HIGH STRAIN-RATE DEFORMATION EXPERIMENTS ON CARBONATE-SILICATE ROCKS: IMPLICATIONS FOR IMPACT CRATERING PROCESSES.

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Introduction: The response of carbonates to shock experiments has raised considerable interest and controversy. Carbonates do not respond to experimental shock deformation as predicted by theoretical calculations [e.g., 1, 2, 3]. Specifically, devolatilization is expected to occur at pressures exceeding 40 GPa [1,3], with vaporization taking place upon decompression from 37 GPa for calcite and 14 GPa for dolomite [3]. Instead, incipient CO_2 loss begins at about 10 GPa for calcite [4]. Indeed, Lange and Ahrens (1986) note that the formation of shear bands within their samples caused heating which led to devolatilization, but that this was not clearly related to experimental shock pressures [4]. Oblique impact experiments with dolomitic marble targets show increasing devolatilization with decreasing impact angle [5], which implies that shear heating plays an important role in vaporization and decarbonation processes [6].

Previous investigations of carbonate target materials have involved both shock and impact experiments. The benefit of performing frictional melting experiments is that they allow us to investigate target material behavior independently from shock deformation and for longer duration than impact experiments. This allows the independent investigation of conditions analogous to high strain-rate deformation during impact events, which occurs either in response to shock deformation, just after it (i. e. modification stage processes), or due to downrange material motion associated with oblique impact. Similar studies have been conducted with ordinary chondrite meteorites [7].

Samples and Techniques: A frictional melting experiment was performed using separate dolomitic marble and quartzite samples to simulate conditions during an impact into carbonate-silicate target rocks. The experiment followed the method of Spray (1995)[8]. The samples, one cube of quartzite (~99.5% quartz with trace magnetite) and one cube of dolomitic marble (~99% dolomite, ~1% calcite and phlogopite), 1.5 cm on each side, were mounted onto separate steel cylinders with epoxy. Using a computer-controlled Blacks FWH-3 axial friction-welding rig, the samples were brought into contact at room temperature and under dry conditions with ~5 MPa applied pressure. Contact was maintained for two seconds at 750 rpm for a sustained strain-rate of 10^2 to 10^3 s^{-1}.

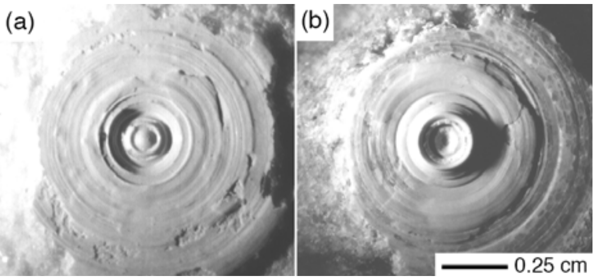

Figure 1. Dolomitic marble (a) and quartzite (b) contact faces after axial friction-welding at a strain-rate of 10^2 to 10^3 s^{-1} for two seconds.

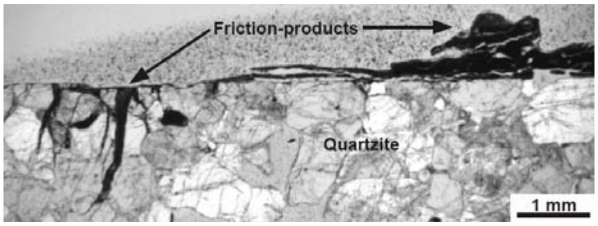

Figure 2. Thin section of the quartzite sample perpendicular to the rotation axis (right edge) showing opaque friction products adhered to the sample surface and injected into fractures that formed in the sample.

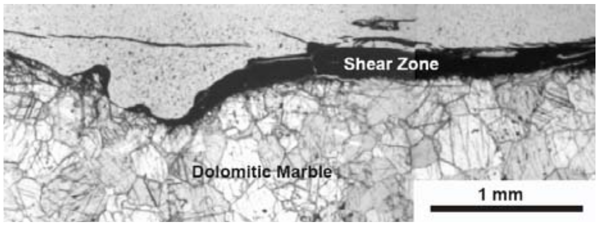

Figure 3. Thin section of the dolomitic marble sample perpendicular to the rotation axis (left edge). Only minor fracturing and infiltration of material into the sample occurred. Besides the shear zone, mechanical twinning was the dominant effect.

Results: Vapor or fine dust escaped from the interface during the experiment. Immediately after sample separation, the interfaces were incandescent. Once cooled, opaque white material adhered to the quartzite sample (Fig. 1, 2), particularly around the axis of rotation, leaving a complementary depression in the carbonate sample (Fig. 1, 3).

Quartzite sample. Material was injected into cracks that formed in the quartzite sample. Cooling and crystallization of the friction products resulted in the formation of minerals such as periclase and calcium-magnesium-silicates. No pure lime was observed to be present. Elemental mapping and EMP analyses reveal segregation of MgO and CaO (Fig. 4). While pure MgO was observed, CaO combined with SiO to form Ca-silicates and with CO_2 to form new carbonate phases. The formation of vesicles and the greater abundance of MgO in the friction products, versus the original marble, implies that ≥ 5 wt % CO_2 was lost during the experiment.

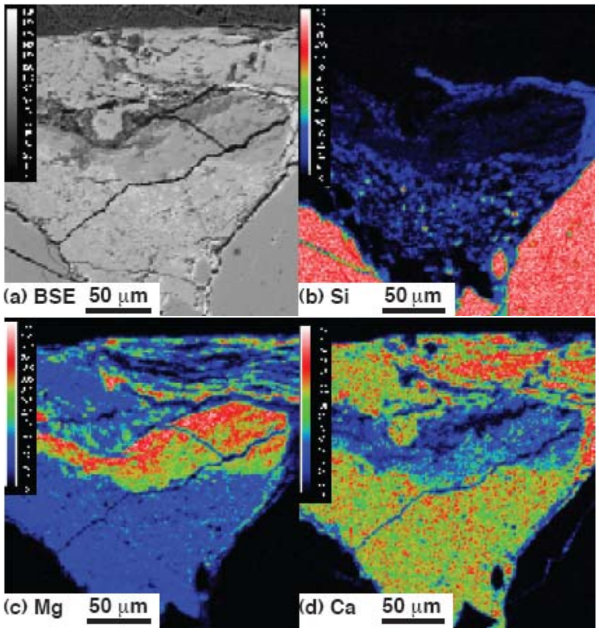

Figure 4. BSE image and Si, Mg and Ca maps for an indented area of the quartzite sample face that retained friction products. Note the segregation of Mg and Ca.

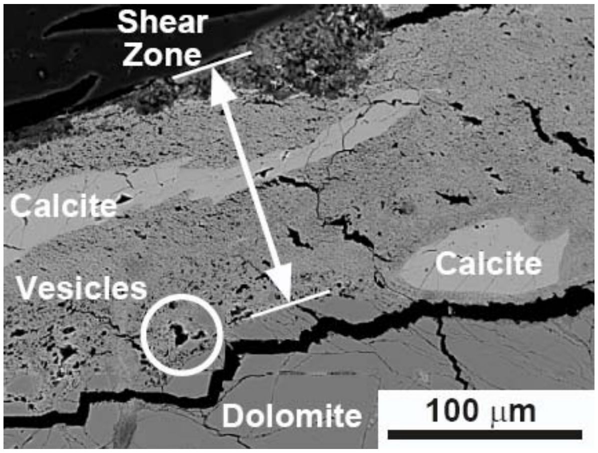

Figure 5. BSE image of the dolomitic marble sample showing the experimental shear zone. Note the pervasive small vesicles and new calcite grains.

Dolomitic marble sample. The dolomitic marble section exhibited thinner and shorter fractures than the quartzite sample. Mechanical twinning was induced by the deformation, in particular around the axis of rotation. The adhered friction products exhibit very fine-grained material with larger, freshly crystallized calcitie and possible huntite, in addition to pervasive micron-scale vesicles (Fig. 5).

Discussion: Because one of the most important factors for the decarbonation of target materials is the confining pressure [10], it has been proposed that decarbonation of carbonate target rocks only occurs upon decompression, thus limiting the overall volume of CO_2 gas released [11]. In addition, back-reactions between trapped CO_2 and highly reactive CaO also reduce the overall volume of CO_2 gas thought to be released during an impact [12]. These factors limit the amount of CO_2 released as a result of shock.

However, the results of this and other studies [6] indicate that high strain-rate deformation can cause significant devolatilization of carbonate target rocks. The presence of akermanite indicates temperatures in excess of 700° C were generated by the experiment [9]. Thus, the temperature conditions are similar to those caused by the post-shock temperature increase following a 55-60 GPa shock alone [3]. When this temperature increase is coupled with fracturing, comminution and subsequent melting associated with high strain-rate deformation and the effects of shock deformation, the loss of CO_2 is enhanced.

Especially during oblique impacts, high strain-rate deformation continues after shock decompression and creates pathways for CO_2 gas to escape by further fracturing target rocks. In addition, high strain-rate deformation affects a greater volume of the target than shock deformation alone, thus increasing the overall volume of material subject to decarbonation. High strain-rate deformation is thus an important impact process, leading to enhanced vaporization, decarbonation, melting and deformation of the target rocks.

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