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Experimental impact cratering provides ground truth data for understanding planetary-scale collision processes

Michael H. Poelchau (1), Alex Deutsch (2), and Thomas Kenkmann (1)

(1) Institut für Geo- und Umweltnaturwissenschaften, Universität Freiburg, Freiburg, Germany, (2) Institut für Planetologie, WWU Münster, Germany

Impact cratering is generally accepted as one of the primary processes that shape planetary surfaces in the solar system. While post-impact analysis of craters by remote sensing or field work gives many insights into this process, impact cratering experiments have several advantages for impact research: 1) excavation and ejection processes can be directly observed, 2) physical parameters of the experiment are defined and can be varied, and 3) cratered target material can be analyzed post-impact in an unaltered, uneroded state.

The main goal of the MEMIN project is to comprehensively quantify impact processes by conducting a stringently controlled experimental impact cratering campaign 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.

In total, we have carried out 24 experiments at the facilities of the Fraunhofer EMI, Freiburg - Germany. 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. Targets were solid rocks, namely sandstone, quartzite and tuff 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.

The experiments resulted in craters with diameters up to 40 cm, which is unique in laboratory cratering research. Target porosity exponentially reduces crater volumes and cratering efficiency relative to non-porous rocks, and also yields less steep ejecta angles. Microstructural analysis of the subsurface shows a zone of pervasive grain crushing and pore space reduction. This is in good agreement with new mesoscale numerical models, which are able to quantify localized shock pressure behavior in the target's pore space. Planar shock recovery experiments confirm these local pressure excursions, based on microanalysis of shock metamorphic features in quartz. Saturation of porous target rocks with water counteracts many of the effects of porosity. Post-impact analysis of projectile remnants shows that during mixing of projectile and target melts, the Fe of the projectile is preferentially partitioned into target melt to a greater degree than Ni and Co.

We plan to continue evaluating the experimental results in combination with 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.