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The MEMIN Research Unit: New results from impact cratering experiments into geological materials

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1. Introduction

The MEMIN research unit (Multidisciplinary Experimental and Modeling Impact research Network) is focused on performing hyper-velocity impact experiments, analyzing experimental impact craters and modeling cratering processes in geological materials. The main goal of the MEMIN project is to comprehensively quantify impact processes by conducting stringently controlled experimental impact cratering campaigns on the meso-scale with a multidisciplinary analytical approach. As a unique feature we use two-stage light gas guns capable of producing impact craters in the decimeter size-range in solid rocks that, in turn, allow detailed spatial analysis of petrophysical, structural, and geochemical changes in target rocks and ejecta.

2. Cratering experiments

A total of 24 experiments were performed at the facilities of the Fraunhofer EMI, Freiburg. Steel, aluminum, and iron meteorite projectiles ranging in diameter from 2.5 to 12 mm were accelerated to velocities ranging from 2.5 to 7.8 km/s. Solid rock targets were chosen to cover a range of porosities and included sandstone, quartzite and tuff (Fig. 1) that were either dry or saturated with water. In the experimental setup, high speed framing cameras monitored the impact process, ultrasound sensors were attached to the target to record the passage of the shock wave, and special particle catchers were positioned opposite of the target surface to capture the ejected target and projectile material. In addition to the cratering experiments, planar shock recovery experiments were performed on the target material, and numerical models of the cratering process were developed. (See also Poelchau et al. 2013 and references therein [1].)

3. Results

Crater morphology was analyzed with a 3D scanner to obtain depth, diameter and volumetric values. Crater volumes of experiments performed under the same conditions in dry tuff, quartzite and dry sandstone are all similar, despite the wide range of target strengths. In the strength regime, crater volumes are affected by the target's strength and porosity. An increase in either value reduces crater size. Interestingly, a rock's compressive strength is usually reduced for increasing porosity values, following a power law. Saturating pore space with water leads to an increase in crater volume in both tuff and sandstone by reducing the dampening effects of porosity on the shock wave, while keeping the target's strength roughly constant.

Depth-diameter ratios are much higher for craters in dry tuff than for those in sandstones or quartzites. The increase in depth-diameter ratios is correlated with decreasing target density and the corresponding increase in target porosity, and may reflect a longer coupling period of the projectile with the target.

A structural analysis of the crater subsurface of dry and water-saturated sandstone targets was carried out on thin-sections. Near the crater surface, areas of pervasive grain crushing and compaction are located that contain tensile fractures sub-parallel to the target surface. The zone of grain crushing is highly subdued in experiments with saturated targets. In the area below, localized bands of intense deformation occur within otherwise intact sandstone. Using image analysis software, the change in porosity with depth was measured. Near the surface, dilatancy increased the porosity due to open cracks, underneath porosity is strongly reduced in dry targets and slowly increases with depth. This phenomenon is not visible in water saturated targets, where subsurface pore space remains intact.

The damaging of the subsurface of impacted sandstone and quartzite targets was also imaged via ultrasound measurements. Interestingly, reduction of p-wave velocities indicates a much larger volume of damaging than determined by optical and scanning-electron microanalysis of the sandstone targets. Furthermore, the zone of velocity reduction is much less pervasive in quartzite targets than in sandstone targets, possibly due to the quartzite's higher strength.

The behavior of porous geological materials under shock loading is also subject to simulation in new mesoscale numerical models that quantify localized shock pressure behavior in the target's pore space. Modeled data concur well with microanalytical results of planar shock recovery experiments in sandstone, in which localized shock metamorphic features in quartz are described. These features suggest highly increased local pressure excursions relative to the average pressure of the shock wave.

Finally, post-impact analysis of projectile remnants shows significant melting and mixing of iron meteorite projectile and target material. During mixing of these melts, the Fe of the projectile is preferentially partitioned into target melt compared to Ni and Co. This partitioning is stronger in non-porous quartzite targets than in porous, dry sandstone targets.

4. Summary and Conclusions

Based on our systematic, quantitative data, we plan to refine numerical models. These models help to quantify and evaluate cratering processes, while experimental data serve as benchmarks to validate the improved numerical models, thus helping to "bridge the gap" between experiments and nature. The results confirm and expand current crater scaling laws, and make an application to craters on planetary surfaces possible.

Fig. 1: Craters formed in quartzite, tuff and sandstone targets (back to front). Large targets are 80 cm wide, small targets are 20 cm cubes.

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References

[1] Poelchau, M. H., Kenkmann, T., Thoma, K., Hoerth, T., Dufresne, A., and Schäfer, F.: The MEMIN research unit: Scaling impact cratering experiments in porous sandstones, Meteoritics & Planetary Science Vol. 47, pp. 8-22, 2013.