SHOCK RELEASE ADIABAT MEASUREMENTS ON VOLATILE BEARING MINERALS
AND IMPLICATIONS FOR AN IMPACT GENERATED ATMOSPHERE
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Introduction: Water and carbon dioxide comprise 84 and 15 atomic% of the Earth's total volatile budget. Their role is therefore central for an understanding of the origin and evolution of the terrestrial atmosphere/hydrosphere. There is growing evidence that the Earth acquired most of the volatiles very early in its history (e.g., 1). Archenius et al. (2) and Benlow and Meadows (3) propose the generation of a terrestrial atmosphere due to the release of volatiles from impacting planetesimals during accretion of the Earth. Further outgassing during core formation and via volcanism is only seen as a secondary process, leading to minor increase and modification of the atmosphere/hydrosphere. The requirements of this type of model were examined (4, 5) and it appears that specification of the amount of a volatile released upon impact depends on the release adiabats of the minerals, a parameter we call dehydration efficiency, and the infall rate and mass distribution of planetesimals. The behavior of volatile bearing minerals and the physical conditions for devolatilization under shock compression are therefore of importance.

We present shock compression (Hugoniot) and release adiabat measurements on two hydrous minerals (chrysotile-serpentine, Mg_3 Si_2 O_5 (OH)_4; brucite, Mg (OH)_2) and calcite (CaCO_3) which are prominent in volatile rich carbonaceous chondrites (6, 7) and are likely candidates for volatile bearing phases in planetesimals during accretion of the Earth (2). Release states of shocked sample materials are determined at the intersection of the sample release path with Hugoniot of two solid buffers with lower shock impedance than the sample (porous graphite and polystyrene foam with initial densities of 1.081 and 0.056 g/cm^3, resp.) (8). Measurements of release adiabats provide a useful tool for determining the onset of shock induced volatile loss. Gases, being driven out of the shocked sample, lead to high particle velocities and relatively low shock velocities in buffers (which we measure in our experiments). Hence, unusually shallow release paths, resulting in zero pressure densities of the shocked material significantly below the initial sample density, are indicative of shock induced devolatilization of the sample (9). The results of this study can be compared with shock recovery experiments which enabled quantitative estimates of shock induced volatile loss in hydrous minerals (10) and calcite (11).

Experimental Details: We used samples of chrysotile - serpentine, brucite, and single-crystal calcite with zero-pressure densities of 2.5, 4.4, and 2.7 g/cm^3, resp. Cylindrical and rectangular sample sizes (5mm thick, 3mm, and 10mm long, respectively) were polished from 1" tungsten driver plates. Lexan arrival mirrors were mounted on the free surfaces of driver plate, sample, and buffer. We attempted to achieve identical shock states for each pair of experiments, yielding one point on the Hugoniot and two release states. A 40 mm propellant gun was used to launch lexan projectiles with tungsten flyer plates to velocities of 2 to 2.4 km/s. Sample- and buffer shock velocities were obtained from an analysis of streak camera records which show the successive reflectivity loss of the lexan mirrors upon arrival of the shock wave on the free surface - mirror interfaces. Hugoniot and release states were determined by the impedance match procedure and by use of known Hugoniot parameters for the buffer materials (9).

Results and Discussion: The release path, obtained for two experiments on brucite suggest shock induced water loss for pressures > 37 GPa (Fig. 1). This is supported by our shock recovery experiments on the same material, which indicate 30-40 wt.% loss of available water at shock pressures > 20-25 GPa and theoretical predictions (4, 5). The Hugoniot points agree well with data of (12).

The experiments on chrysotile are less conclusive (Fig.2). Results from shots 545 and 546 indicate shock induced dehydration for pressures > 35 GPa, while shots 551 and 552 do not. However, based on our experiments on antigorite-serpentine (10), as well as theoretical estimates (4, 5), we predict a shock induced water loss of 40 wt.% of the available water for shock pressures in excess of 30 GPa. Fibrous chrysotile as used here is highly anisotropic. Although we attempted to mount all samples such that they would be shocked parallel to the c- or fibre axis, it was difficult to prepare the samples uniformly. This might have led to variations in shock propagation direction with respect to crystallographic orientation and might explain the scatter in release data. Our data for chrysotile (density = 2.5 g/cm^3) are clearly offset from earlier Hugoniot data for serpentine (unspecified type) (13), which is likely the result of a higher initial density (2.9 g/cm^3) of the LASL samples.

The four single-buffer experiments on calcite do not indicate any volatile loss in samples shocked to 30 - 38 GPa (Fig. 3). This is contrary to one possible interpretation of shots 514 and 522 (9) of each of the employed three different buffer materials), which suggested loss of CO_2 upon compression of calcite to 37 GPa. However, an alternative interpretation of these experiments results in good agreement with our present results (Fig. 3). Gas recovery experiments on calcite by (11) yielded only minor amounts of released CO_2 in samples shocked to 17.4 to 18.8 GPa. Theoretical calculations indicate that calcite begins to break down to CaO and CO_2 over a pressure range of 45 - 70 GPa (14), well in excess of shock pressures reached in our experiments. Our Hugoniot data agree well with data on polycrystalline calcite (15) and suggest the existence of a high pressure phase for pressures > 30 GPa.

Conclusions: The measurement of shock release adiabats of volatile bearing minerals demonstrate that shock induced devolatilization occurs. Our results are in good agreement with quantitative estimates of volatile release under shock compression as obtained in recovery experiments (10, 11). We conclude that water is released from hydrous minerals at shock pressures > 30 GPa, well below those

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required for release of CO₂ from calcite. Shock pressures up to 39 GPa did not result in observable volatile release from calcite.

Planetesimals, containing volatile bearing phases, will start loosing their structural water when they impact the accreting Earth at velocities of 2-3 km/sec, corresponding to the escape velocity of an Earth which has acquired 15% of its size or 0.4% of its mass. Since the onset of CO₂ release upon impact requires a velocity of 6-7 km/sec, this infall velocity will occur only when 60-70% of the Earth's final size is reached. Hence, while impact devolatilization appears to be a viable mechanism for the generation of a primary hydrosphere, a CO₂ atmosphere is less readily explained by this process.


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