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Constraining shock wave propagation direction from planar microstructures in quartz and feldspar

L. Pittarello (1), L. Ferrière (2), G. R. Osinski (3)
(1) University of Vienna, Austria, (2) Natural History Museum, Vienna, Austria, (3) University of Western Ontario, London, Ontario, Canada (e-mail: lidia.pittarello@univie.ac.at)

Abstract

Shock effects in minerals are heterogeneously distributed in impactites, both in intensity and frequency. However, specific crystallographic directions within minerals might be favored in developing shock-induced planar microstructures depending on their orientation with respect to the shock wave propagation. The occurrence of this relation is here proved by microstructural measurements on selected samples from terrestrial impact structures. Samples containing shocked minerals at a close distance from shatter cone striation, which permits to infer the main shock wave propagation direction, were selected. The information on shock wave propagation direction inferred from shock-induced microstructure distribution may contribute to a better understanding of impact cratering processes in general.

1. Introduction

Local shock wave scattering induced by discontinuities (e.g., mineral grain boundaries, cooling joints, inclusions, etc.) results in heterogenous distribution of shock effects in impactites. The crystallographic orientation of mineral grains can also affect the response to shock metamorphism, such as that even an apparently homogenous quartzite contain uneven frequency distribution of planar deformation features (PDFs) in quartz crystals. However, the relation between the shock wave propagation direction and the orientation of shock features at the bulk rock scale has never been investigated in detailed. Statistical measurements of PDFs in quartz are commonly used as shock barometer [1], with pressure values derived from shock recovery experiments on single crystal. This method provides reliable values only in first approximation when applied in polymineralic rocks, as the interaction between shock waves and crystals of different internal symmetry and orientation might affect the shock intensity recorded in individual phases. Nevertheless, shock pressure values obtained with this method have proven to be useful in shock attenuation studies (e.g., [2]). To address the influence of shock wave propagation direction in the development of shock features, we have investigated the orientation of shock-induced planar microstructures in quartz and feldspar grains in shatter cone sample formed in variously deformed granitoids from different terrestrial impact structures. The clear preferred orientation of the measured microstructures provides indication on the shock wave propagation direction across the different samples.

2. Methods

Shatter cones formed in granitoids recording different pre-impact tectonic deformation stages, from undeformed to strongly foliated, have been selected from Charlevoix (Canada); [3]), Keurusselkä (Finland; [4]), and Manicouagan (Canada; [5]) impact structures. Thin sections were cut normal to shatter cone surface and striation. Planar microstructures, such as PDFs in quartz, planar fractures (PFs), PDFs, and (likely shock-induced) micro-twins in feldspar [6] were measured with the Universal-stage and plotted with the program Stereo32, using as reference either the foliation (whenever present) or the long side of the thin section. For convention, the z direction is normal to the stereoplot and is parallel to the shatter cone striation, x is horizontal and sub-parallel to the shatter cone surface, and y is vertical (N-S). For quartz containing PDFs, the c-axis orientation was also plotted, to exclude any bias caused by pre-impact dynamic recrystallization.

3. Results

The sample from Manicouagan (WMM-102A-64C1) consists of a weakly foliated, garnet-bearing metagranite, dominated by shocked oligoclase and a few shocked quartz grains with mainly basal PDFs. Shock features in oligoclase include micro-twinning and PDFs, forming a dense network of planar microstructures. Measurements along a transect normal to the shatter cone surface show that these planar microstructures are spread in any *x*-*y* direction but sub-parallel to *z* (Fig. 1). The sample from Charlevoix (CHA09-12-01) consists of an undeformed granitoid, mainly containing quartz, plagioclase, hornblende, and opaque minerals. Quartz exhibits up to three PDF sets and plagioclase PFs and microtwins, with local occurrence of possible PDFs. All these planar microstructures insist on planes sub-parallel to *z* (Fig. 1), whereas quartz containing PDFs shows random orientation of the c-axis for *x* and *y*, but normal to *z*. The sample from Keurusselkä (VN3) consists of a strongly foliated gneiss, with elongated quartz ribbons, sub-rounded sericitized feldspar, and partially chloritized biotite layers. Quartz grains larger than 50 µm locally contain decorated PDFs. A few feldspar grains in the groundmass exhibit micro-twinning. Despite the extended dynamic recrystallization, large quartz grains show no crystallographic preferred orientation, but those that contain PDFs have c-axis normal to *z*. Both PDFs in quartz and microtwins in feldspar develop along crystallographic planes sub-parallel to *z*. Generally, no apparent influence of the tectonic deformation history of the rocks could be observed, except for a very weak asymmetry of quartz c-axis orientation in the strongly foliated sample.

4. Discussion and conclusions

Although the formation mechanism of shatter cones is still debated [7], we can assume that the shatter cone striation represents the local propagation direction of the scattered shocked waves. Shock pulse duration is too short to determine changes in the crystallographic preferred orientation of minerals, but those with crystallographic orientation favorably oriented with respect to the shock wave propagation direction will more likely develop planar microstructures. Preliminary results in this work show that both planar microstructures in feldspar and PDFs in quartz preferentially form along crystallographic directions that are sub-parallel to the supposed shock wave propagation direction, whereas quartz grains with c-axis lying on the surface normal to the local shock wave propagation direction generally contain PDFs. Thus, the crystallographic orientation of minerals with respect to the shock wave propagation does affect the intensity and the type of shock effects. Whenever the shock wave propagation direction cannot be inferred from other features, it can be constrained by the preferred orientation of planar microstructures in feldspar and quartz grains. Further systematical work to confirm these preliminary results is currently in progress on oriented drill core samples.

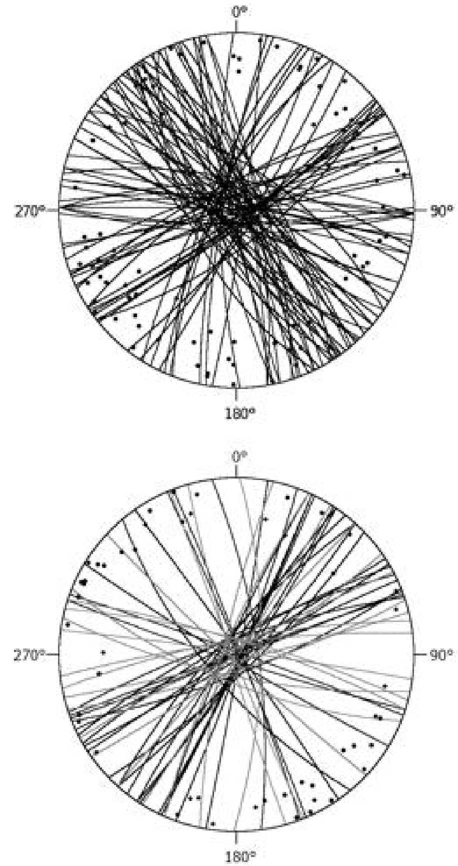

Figure 1: Stereoplot showing the poles and the corresponding great circle for 84 planar microstructures in plagioclase in the sample from Manicouagan impact structure (upper plot) and for 30 planar microstructures in plagioclase (dots and black lines) and 19 PDF sets in quartz (diamonds and gray lines) in the sample from Charlevoix impact structure. Equal angle, lower hemisphere.

References and acknowledgments

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