TWINNED MAGNETITE IN GRANITIC SAMPLES FROM THE SILJAN IMPACT STRUCTURE, SWEDEN.

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Introduction: Impact cratering is a ubiquitous process throughout the solar system and has played a key role for the geologic evolution of Earth and other planets [1]. Magnetic anomalies are common characteristics of impact craters [2], so understanding how magnetite ($Fe_2^{3+}Fe^{2+}O_4^{2-}$), an important magnetic carrier in both terrestrial and extraterrestrial rocks, is affected by shock waves, especially structurally and magnetically, is crucial. Magnetic minerals have been studied to gain insight into the geologic evolution of Mars, with specific focus including understanding the Martian crustal structure and the oxidization state of Martian rocks (e.g., [3,4,5]). Shock waves permanently alter the intrinsic magnetic properties of rocks (e.g., [6]), as do twinning in natural environments with less extreme P/T conditions [7]. In fact, pressure conditions induced by impacts have been suggested to explain demagnetization signatures observed around Martian impact basins [8].

It is still poorly understood what effects shock has on the crystallographic structure of magnetite and thus its intrinsic magnetic properties, and how that affects the bulk magnetic properties of rocks (e.g., [9]).

Limited experimental studies have investigated the effects of shock compression on magnetite, especially with the aim of describing crystallographic deformation (e.g., [9] and references therein). In this work we report preliminary results of an investigation of microstructures in magnetite, an "unconventional" mineral in shock studies, in granitic samples from the ca. 380 Ma ~52 km-in-diameter Siljan impact structure, located in south-central Sweden.

Material and Methods: The investigated samples are medium- to coarse-grained granitoids dominated by K-feldspar, quartz, plagioclase, amphibole, and biotite, with minor titanite, zircon, apatite, and opaques. The samples belong to two "groups": either they were subjected to shock pressures, as determined by the planar deformation feature (PDF) orientations in quartz, of 15-20 GPa, or they record no indications of being affected by shock compression (see [10] for detailed description of samples). Initial investigation of thin sections was performed with a polarizing microscope. Samples were then examined with a Tescan Mira3 High Resolution Schottky FE-SEM equipped with an Oxford Instruments energy dispersive spectrometer (EDS), an electron backscatter diffraction (EBSD) detector, and a cathodoluminescence (CL) system, located at the Dept. of Geology, Lund University, Sweden. Thin sections were imaged and analyzed with EBSD. Before the analysis, thin sections were polished with colloidal silica and mounted on a 70° pre- tilted specimen holder. Orientation data was collected at 20 kV and with a step size of ~0.5 µm depending on the region of interest, with match units defined based on [11,12]. Post-analysis and construction of pole figures was performed with Channel5 software packages Mambo and Tango from Oxford Instruments. Noise-reduction of the data included removal of wild-spikes and replacement of zero solution pixels by extrapolation from neighboring pixels.

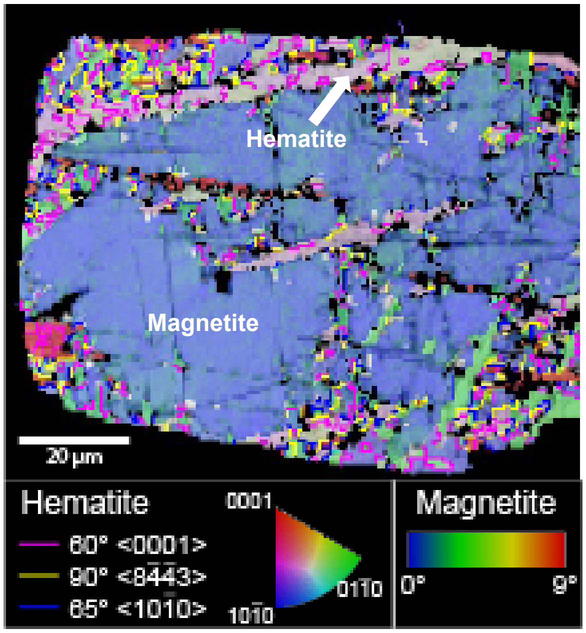

Fig. 1. A weakly shocked magnetite grain showing extensive hematite alteration. The orientations of the hematite lamellae are controlled by the magnetite host.

Results and Discussion: Investigated Magnetite crystals are typically 100-600 microns in size and found associated with mafic minerals in the thin sections. In many of the investigated samples magnetite is partly, or wholly, altered to hematite (Fig. 1). This is correlated with alteration in other minerals in the samples, such as biotite and amphibole to chlorite (see also [10]). Orientation analysis of the partially altered magnetite grains with hematite regions show that the transformation is controlled crystallographically, e.g., with the $\{111\}_{\mathrm{mag}}$ plane aligned with the basal $\{0001\}_{\mathrm{hem}}$, and $<110>_{\mathrm{mag}}$ aligned with $<10\bar{1}0>_{\mathrm{hem}}$.

Magnetite naturally twins according to the spinel law along {111}, and experimental studies show that magnetite responds to shock compression by developing grain fragmentation, microshear bands, and twins [9]. We observe multiple twinning in magnetite along {111} in samples that have PDFs in quartz (Fig. 2). So far, we have not detected any such features in magnetite from samples that are devoid of shock features in quartz. Observed twins occur in multiple orientation sets, and many have features that are normally attributed to deformation twins rather than growth twins, such as changes in twin lamellae width across the investigated crystal and tapered terminations (Fig. 2A). Twins are on the order of a couple of µm wide and with lengths corresponding to that of the investigated mineral grain, so on the order of maximum ~500 µm (Fig. 2A). While twins have been produced in magnetite from experimentally shocked rocks [9], they occur in minute portions of the host magnetite crystal only observable with TEM, which could result from the differences in shock duration between natural and experimental impacts. Experimentally produced shock twinning in magnetite has been observed to start at 10 GPa [9], consistent with our results.

To our knowledge, only one other description of naturally formed shock-induced twins has been reported in magnetite from a terrestrial impact structure (Vredefort) [13]. Since shock compression is known to affect the magnetic properties of minerals due to changes induced by fracturing and/or crystal-plasticity (e.g., [8, 9], and references therein), our results offer important constraints on the response of magnetite to well characterized shock pressures. Thus, our results can help better understanding the effects of impact cratering on crustal magnetic properties, not only on Earth but also other planetary bodies such as Mars.

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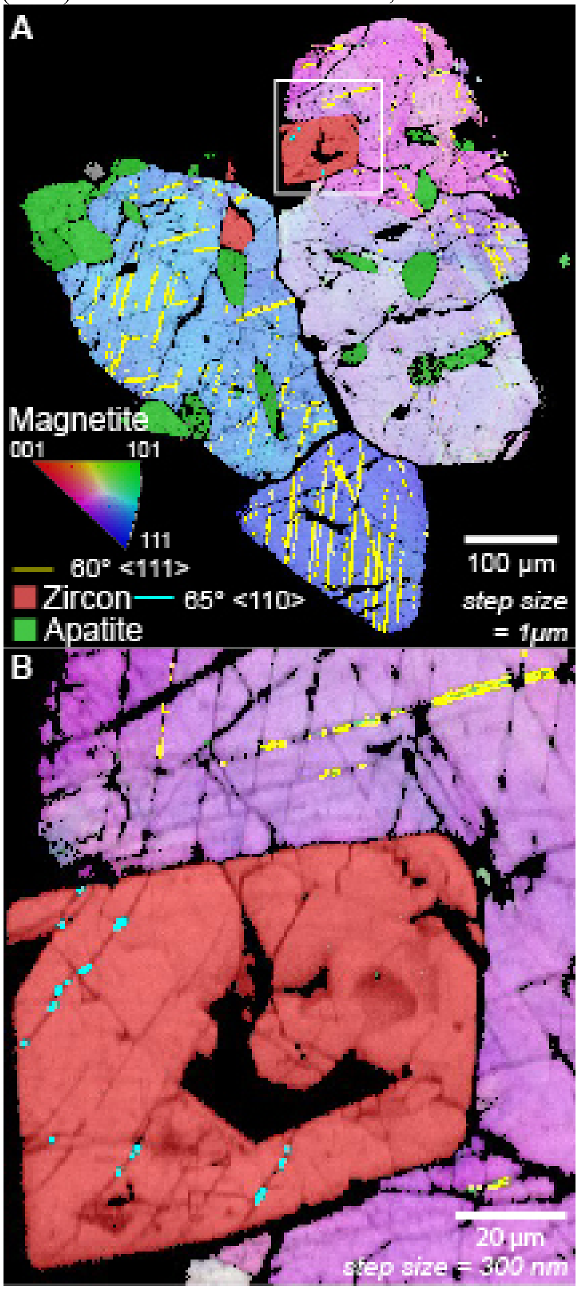

Fig. 2. Shocked magnetite intergrown with zircon and apatite. Magnetite exhibit mechanical {111} twins, and the zircon intergrowth displays {112} shock twins. Note angular misorientation across the magnetite, supporting our analysis that the grains record shock-induced deformation.