SHOCK EFFECTS IN QUARTZ: STRONG DEPENDENCE ON THE PRE-SHOCK TEMPERATURE

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Shock metamorphic features are the prime diagnostic tool for recognizing impact phenomena (1-4). In defining the pressure history of impact metamorphic rocks experimentally calibrated shock effects in quartz have played a key role. However, most experiments were performed at room temperature (except (5,6)), and in consequence the results are not directly applicable to target rocks at elevated temperatures. For such impacts into "hot" target rocks on terrestrial planetary objects the lunar multi-ring basins and the Sudbury structure with a transient cavity reaching the lower crust (7-9) stand as instructive examples.

Our shock loading experiments were performed with < 500µm thin disks of gem-quality single crystal quartz using a previously described high-explosive device (10); the plane shock front travelled parallel to the {1010}-face. "Heated" quartz samples were immediately before the passage of the shock wave at 630 ± 5°C. The recovered quartz was investigated by universal stage, spindle-stage, X-ray diffraction, micropyknometric, and TEM techniques.

Orientation of PDF’s (Fig. 1): The unheated quartz shocked at 20 GPa shows the distinct peak at {1013} as known from previous investigations on experimentally (2) and naturally (11) shocked samples. In contrast, PDF’s in the heated quartz shocked to the identical pressure lack such an diagnostic orientation and the distribution of crystallographic orientations for PDF’s is broad and difficult to index.

Refractive indices (Fig. 2): Two more experiments at 26 GPa, 630°C, and at 27.5 GPa, 20°C, confirm our previous results (12-14) for this sensitive pressure range where shocked quartz transforms into diaplectic glass. Between 25 and 26 GPa heated quartz displays an abrupt decrease in the refractive indices n_o and n_e whereas in unheated quartz an equivalent change takes place in the pressure range from 25 to 36 GPa.

X-ray diffraction (Fig. 3): The data corroborate our optical results. Compared to unheated shocked quartz, heated shocked quartz becomes at lower pressures totally X-ray amorphous. Moreover, d-spacings ({1010},{1011}) and lattice parameters of heated quartz increase more drastically above 25 GPa than those of unheated specimen.

Density (Fig. 4): The densities of heated and unheated shocked quartz were determined on 20-100 mg samples by micropyknometric techniques. Between 25 and 26 GPa the density of heated quartz decreases from a value similar to that for unshocked quartz, to -2.205 g/cm³ which is comparable to the density of silica glass. Unheated quartz, however, displays a smooth and continuous decrease in density from 25 to 35 GPa.

TEM investigations: In accordance with published observations (15,16), the experimentally shocked unheated quartz does not show significant shock-induced dislocations; this is also valid for heated specimen. In shocked quartz we found two types of typical sub-microscopic lamellae: Below the transition to diaplectic glass unheated and heated shocked quartz display glassy lamellae. In the heated quartz shocked at 26 GPa we detected for the first time tiny relic crystalline veins embedded in the totally amorphous matrix.

All our results give a consistent pattern and reflect the different behaviour of heated and unheated quartz under shock loading. Consequently, the currently used shock wave barometers cannot be applied to high temperature target rocks. New shock wave barometers must be established experimentally and pre-shock thermometers are required in order to understand the shock pressure history of terrestrial and planetary impact formations.
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FIG. 1: Comparison of orientations of planar deformation features in quartz experimentally shocked at 20°C and at 630°C

FIG. 2: Refractive indices of quartz experimentally shocked at 20°C and at 630°C versus shock pressure.

FIG. 3: Lattice constant a of quartz experimentally shocked at 20°C and at 630°C as function of shock pressure.

FIG. 4: Densities of quartz experimentally shocked at 20°C and at 630°C versus shock pressure.