TRACING SHOCK WAVE ATTENUATION IN POROUS, PARTICULATE TARGETS: INSIGHTS FROM IMPACT EXPERIMENTS AND NUMERICAL MODELING.

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Introduction: Hypervelocity impacts create high-pressure shock waves that lead to distinct shock-metamorphic effects in both projectile and target. Specifically, the point of impact is surrounded by hemispherical zones of decreasing shock pressure and, hence, by a continuum of decreasingly intense shock-metamorphic effects in the target material [1]. This shock attenuation has been reconstructed at some terrestrial craters (*e.g.*, [2]). However, at the laboratory scale, descriptions of successively decreasing shock-metamorphic effects that cover large pressure ranges (from complete melting to Hugoniot elastic limit) in a given sample are rare (*e.g.*, [3,4]). Here, we study shock wave attenuation in quartz sand targets by comparing results from impact experiments with numerical modeling.

Methods: 6.36-mm-diameter aluminum spheres were shot vertically at 5.9–6.5 km/s into quartz sand targets (~42% porosity), producing craters of ~33 cm diameter and ~6 cm depth [3,5]. Tracing of particle movement was facilitated by 9-mm-thick, horizontal strata of differently colored quartz sand that were placed at different positions in the target, and ejecta were collected up to 6 crater radii [5]. Furthermore, we used the iSALE shock physics code [6,7] to simulate a representative experiment. The behavior of the quartz sand was modeled using a Drucker-Prager rheology and the ANEOS for SiO_2 [8], combined with the ε–α compaction model [7]. Moreover, we used tracers to record shock conditions (*e.g.*, peak pressure) and particle trajectories inside the crater and in the ejecta curtain.

Results and Discussion: We analyzed melt particles recovered from the crater floors and the ejecta blankets using optical and electron microscopy. The melt particles have a layered structure of decreasing shock metamorphism (Fig. 1). A topmost layer consists of fused Al metal that documents complete melting of the Al. The Al metal crust is underlain by vesicular lechatelierite, in which relic, PDF-bearing quartz grains and spheres of Al metal are embedded. These two layers are underlain by shock-lithified and fractured quartz grains that show grain-boundary melting. Based on previous attempts to calibrate shock effects in sandstone [2,9], we can assign shock pressure and post-shock temperature ranges under which these layers have formed: the uppermost layers formed between 13 and ~59 GPa and >2000 °C, whereas the bottom layer formed between 5 and 13 GPa and several hundred degrees Celsius. Grain-boundary melting in the bottom layer was induced by pore collapse, which locally increased shock pressure and post-shock temperature. The melt particles thus document the effect of shock wave attenuation in porous quartz. Our numerical model furthermore constrains at which time step of crater formation and at which initial location these particles may have formed (Fig. 1). Moreover, we can reconstruct particle movement in the growing crater by comparing internal structure and final position of the melt particles with trajectories of the tracers in the model.

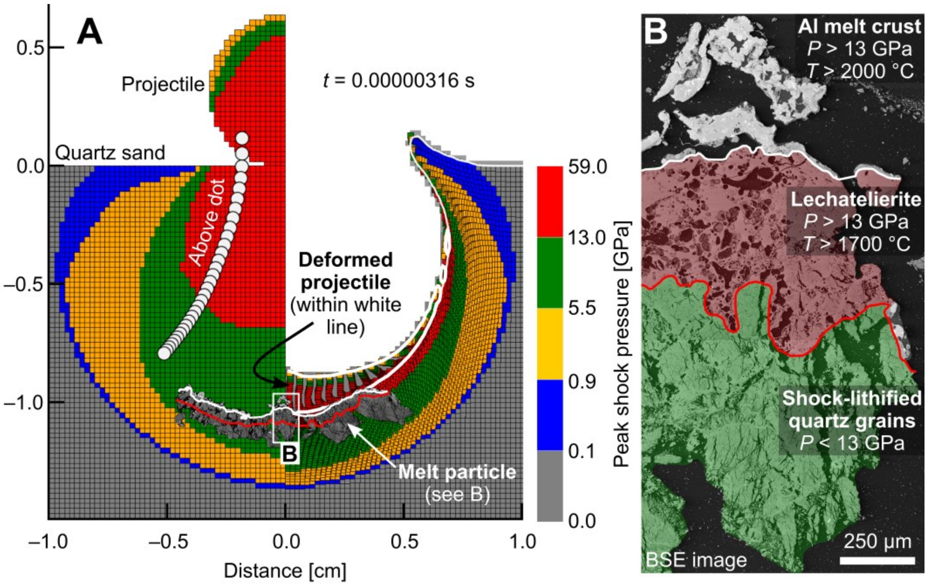

Fig. 1: (A) Peak shock pressure (color contours) as a function of distance (left) and snap-shot of crater formation (right; 3.16 µs after impact) from numerical modeling compared to the shock zoning documented in the melt particles (B; BSE image).

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