SHOCK BEHAVIOR OF CALCITE AND BASALT IN A MEMIN HYPERVELOCITY IMPACT EXPERIMENT AND LASER MELTING EXPERIMENTS.

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Introduction: In recent years, one of the most controversially discussed topics in impact cratering is the fate of carbonates upon impact. Particularly, the question is whether carbonates released from high shock pressures (sufficient to melt coexisting silicate minerals) will (i) decompose and liberate CO_2, one of the most potent climate-active greenhouse gases, (*e.g.*, [1–3]), or (ii) whether they will be preserved as melt in impact glasses and melt rocks (*e.g.*, [4–6]). In a classic study, [7] re-evaluated the phase diagram of $CaCO_3$ and concluded that both melting *and* devolatilization may take place upon impact, depending on specific *PT* conditions. Moreover, [8] showed experimentally that calcite (Cc) melts can indeed be produced by hypervelocity impacts. However, while most agree that both processes *can* occur, it is considerably debated *which* process, if any, predominates—a question which's answer may ultimately shed light onto the extent of impact-released CO_2 to the mass extinction at the Cretaceous–Paleogene boundary 65 Ma ago (*e.g.*, [3]).

Here, we present first results of an ongoing experimental hypervelocity impact cratering campaign in the context of the MEMIN research group [9] that uses basalt projectiles and Cc targets. Additionally, in order to better constrain primary melts derived from the starting materials, as well as mixtures of them, we conducted a series of laser melting experiments. Our aims are to (i) investigate the shock behavior of basalt and Cc, (ii) evaluate whether devolatilization or melting of Cc takes place upon impact, and (iii) study interaction processes between projectile and target.

Experimental Setup: A series of hypervelocity impact cratering experiments have been performed using a two-stage light-gas gun at the Fraunhofer Ernst-Mach-Institute, Freiburg, Germany. Here, we report on experiment A30-5610, which involved the impact of a 6.17-mm-diameter basalt projectile onto a 25 × 25 × 25 cm block of Carrara Marble. An impact velocity of 4.94 km s^{-1} and a projectile mass of 0.3632 g resulted in an impact energy of ~4.4 kJ and a peak pressure of ~51 GPa [11]. Ejecta were collected with a set of ejecta catchers. Additionally, laser melting experiments have been performed using a pulsed laser welding system at Technische Universität Berlin, Germany. In these experiments, centimeter-sized blocks of Carrara Marble and basalt were fixed either separately or conjoined onto aluminium plates; the laser beam was conducted with variable settings along 15-mm-long lines.

Results: Samples were prepared for optical microscopy, SEM, and field-emission EMPA. The Carrara Marble is virtually pure Cc interstratified with minor amounts of dolomite; pyrite, fluorite, and feldspar occur as accessories. Calcite grain sizes range between ~20–50 µm (along dolomite veins) and ~100–200 µm (bulk of the material). The projectile used is an aphanitic, holocrystalline, porphyric basalt. It shows olivine (Ol) phenocrysts in a fine-grained matrix of plagioclase (Plag), pyroxene (Px) and ilmenite. Accessory minerals are K-feldspar and magnetite.

Hypervelocity impact experiment. Experiment A30-5610 yielded three types of ejecta, given with decreasing abundance: (i) weakly deformed, transparent, millimeter-sized Cc fragments, (ii) highly deformed, sugary-white, micrometer- to millimeter-sized Cc fragments, and (iii) highly shocked, partially molten, greyish to brownish, micrometer-sized basalt fragments and composite particles composed of a mixture of siliceous glass and shocked Cc.

The highly deformed Cc fragments show extensive fracturing and twinning (Fig. 1). Although Cc shows distinctive pre-impact twinning, twinning and fracturing is much more pronounced in the highly deformed particles. The highly shocked basalt particles show intense fracturing of olivine and pyroxene. Furthermore, incipient to complete melting of plagioclase and K-feldspar to a vesicular glass is frequently observed (Fig. 2a); in some cases, incipient melting of olivine, pyroxene, ilmenite, and magnetite along grain boundaries and margins is also observed (Fig. 2b). In these cases, the melt derived from these minerals has mixed with the melt derived from plagioclase and K-feldspar. In general, the experimentally shocked basalt shows much resemblance to shocked basalt from Lonar crater, India [10].

Rare composite particles of shocked Cc and siliceous, frothy glass (Fig. 3a) show vesicular, CaO-rich (~60–70 wt.% CaO) areas lacking recognizable grain boundaries (Fig. 3b), which could be interpreted as degassed and/or molten Cc (which has ~56 wt.% CaO). However, this study is in an early state, so we cannot make a strong statement concerning the nature of this material yet.

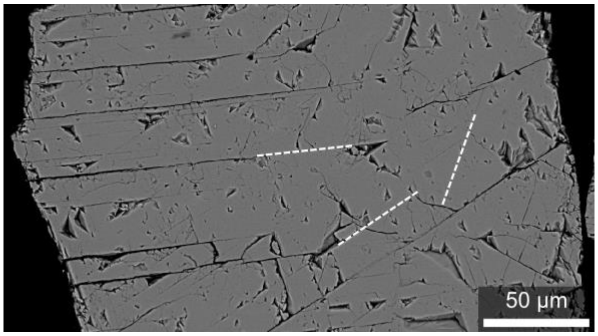

Fig. 1 BSE image of highly deformed Cc fragment showing three sets of cross-cutting twins (white lines).

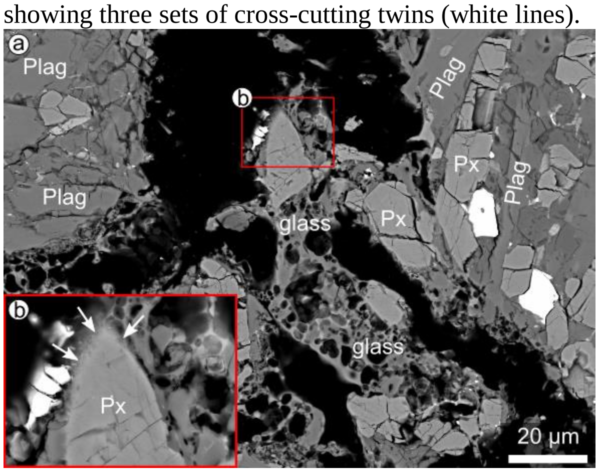

Fig. 2 BSE image showing melting of plagioclase to vesicular glass (a) and incipient melting (arrows) of pyroxene (b) in highly shocked basalt.

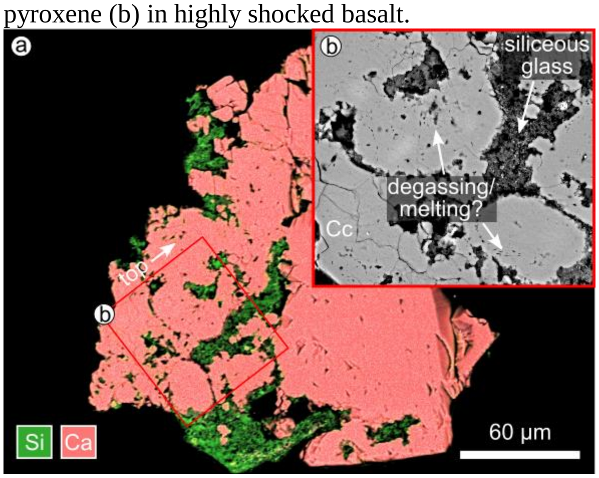

Fig. 3 (a) Elemental distribution map of a composite particle composed of shocked Cc (red) and siliceous melt (green). (b) BSE image showing vesicular, CaO-rich material without recognizable grain boundaries (indicating incipient degassing/melting?).

Laser melting experiments. In these experiments, funnel-shaped pits several hundred micrometer in size were excavated in the basalt (Fig. 3a), with the formation of schlieren-rich, vesicle-poor glass. At the margins of these pits, incipient melting of all constituent minerals is present (Fig. 3b). In the Cc, comparatively small pits that show intense fracturing and twinning, but no signs of melting, were excavated.

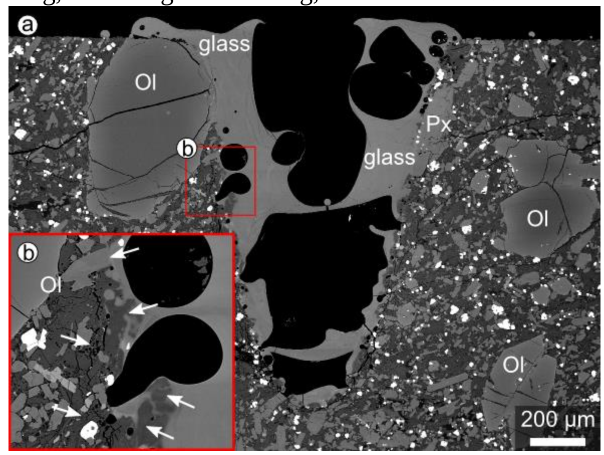

Fig. 4 Funnel-shaped laser excavation pit in basalt with extensive melting (a) in the pit and incipient melting (arrows) at the margins of the pit (b).

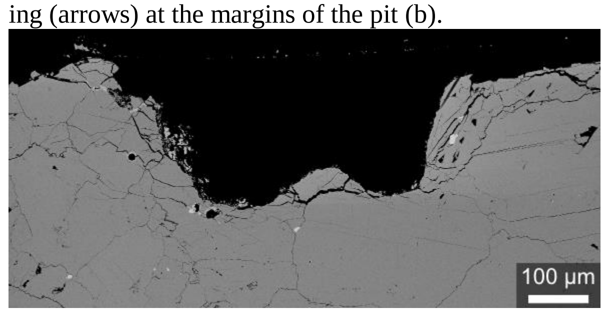

Fig. 5 Irregular laser excavation pit in Cc.

Conclusions and Outlook: Although in an early state, this study yielded preliminary results very similar to nature (*e.g.*, to shocked basalt from Lonar crater, India; [10]). A detailed analysis of the experimentally shocked materials is currently performed, with specific focus on shock behavior of Cc in hypervelocity impact cratering experiments.

Acknowledgments: The MEMIN program is supported by the DFG (research unit FOR-887; He-2893/8-2).

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