POST-SHOCK CRYSTAL-PLASTIC PROCESSES IN QUARTZ FROM CRYSTALLINE TARGET ROCKS OF THE CHARLEVOIX IMPACT STRUCTURE.

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Introduction: The extraordinary stress and temperature conditions, that prevail in target rocks during and after hypervelocity impact, change abruptly, causing complex and dynamic effects. The activated deformation mechanisms can result in specific microstructures, which may provide crucial information on the rheological behaviour of the rocks. The microfabric of shocked quartz from crystalline target rocks of the Charlevoix impact structure has been investigated by optical microscopy, scanning electron microscopy, combined with electron backscatter (EBSD) techniques, cathodoluminescence (CL) microscopy and transmission electron microscopy (TEM).

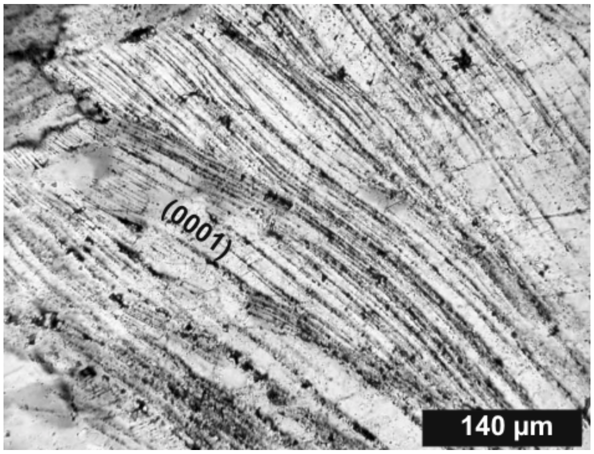

Fig. 1 Optical micrograph (cross-polarised light) showing bent PDFs parallel to the basal plane.

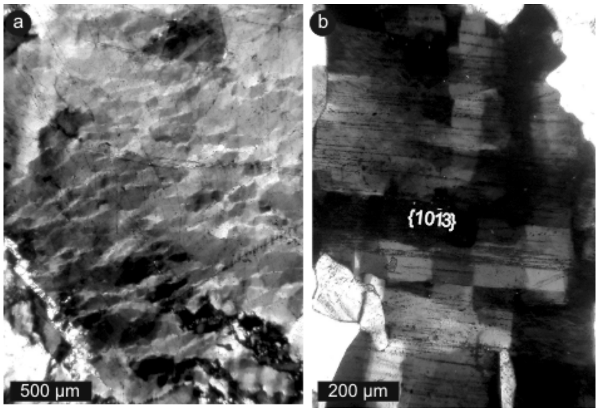

Fig. 2. Optical micrographs (cross-polarised light). (a) Irregular subgrains show undulose extinction. (b) Well-defined blocky subgrains reveal boundaries parallel to PDFs.

Microfabric: In charnockitic gneisses devoid of shock features from the outer part of the Charlevoix impact structure, quartz shows hardly any undulose extinction and only very few subgrains. In contrast, shocked quartz in charnockitic gneisses from the central uplift shows conspicuous undulose extinction, subgrain and grain structure. The undulose extinction can be very fine-scaled, with a mottled appearance. Bent planar deformation features (PDFs) can reflect the continuous bending of the crystal lattice (Fig. 1).

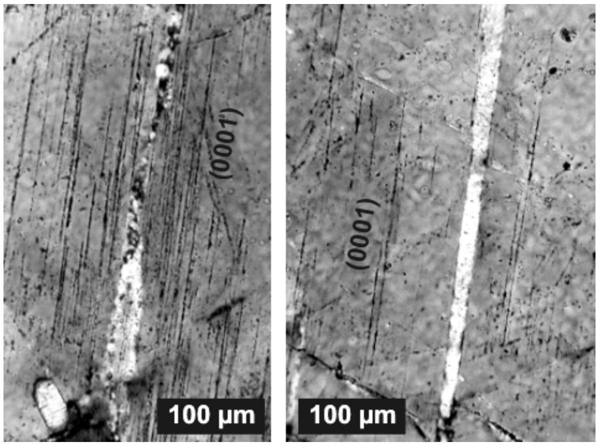

Fig. 3. Optical micrographs (cross-polarised light) showing bands of new recrystallised grains parallel to basal PDFS.

Undulose extinction can grade into irregular domains with a small crystallographic mismatch, forming subgrains (Fig. 2a). Well-defined subgrains exhibiting a blocky shape are also common (Fig. 2b). The subgrain boundaries can be aligned parallel to PDFs (Fig. 2b). Recrystallisation bands can occur parallel to basal PDFs (Fig.3).

A conspicuous mosaic structure (Fig. 4) in quartz is characterised by straight, but highly sutured, grain boundaries in two directions at a high angle to each other. The orientation of these grain boundaries appears to be crystallographically controlled, and preferentially parallel to $\{10\bar{1}1\}$ rhombohedra, as shown by EBSD measurements. Blocky new grains of similar size as the sutures can occur along high angle boundaries. These features indicate grain boundary migration. CL-investigation and microstructural observations suggest that the grain boundary migration took place after the development of PDFs.

PDFs in quartz from the Charlevoix target rocks are mostly crystallised [1] and are now represented by dislocation bands, as observed in the TEM (Fig. 5). The high dislocation density in these can result in a crystallographic mismatch between the domains on both sites of the dislocation band, which therefore has the character of a subgrain boundary (Fig. 6). Dislocations that cross-slipped out of the bands and numerous dislocation loops (Fig. 6) indicate recovery.

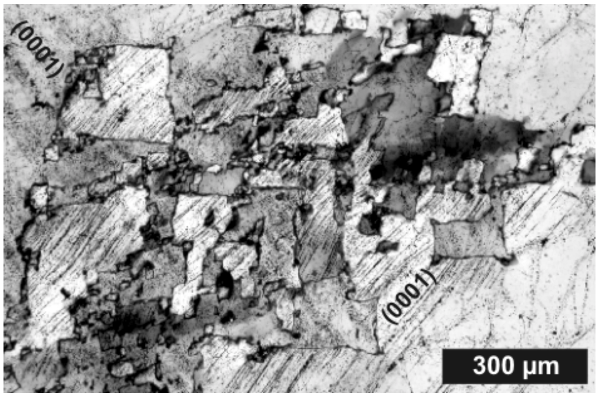

Fig. 4. Optical micrograph (cross-polarised light) showing blocky and highly sutured grain boundaries.

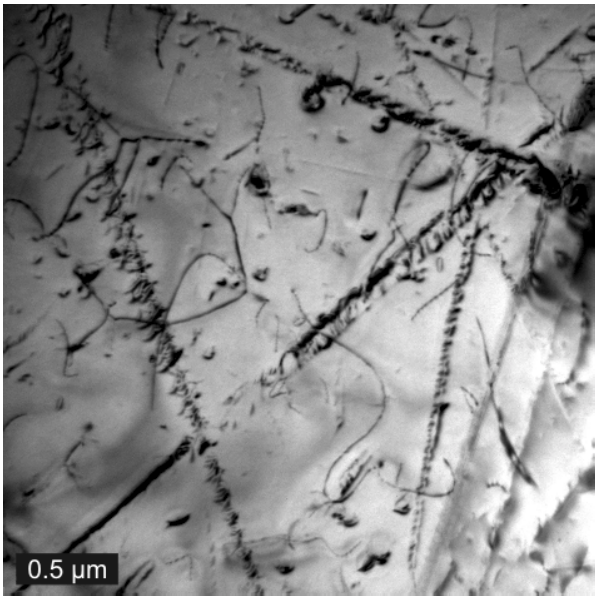

Fig. 5. TEM bright field image showing multiple sets of intersecting narrow dislocation bands, representing PDFs.

Discussion: The strong undulose extinction of shocked quartz and the high dislocation density accumulated along PDFs [1] indicate inhomogeneous crystal-plastic deformation under an external differential stress, where PDFs probably have acted as dislocation sources. The accumulation of dislocations in broad bands resulted in the formation of subgrains. Dislocation loops, cross slip of dislocations, subgrains, highly sutured grain boundaries and new grains indicate recovery and recrystallisation, eventually under quasi-static conditions at temperatures of at least 300°C. The microstructural observations indicate that these crystal-plastic processes occurred after the development of the PDFs, and are thus not due to a tectonic event before the impact. Evidence for a post-impact regional thermal overprinting in the Charlevoix area is lacking. Biotite K/Ar ages of ~ 900 Ma from gneisses in the outer western part of the impact structure [2] indicate that the rocks of the Charlevoix area, that have not been affected by shock metamorphism, have remained below the closure temperature of biotite (~ 300°C) since that time. Therefore, these crystal-plastic processes are proposed to be impact-related. This is consistent with the lack of similar microstructures in quartz of charnockitic gneisses outside, or at the outer part, of the impact structure. As in shock experiments on quartz, an increased dislocation density has not been observed [*e.g.*, 3], so crystal-plastic deformation has most likely taken place after shock-wave passage. The required differential stress, confining pressure and temperature conditions might have been realised during the formation of the central uplift, where rocks have been elevated from ~6 km depths [4]. However, crystal-plastic deformation may also be possible during later isostatic readjustment processes. Recovery and recrystallisation under static conditions might have taken place as long as the rocks were not cooled below ~300°C, provided the driving force to minimize the dislocation density was sufficiently high.

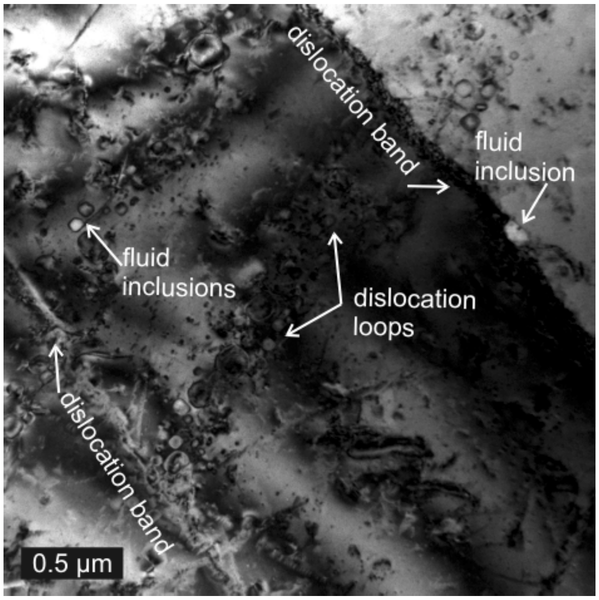

Fig. 6. TEM bright field image showing parallel broad dislocation bands, which probably represent former PDFs, now acting as low angle grain boundaries. Note common tiny dislocation loops and fluid inclusions.

References: [1] Goltrant O., Leroux H., Doukhan J.C., and Cordier P. (1992) Earth and Planetary Interiors, 74, 219-240. [2] Wanless R.K., and London J.A. (1961) Geological Survey of Canada, 61-17, 127. [3] Langenhorst F. (1994) EPSL, 128, 683-698. [4] Roy D.W. (1979) Ph.D. thesis, Princeton, Princeton University, 190p.