EFFECT OF SHOCK WAVES ON MAGNETIC SUSCEPTIBILITY AND MICROSTRUCTURE OF MAGNETITE.

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Introduction:

Impact cratering is one of the most important geological processes in our Solar System which often is associated with magnetic anomalies related either to shock or/and post-impact heating. These shock deformations can affect the magnetic properties of meteorites or impact structures on a planetary body. Frequently, enhanced magnetic susceptibility of rocks is caused by magnetite, which is therefore the dominant indicator of magnetic anomalies [e.g. 1, 2]. Correspondingly, a lot of research activity has been devoted to establish the effect of high pressures on the structural and magnetic properties of magnetite-bearing rocks. However, up to now, much of the experimental work was performed using static laboratory pressures [3-5]. This comes into question, how can the static data be related to the data obtained for shocked rocks? In particular, there is a lack of information on the correlation between the magnetic susceptibility and shock-induced particle fragmentation accompanied by lattice defect formation. This study investigates the effect of laboratory shock waves on the magnetic susceptibility and structural behavior of magnetite, and its usage for shock pressure barometry in terrestrial rocks and meteorites.

Samples and methods: A magnetite-bearing ore was experimentally shocked to well defined pressures ranging from 5 to 30 GPa in a high-explosive shock reverberation set-up at the Ernst-Mach Institute in Freiburg [6]. The selected shock pressures are comparable with pressures occurring in impact breccias and suevites during meteorite impacts [1].

Hysteresis measurements were conducted at the Institute for Rock Magnetism (IRM), Minneapolis, USA, on a Princeton Measurements vibrating sample magnetometer at room temperature. The magnetic susceptibility values were extracted from the initial magnetization curves of hysteresis loops [7].

Shock-induced fracture morphology was investigated by high-resolution scanning electron microscopy (HRSEM) using a LEO Gemini 1530 microscope operated at 10 kV.

Results: Fig. 1 shows the effect of shock pressure on the magnetic susceptibility. First, the susceptibility drops rapidly from its initial value to 5 and 10 GPa. The next slight susceptibility decrease occurs at 20 GPa. Finally, the lowest susceptibility value is achieved at 30 GPa. These data strongly suggest the magnetic susceptibility can be used for shock pressure barometry in impacted magnetite-bearing rocks and meteorites. Generally, it is accepted that magnetic susceptibility of magnetite is a function of grain size, which variation is closely related to size of the magnetic domains [8].

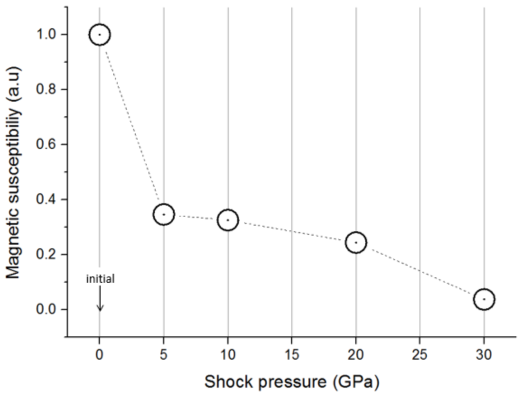

Fig. 1. Bulk magnetic susceptibility as a function of shock pressure. The values of the susceptibility are normalized to the value of the intial (unshocked) sample. Note that the magnetic susceptibility exhibits a good sensitivity to the increasing shock pressure.

Correspondingly, the drop of the specific magnetic susceptibility can be associated with a shock-induced particle refinement. However, as it is mentioned above, it is not clear whether the brittle particle refinement is accompanied by plastic deformation or not.

HRSEM observations of impact-generated fracture morphology are presented in Fig. 2. In the manually fractured initial (unshocked) samples (Fig.2a), intergranular fracture reveals boundaries between quartz and magnetite grains. Frequently, magnetite grains exhibit well-developed cubic smooth faces and brittle fracturing parallel to {001} planes. All shocked samples are characterized by an intensive particle fragmentation and development of shear bands as it is shown e.g. in Fig. 2b. Starting from 20 GPa (Fig. 2c), nanosized globular grains along sheared planes are observed. This finding suggests a local overheating that can lead to an irreversible melting or amorphization. Formation of twin-like lamellae is typical for samples shocked at 30 GPa (Fig. 2d).

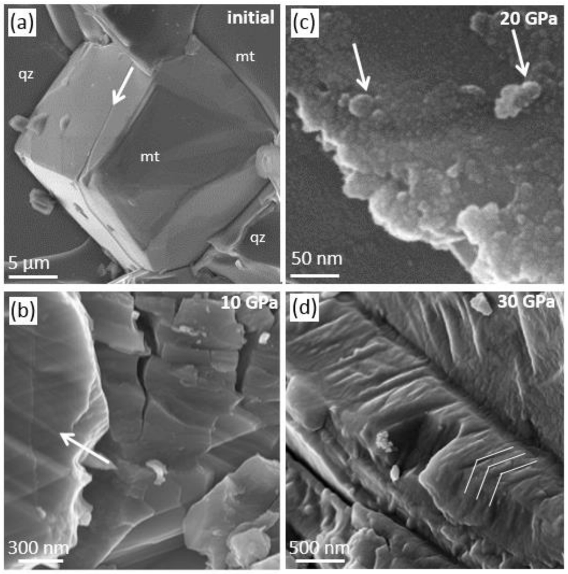

Fig. 2. HRSEM observations of fracture morphology. (a) Manually fractured initial (unshocked) sample composed of quartz (qz) and magnetite (mt) grains some of which exhibit well developed cubic smooth faces. The arrow points the crack propagating parallel to {001} planes; (b) Particle fragmentation and shear bands (arrow) in sample shocked at 10 GPa; (c) Globular nano-grains (arrows) at shear terraces in sample shocked at 20 GPa; (d) Twin-shaped lamellae in sample shocked at 30 GPa.

Conclusion: We show that the magnetic susceptibility exhibits a good sensitivity to the studied shock pressure values. Therefore this is a promising parameter which can be used as a geobarometer of impact events. For all shocked samples, the decreasing magnetic susceptibility correlates with shock-induced brittle deformation leading to particle refinement as well as with development of shear bands resulted from plastic deformation. Appearance of globular grains at pressures of 20 GPa and upward, may be indicative for irreversible overheating occurring during the shearing process. The formation of twinned lamellae at 30 GPa is characteristic for advanced stages of plastic deformation leading to drastic irreversible changes of the crystal lattice. To summarise, in addition to grain fragmentation, the locally accumulated irreversible defects may contribute significantly to the reduction of magnetic susceptibility of shocked rocks and cause a further decrease of magnetic susceptibility.

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