MEASURED SHOCK TEMPERATURES IN CALCITE AND THEIR RELATION TO IMPACT-MELTING AND DEVOLATILIZATION. Stanley G. Love[1] and Thomas J. Ahrens[2],
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Carbonate crustal rocks are abundant on the Earth and inferred on the surfaces of Mars and Venus, but the impact-induced release of CO_2 and the concurrent effect on the Earth's global climate has until recently been only loosely constrained by theoretical and experimental results. In order to constrain the energetics of impact melt and vapor production, we have measured the radiative temperatures induced in calcite upon shock-compression in the 115 to 185 GPa range and obtained values of 3250 to 5400 K. These values are slightly below but basically in agreement with the values predicted by Yang and Ahrens [1] on the basis of previous measurements at much lower pressures of particle velocity profiles induced upon isentropic expansion of shocked porous carbonate samples. The new shock temperature data are in a pressure range well above that believed to be required to induce incipient (50 GPa) and complete (100 GPa) vaporization upon shock compression of crystal density carbonates. The low temperatures measured over the 115 to 184 GPa pressure are ~1600 to 3000 K below those that would occur if impact vaporization did not take place, and strongly support the model of bond destruction in the shock compressed state (Fig. 1).

Experiments

Optical grade single crystal (c-cut) calcite crystals (3 mm thick and 13 mm in diameter) were mounted on Ta driver plates and impacted with Ta-faced projectiles in the 5-7 km/sec range at the Caltech 2-stage light gas gun facility. As the shock propagated through the sample an optical image of the central 1.5-5.0 mm portion of the sample free surface was projected onto the Caltech pyrometer apparatus. Spectral irradiances were measured in 6, 5 nm wide bands centered at 450 to 905 nm and sampled at a rate of one sample per nanosecond using New Focus, Model 1801, PIN, photodiodes in an improved optical pyrometer [2] (Fig. 2).

In two of the experiments the sacrificial mirror that directs the light out put from the experiment were replaced by a 50% beamsplitter and the image of the masked sample was observed with either a streak or framing camera.

Results

In the radiance versus time records obtained by the pyrometer, a prominent ~ 50 ns duration gap "flash" signal was observed in some cases, in spite of our coating the driver plate side of the samples with a 1500Å thick layer of silver. Typically, this signal was followed by a ~100 ns long "plateau" signal which we assume corresponded to the intrinsic shock temperature in the crystal. Upon fitting these signal levels to a Planck greybody function the shock temperatures plotted in Fig. 1 are obtained. The results are in good agreement with the model of Yang and Ahrens [1], which assumes dissociation at the shock front. Moreover, both streak and framing camera images surprisingly indicate that the inhomogeneous radiation observed by Kondo and Ahrens [3] in calcite shocked to 40 GPa persists into the present high-pressure range. The present data appear to intersect the melting line of Kerley [4] at ~80 GPa, and thus suggest that melting, in addition to partial vaporization, is induced at the pressure along the Hugoniot. Whether melting of $CaCO_3$ can be achieved upon isentropic release from lower shock pressures, e.g. the 50 GPa inferred by Scott et al. [5] for the exposure shock pressure of martian meteorite ALA84001, is not yet demonstrated, but is plausible.

When the present results are considered in comparison with previous results on impact vaporization [6], and Kotra et al. [7], and the recent results of Martinez et al. [8]), we conclude that the non-homogeneous vaporization of $CaCO_3$ reported by Lange and Ahrens [6], starting at ~10 GPa does indeed occur. The Lange and Ahrens' optical microscopy and SEM images unequivocally demonstrates that this process occurs below the 50 GPa shock pressure inferred by Yang and Ahrens [1] on the basis of continuum particle velocity profiles and thermodynamic data. Since the present shock temperature data agrees closely with the thermodynamic model, we conclude that the shock pressures range required for incipient to complete vaporization of $CaCO_3$ extends from ~10 to 100 GPa and at higher pressure, inhomogeneous deformation still occurs even in the complete vaporization regime.

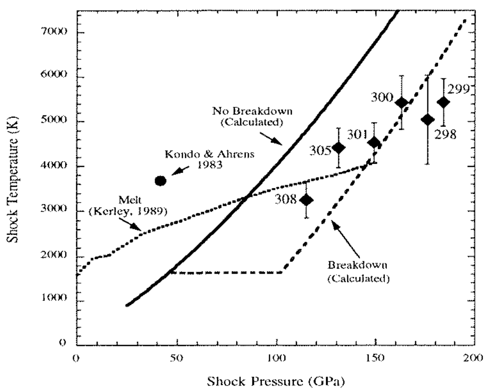

Figure 1. Shock temperatures obtained in this study, with conservative uncertainties of 10% for most points (Experiment 298 had fewer channels of useful data and a correspondingly larger uncertainty). Also plotted are calculated shock Hugoniot temperatures (W. Anderson, private communication) for crystal calcite with (dotted line) and without (solid line) decomposition. The data are more consistent with the former interpretation. Also shown is the datum of Kondo and Ahrens [3] with a very high shock temperature and very low emissivity (0.0025) interpreted as shear banding.

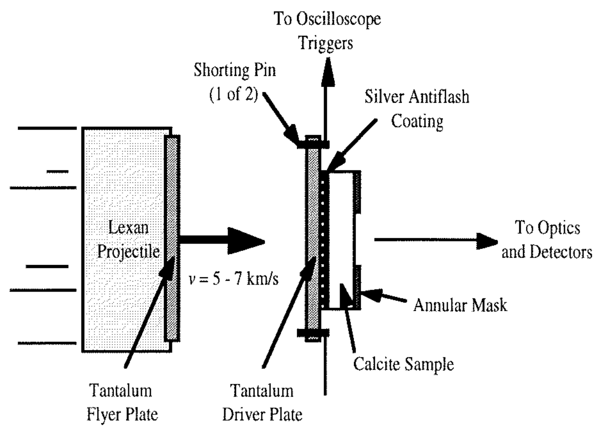

Figure 2. Drawing (not to scale) of the experimental setup during a shot. Light from the hot shock escapes through the hole in the center of the mask on the downrange face of the sample. A sacrificial turning mirror directs the light through a window in the evacuated target tank, then into a bundle of optical fibers which distributes the light equally through six broadband optical filters (center wavelengths 451.5, 555.5, 603.7, 661.5, 748.2, and 904.0 nm). Behind each filter is a photodiode, amplifying electronics, and a high-speed digital oscilloscope which records the electrical signal from the diode. In two experiments (numbers 305 and 308), the first turning mirror is replaced with a 50% beamsplitter, which transmits half the light to a second turning mirror and thence via window to a streak or framing camera.

References: 1. Yang W. and Ahrens T. J. (1998) *EPSL* , submitted, 2. Yang W., Impact volatilization of calcite and anhydrite and the effects on global climate from the K/T impact crater at Chicxulub, Ph. D. thesis, California Institute of Technology, Pasadena, CA, 1996. 3. Kondo K.-I. and Ahrens T. J. (1983) *Phys. Chem. Minerals* , 9, 173-181. 4. Kerley G. I. (1989) *High Pressure Research* , 2, 29-47. 5. Scott E. R. D., *et al.* (1997) *Nature* , 387, 377-379. 6. Lange M. A. and Ahrens T. J. (1986) *Earth Planet. Sci. Lett.* , 77, 409-418. 7. Kotra R. K., *et al.* (1983) *Lunar and Planetary Science Abstracts*, XIV, 401-402. 8. Martinez I., *et al.* (1995) *J. Geophys. Res.* , 100, 15,465-15,476.