 2 microstructure records highly heterogeneous and localised glide-controlled deformation accompanied by twinning and microcracking. Glide-controlled deformation of quartz is characteristic of high stress and strain rate conditions, e.g. during co-seismic loading (Trepmann & Stöckhert 2003). Therefore, this crystal-plastic deformation is interpreted to be due to high deviatoric stresses and high loading rates during shock.

The dominant occurrence of rhombohedral PDFs in the type 1 microstructure, in contrast to their rare occurrence in the type 2 microstructure in combination with the abundance of mechanical Brazil twins, indicates that the deviatoric component of the shock wave-associated stress increases relative to the hydrostatic component with increasing distance from the centre of the impact structure. This relationship has also been reported from other impact structures (Leroux et al. 1994; Leroux & Doukhan 1996).

Post-shock recovery is indicated in the type 1 microstructure by the actual microstructure of rhombohedral PDFs, dislocations in climb configuration and well-ordered low angle grain boundaries, as well as in the type 2 microstructure by the occurrence of small elongate subgrains with low angle grain boundaries paralleling low-index planes. This has probably taken place during annealing shortly after the impact event at quasi-static conditions and still sufficiently high post-shock temperatures, rather than during a separate regional thermal event.

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