Ber. Inst. Erdwiss. K.-F.-Univ. Graz	ISSN 1608-8166	Band 9	Graz 2004

EVIDENCE FOR HIGH TEMPERATURES IN QUARTZITIC SANDSTONE DEFORMED UNDER A NEOPROTEROZOIC GLACIER

Michel BESTMANN[1], A. Hugh Neville RICE[1], F. LANGENHORST[2], F. HEIDELBACH[2] & Bernhard GRASEMANN[1]

[1] Department of Geological Sciences, Vienna, Austria
[2] Bayerisches Geoinstitut, Bayreuth, Germany

Introduction

It is a well-known phenomenon that moving glaciers can produce striations in the underlying bedrock. In this study, we characterise and discuss the deformation microstructure formed in a quartzitic sandstone under a Neoproterozoic glacier using optical microscopy, electron backscatter diffraction (EBSD) and cathodoluminescence (CL) in the scanning electron microscope (SEM), and by transmission electron microscopy (TEM).

Regional setting

The Oaibaccanjar´ga (Bigganjarga) outcrop in E. Finnmark, N. Norway, exposes a striated smooth surface of cross-bedded sandstones of the Tanafjord Group, overlain by a lens of diamictite of the Smalfjord Fm. (Neoproterozoic, Marinoan). Generally, the striated platform has a sandpaper-like surface but some striations have preserved a thin (<1.5 mm) translucent polished surface exhibiting a platy fabric in the SEM (Rice and Hofmann, 2000). This thin layer forms the basis of the microstructural studies described here (Fig. 1a). The striations are generally believed to have formed by the movement of the diamictite over the sandstone. The striations, which can be a metre long, trend ~103° and ~325°, subparallel to other Neoproterozoic striations in the region. The whole succession is very gently folded on a kilometre scale; no cleavage is seen in nearby silty rocks. Illite crystallinity in overlying pelitic units indicate a diagenetic to low anchizone alteration.

Results and discussion

The undeformed bedrock is a relatively pure quartz sandstone with a dominant grain size range of 200-500 µm. CL images reveal that detrital quartz grains are well rounded and spherical. Quartz cementation seems to have occurred after considerable compaction, since adjacent grains are frequently in contact and show pressure solution features. Optically, the quartz grains show uniform to weak undulose extinction. The latter can be related to free dislocations and low-angle subgrain boundaries, observed by TEM.

Towards the polished surface (striation) the microstructure is characterised by a sharp deformation gradient. In the optical microscope, pronounced undulatory extinction goes along with patchy grain segmentation – sometimes localized in intra- and transgranular microfaults (Fig. 1a). Directly under the polished surface, fine-grained zones cut sharply through the sandstone fabric and develop a flow fabric parallel to the surface. Some segmented quartz grains are also elongated parallel to the surface, surrounded by fine-grained quartz material. Orientation maps constructed from EBSD data reveal low-angle subgrain boundaries and Dauphiné twin boundaries in segmented clasts. Low-angle subgrain boundaries and grain segmentation are associated with microcracks visible in CL images. Occasional intragranular fluid inclusion trails decorate subgrain boundaries and give evidence of healed microfractures. Analysis of misorientation axes indicate, at least for some of the deformed quartz grains, that microcracks initiated crystallographically controlled block rotation at the microscale. The appearance and density of Dauphiné twin boundaries varies within the samples, showing the highest concentration of twins in areas with the cataclastic deformation microstructure. TEM observations show that the twin boundaries are free of partial dislocations and follow a zigzag pattern. Dauphiné twins are usually interpreted as the result of the α- to β-quartz transformation but a mechanical formation mechanism has also been described. Since the atomic movements in the Dauphiné twin operation are small and do not involve the breaking of Si-O bonds they may not result in the formation of partial dislocations. Thus, it is difficult to distinguish the transformation from the deformation mechanism.

In fine-grained parts of the deformation zone, TEM analyses reveal grain sizes between 0.2-1 µm (Fig. 1b). In general, the grains are almost completely free of dislocations, in contrast to the higher dislocation densities in larger quartz grains or fragments. A compact grain boundary network with frequent 120° triple junctions characterizes the microstructure of the fine-grained areas, whereby interstitial voids are rare. This microstructure, with 120° junctions, points to an equilibrium formation at elevated temperatures, either by solid-state recrystallization or by crystallization from a silica melt. A cementation process is unlikely to explain the observed microstructure, since cement phases such as carbonates and pores are absent. It is also unlikely that the observed microstructure reflects an overgrowth of quartz, since the solubility of quartz and the rate of precipitation depend on temperature (Dove and Rimstidt, 1994), and for such a scenario the conditions were around the freezing point. The fine-grained microstructure is similar to that of shock veins representing the quench products of frictional melting (Langenhorst and Poirier, 2000; Langenhorst et al., 2002). Langenhorst and Poirier (2000) and Langenhorst et al. (2002) have shown that crystallization from a melt may occur in one second or even less. Such a rapid solidification process would explain why the cataclastically fractured zone has not been removed by the ongoing movement of the glacier across the bedrock. The temperature needed for frictional melting can only be generated in this environment by the sudden release of high stresses, which built up between pebbles and bedrock over a relatively long time span. Calculations are in progress.

Conclusions

The movement of a Neoproterozoic glacier across quartzitic sandstone has produced a 1-1.5 mm thick zone of brecciation forming a surface polish. The initial deformation mechanisms during brittle failure were cataclastic processes, including microfracturing and frictional sliding. The compact grain fabric of the fine-grained microstructure (grain size 0.2-1 µm), with 120° triple junctions in the cataclastic zone, is probably related to friction-induced partial melting and subsequent crystallization, caused by stress-induced seismic events of sliding pebbles across the quartzitic sandstone bedrock. The high concentration of Dauphiné twins in highly deformed cataclastic zones is compatible with this high temperature event.

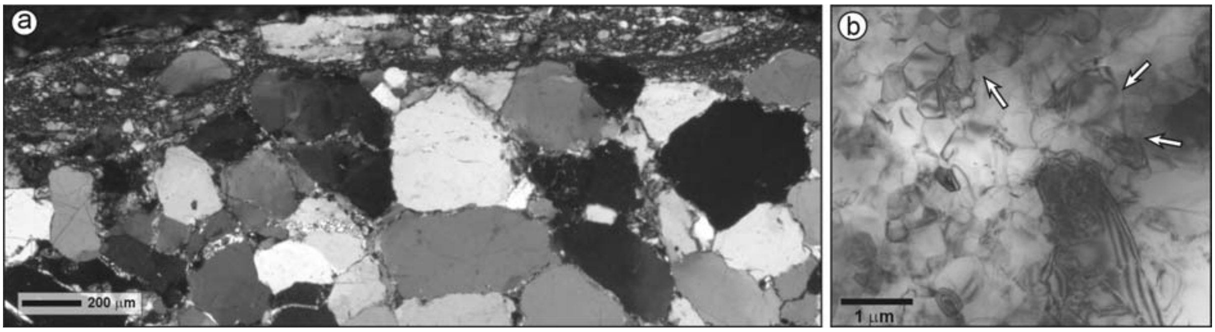

Fig. 1. (a) Deformed microstructure of quartzitic sandstone directly under striated surface. (b) TEM micrograph of fine-grained microstructure in highly deformed zone. Note compact grain boundary network with straight grain boundaries and approximately 120° triple junctions (arrows). Grains are free of dislocations except elongated grain.

References

DOVE, P.M., RIMSTIDT, J.D., 1994. Silica-water interactions. Reviews in Mineralogy 29, 259-308.

LANGENHORST, F., POIRIER, J-P., 2002. Anatomy of black veins in Zagami: clues to the formation of high-pressure phases. Earth and Planetary Science Letters 184, 37-55.

LANGENHORST, F., POIRIER, J-P., DEUTSCH, A., HORNEMANN, U., 2002. Experimental approach to generate shock veins in single crystal olivine by shear melting. Meteoritics and Planetary Science 37, 1541-1553.

RICE, A.H.N., HOFMANN, C.-C., 2000. Evidence for a glacial origin of Neoproterozoic III striations at Oibaccannjar`ga, Finnmark, northern Norway. Geological Magazine 137, 355-366.