IMPACT-RELATED DEFORMATION OF PDFs IN QUARTZ: WHEN IDENTIFICATION OF TRUE PDFs BECOMES CHALLENGING. L. Pittarello[1], C. Burlet[2], M. Raes[3], C. Koeberl[4,5], V. Debaille[6], H. Terryn[3], and Ph. Claeys[1], [1]Analytical, Environmental & Geo-Chemistry (AMGC), Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussels, Belgium (lidia.pittarello@vub.ac.be), [2]Royal Belgian Institute of Natural Sciences (RBINS), Geological Survey of Belgium, Rue Jenner 13, B-1000 Brussels. [3]Research Group Electrochemical and Surface Engineering (SURF), Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussels, Belgium, [4]Natural History Museum Vienna, Burgring 7, A-1000 Vienna, Austria, [5]Department of Lithospheric Research, University of Vienna, Althanstraße 14, A-1090 Vienna, Austria, [6]Laboratoire G-Time, Université Libre de Bruxelles, Av. F.D. Roosevelt 50, B-1050 Brussels, Belgium.

Introduction: Planar deformation features (PDFs) in quartz are considered unambiguous microscopic evidence of shock metamorphism (e.g., [1,2]). However, the occurrence of tectonic features that can closely resemble PDFs [3-6], and the effect of post-impact deformation that can completely obliterate former PDFs, make a clear identification of PDFs sometimes difficult, especially if the investigation is limited to the optical microscope. While generally other evidence permit to unambiguously identify impact crater, the problem arises when only unclear PDFs can be observed. This issue has recently triggered an animated debate about the possible misinterpretation as PDFs of some unusual features in old quartz grains [7,8]. Consequently, a statistical criterion for the identification of truly shock-related PDFs has been proposed, based on a maximum number of unindexed planes after U-stage measurements [9]. However, this rigid criterion might not fit some natural situations. For example, the number of unindexed planes in measured PDFs in quartz from El'gygytgyn, Arctic Russia [10], is slightly higher than the proposed limit.

Electron microscopy on shocked quartz from El'gygytgyn has revealed crystal deformation that locally affects PDFs and hampers their correct indexation by means of optical microscope and U-stage. As the area has not been affected by significant regional tectonics after the impact, which is quite recent [11], and as the target rock does not exhibit similar features, the observed deformation must have occurred during the impact event. Crystal plastic deformation, related to the impact event, has been previously described in quartz grains that contain PDFs from the Charlevoix structure [12] and ascribed to the elastic rebound of the central uplift while the rock was still at ~300°C. A shear component in the shock deformation has been invoked for the formation of PDFs with specific orientation and of Brazil twins in quartz from the Rochechouart impact structure [13].

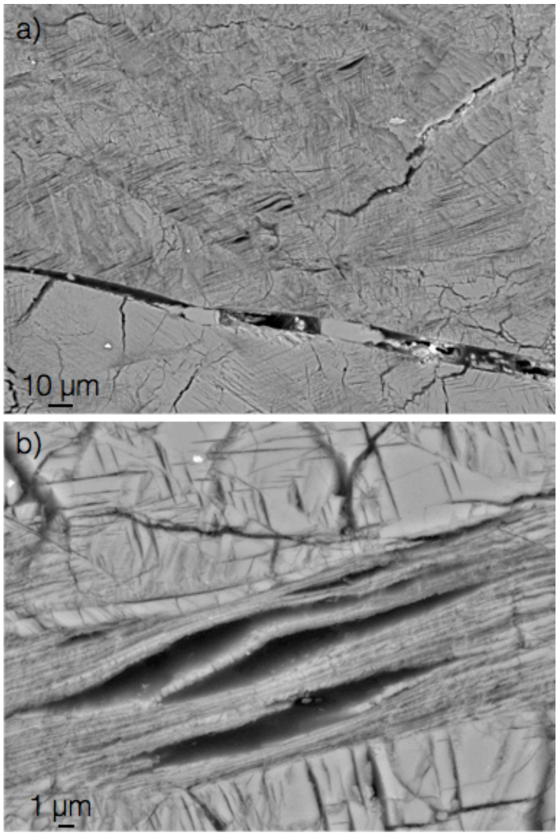
Petrographic and microstructural analysis of the deformation observed in shocked quartz from El'gygytgyn is here presented and interpreted in the framework of the impact event.

Methods: A polished, 35 μm thick thin section from sample 101Q6_W11-13, 326.65 m depth below the lake bottom in the drill core [10], has been selected for this study. Scanning Electron Microscopy (SEM) was performed at the Department of Lithospheric Research of the University of Vienna (Austria), with a FEI Inspect S50, and at SURF (Belgium), with a JEOL JSM-7100F field emission SEM. Backscattered electron (BSE) images were processed with the free software ImageJ (http://rsbweb.nih.gov/ij/) for microstructural analysis. Electron backscattered diffraction (EBSD) analysis was done at the RBINS (Belgium), with a FEI Quanta 200 ESEM equipped with an EDAX-AMETEK Hikari camera. EBSD processing software is OIM Data Collection and Analysis v.5.31.

Results: El'gygytgyn suevite contains individual quartz grains, which are variously shocked, from unshocked to completely molten [10]. The grains selected for this study contain up to five sets of intersecting PDFs. In SEM images, PDFs appear as thin (< 1μm) straight lines crosscutting the quartz grain (Fig. 1a). Locally, PDFs are bent, form pull-apart micro-basins (Fig. 1b), drag folds, and similar features, which clearly indicate that some degree of deformation occurred after PDF formation.

This type of deformation seems to be localized along specific PDF orientations, with characteristic angles between them, generally of 60° or 45°. EBSD analysis shows that crystals involved in this deformation process do not contain deformation bands or any evidence of dynamic recrystallization, supporting the localization of deformation exclusively along PDF. The only pervasive deformation effect that is observed is the possible occurrence of Dauphiné twinning, which was interpreted as resulting from the retrogression from β-quartz into α-quartz during cooling of impact-heated grains in quartz from the Charlevoix impact structure [14].

Fig. 1 *Deformation of PDFs in a quartz grain from El'gygytgyn. Sample 101Q6_W11-13, 326.65 m. BSE-SEM images. a) Different concentration of PDFs in portions of a crystal separated by an open fracture. b) Close up of plastic deformation of PDFs along a shear plane.*



Discussion: Microstructural analysis of these deformation features in El'gygytgyn shocked quartz suggests that crystal plastic deformation occurred in quartz when embedded in the suevite. The observed deformation that affects quartz grains containing PDFs is very likely related to the impact event because (i) completely undeformed quartz grains that preserve original magmatic features are embedded in the same impact breccia, (ii) this deformation does not affect quartz grains in the unshocked target rock outside the crater, (iii) there are no indications of foreign origin for the investigated grains, and (iv), no significant regional tectonic deformation was noted in the area after the impact event, or is exhibited in the suevite. Therefore, the observed deformation must have followed the PDFs formation, and is likely coeval with the suevite deposition. This would imply that the crystals were still hot due to the impact, as suggested in [14;15].

A possible explanation is that the shear stress component, necessary for activating slip systems, was likely produced by a combination of simple axial compression, due to gravitational compaction of the suevite, and crystal orientation with respect to the flattening direction. The deformation was mostly localized along PDFs, filled with amorphous material that, therefore, represented a weak heterogeneity that acted as shear plane. A similar localization process has been modeled in [16]. Only PDFs with a favorable orientation with respect to the principal stress direction were exploited, localizing most of the deformation and locally producing a little offset. A quantitative analysis of the process is in progress.

Assuming the described deformation mechanism, we might expect to observe similar features in other impact structures. Apart from the observations by C. Trepmann [12-14], none have yet been reported, either because the occurrence of other unambiguous impact evidence made detailed research on apparently badly preserved shocked quartz grains unnecessary, or because at El'gygytgyn the combination of local factors has allowed this type of localized deformation.

Conclusion: Crystal deformation has overprinted PDFs in quartz from El'gygytgyn without any possible exogenous causes than the impact itself, making the proper identification and indexation of PDFs challenging. The most probable scenario is strain localization along PDFs that were oriented favorably with respect to the stress directions and that, therefore, were exploited as shear planes. Local shear stress was probably induced by gravitational compaction of the suevite.

This impact-related deformation further confirms that identification of PDFs by only mean of optical microscopy might be challenging in some cases. Electron microscopy, chemical etching, micro-Raman, and similar analytical techniques might be necessary for an unambiguous characterization of true PDFs in absence of any other evidence for an impact event. The strict application of a statistical evaluation, as proposed in [9], might lead to ambiguous interpretations if syn-impact deformation, like that described in El'gygytgyn samples, or post-impact deformation, in old structures, has strongly affected the preservation of PDFs.

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