TWINNING AND AMORPHIZATION IN NATURALLY SHOCKED PLAGIOCLASE: AN EBSD STUDY.

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Introduction: Even though plagioclase is one of the most common minerals in the crust of terrestrial planetary bodies, its response to shock metamorphism is not yet fully constrained. In particular, the occurrence of planar deformation features (PDFs) in plagioclase has been almost exclusively described in shocked rocks from terrestrial impact structures, rarely in meteorites and very rarely reproduced in experiments (e.g., [1-3]). In this work, we focus on a shatter cone sample from the central uplift of the Manicouagan impact structure, Canada (e.g., [4]), which contains shocked plagioclase, characterized by extensive micro-twinning (e.g., [5]) and planar features that were reported as optically consistent with PDFs [6-8] or as possible PDFs [9]. Electron back-scatter diffraction (EBSD) was used to determine the crystallographic orientation and the crystallinity of shocked plagioclase grains, and to quantitatively describe the progression of shock amorphization in plagioclase.

Methods: A petrographic thin section from sample WMM-102A-64C1 was prepared for EBSD after a preliminary survey by optical microscopy. EBSD data were collected using a Zeiss Sigma variable pressure field emission scanning electron microscope (VP-FEG-SEM) equipped with an Oxford Instruments NordlysMax^2 EBSD detector at the ISSAC microscopy facility (University of Glasgow). Plagioclase crystals that were observed to contain shock microstructures in optical microscopy images were mapped. Crystallographic information was extracted from the EBSD data using the Channel 5 software package and noise reduced using a wildspike and 6 point nearest neighbor correction. Finally, the orientation of twins was graphically related to rational crystallographic orientations, according to the more common twinning rules and to the occurrence of PDFs in plagioclase as reported in the literature.

Results: Sample WMM-102A-64C1 is a garnet-bearing metagranite comprised of plagioclase, garnet, biotite, quartz, and accessory phases. Shock metamorphic effects in plagioclase include general decrease in birefringence and development of fine-grained twins, which locally might be optically (mis)interpreted as PDFs. These pseudo-PDFs are organized in crosscutting, multiple sets, with <10 µm spacing and thicknesses of 1-2 µm, consisting of amorphous material, as highlighted by EBSD analysis. The most common amorphous set is oriented along {010}, with further amorphous sets oriented along {100} or {1-20} that contain patches of crystalline material with a twin relationship to the host mineral. Correlated energy dispersive X-ray spectroscopy element maps indicate that concentrations of Na, Ca, and K do not differ between twins and within the same crystal.

Discussion and conclusions: In quartz, PDFs are straight and narrow (<200 nm), closely spaced (< 1µm), parallel amorphous lamellae, which develop along rational crystallographic planes (e.g., [10-11]). Even though they have been extensively studied in the last decades, their formation mechanism is still debated. For comparison, optically isotropic sets of lamellae in shocked plagioclase with similar characteristics to PDFs in quartz are generally described as PDFs, without further investigation. Our observations suggest that in the sample WMM-102A-64C1, amorphous lamellae in plagioclase all follow known twin relationships and have formed as shock-induced (compressional stage) micro-twins in plagioclase, commonly nucleating at grain boundaries. The incomplete or selective amorphization (due to shock decompression) of these twins supports the fact that shock amorphization is controlled by the crystallographic orientation, as already suggested by [1]. All these sets are oriented along the most common orientations attributed to PDFs [1], but are also consistent with plagioclase twin rules. Optically, the amorphous twins might be easily mistaken for PDFs and we cannot exclude that in the literature based on optical observations alone they were described as PDFs. The orientation of each twin or whole crystal relative to the local shock wave scattering determines the shock response of the crystal. This effect may be weakened or strengthened due to the nature of the surrounding phases with different impedance, such as other plagioclase crystals but with a different orientation or other minerals (quartz, garnet). Amorphization in plagioclase is initiated along microtwins that are oriented favorably with respect to the local shock wave propagation direction. Observations limited to optical microscopy might lead to the interpretation of such microtwins as PDFs. Whether these features can be considered PDFs and whether PDFs in quartz might also form initially as twins remain open questions that require further investigations.

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