MORPHOLOGY OF EXPERIMENTAL IMPACT CRATERS INTO SANDSTONE. A. Dufresne[1], M. H. Poelchau[1], T. Kenkmann[1], A. Deutsch[2], T. Hoerth[3] and F. Schaefer[3], [1]Institute of Geological Sciences, Geology, Albert-Ludwigs-Universität, Freiburg, Germany (anja.dufresne@geologie.uni-freiburg.de), [2]Institute of Planetology, Westfälische Wilhelms-Universität Münster, Germany, [3]Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI, Freiburg, Germany.

Introduction: The research group MEMIN (*Multidisciplinary Experimental and Impact Modelling Research Network*) has currently generated 19 experimental impact craters as part of parameter studies [1], including the influence of target pore-space saturation with water, and projectile velocity on the cratering process. The high-velocity (2.5-5.3 km/s) impact experiments were carried at the two-stage light-gas gun facilities of the Fraunhofer Institute EMI (Germany) using steel and meteoritic iron projectiles (and aluminium projectiles at 7-7.8 km/s) and Seeberg Sandstone targets. Data of experimental impact studies have found application in numerous scaling calculations [e.g. 2 for review], whereas few morphological studies exist [3-6]. The primary objectives of this study within MEMIN are to provide detailed morphometric analyses of experimental impact craters into sandstone, and to identify characteristics and trends specific to a given impact parameter.

Methods: Crater topography was investigated visually and with the aid of digital terrain models (DTM's) that were created based on three-dimensional laser scanning technology. Scans of the craters were captured from up to six different angles depending on morphological complexities such as overhangs or steeply dipping surfaces, and post-processed in 3D-Viewer®, Excel® and Surfer®.

General Crater Morphology: All craters reveal four morphometric features (Fig. 1) regardless of impact parameters:

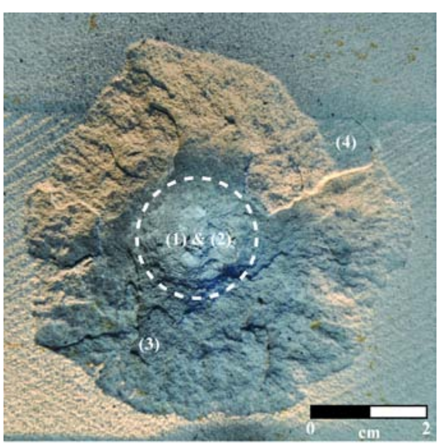

Fig. 1 Typical experimental impact crater features. See text for further explanations.

(1) a fragile, highly fragmented, white-coloured centre, (2) a prominent central depression embedded within this damage zone and often containing a small central "pit", (3) an outer spallation zone, and (4) areas of arrested spallation (i.e. spall fragments that were not completely dislodged from the target) at the crater rim. Large spall fragments can be refitted like jigsaw-puzzle pieces into the spallation-zones; they always form circular inner shapes even if the host crater has an irregular outline. Large spall fragments can make up to 50% of the total crater volume.

Morphological Characteristics related to Experimental Parameters: Distinct trends and differences in crater dimensions and morphological characteristics can be discerned for variations in impact velocity, for "dry" and "wet" targets, and for aluminium-projectile impacts.

Impact Velocity: This parameter study is based on experiments using 10-mm steel projectiles at 2.5, 3.5, 4.4, 4.6 and 5.3 km/s (corresponding to impact energies between 12.8 and 58.4 kJ), and dry sandstone targets. Crater volume increases with increasing impact velocity (Fig. 2). Depth over (average) diameter ratios (d/D) lie between 0.21 and 0.24.

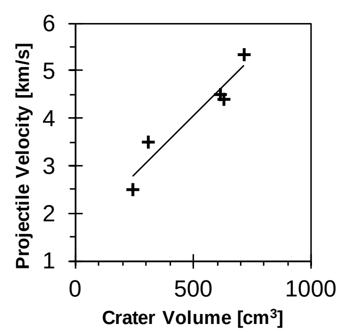

Fig. 2 Projectile velocity vs. crater volume.

Target Layer Orientation: In experiment 5124, layering of the sandstone was oriented parallel instead of perpendicular to the projectile trajectory. This arrangement resulted in a crater 25% smaller in volume. The spallation zone morphology is identical.

Dry Targets: These craters exhibit all the aforementioned features and have outer spallation zone surfaces dipping evenly at 10-20° towards the crater centre (Fig. 1 and zone II in Fig. 3) as their particular characteristic. Their d/D range between 0.18 and 0.24.

Target Pore-Space Saturation with Water: Craters in pore-space (partially or close to fully) saturated targets are generally larger in volume (up tp 76%) and in diameter (150%) at comparatively lesser depth

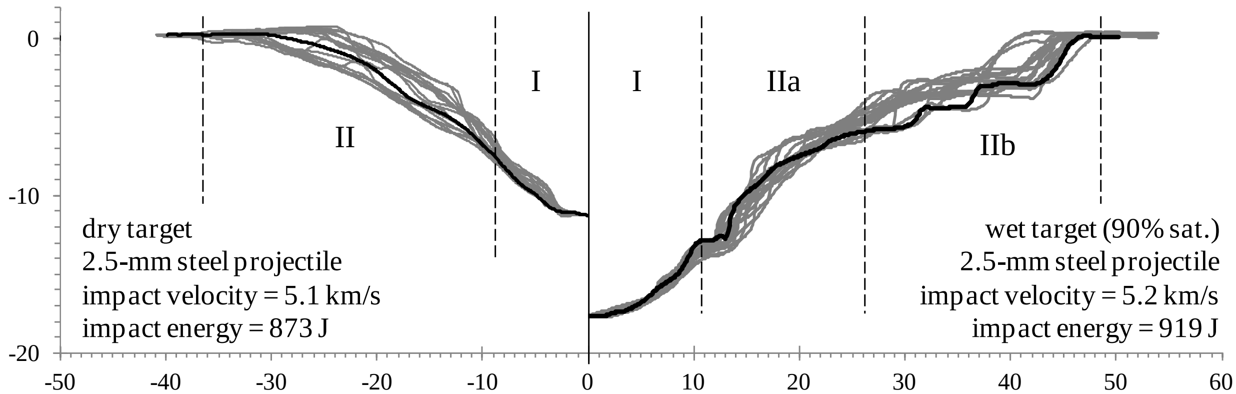

Fig. 3 Comparison of crater profiles between impacts into dry (left hand side) and pore-space saturated targets (right hand side) at comparable impact conditions. Shown are 18 profiles each.

(124%) than impacts at the same energy into dry targets [5]. Their d/D is lower than in dry targets and fall between 0.13 and 0.19. The spallation zones of craters in pore-space saturated targets are distinctly different from dry targets and consist of two parts: one adjacent to the inner depression with slightly convex slopes of 10-35° (area IIa in Fig. 3), and an outer, near-surface zone with two sets of surfaces (IIb), with one oriented sub-parallel and the other at 70-90° to the target surface. These morphological characteristics and the overall lower d/D ratios are considerd as clear distinctive factors to craters in dry sandstone targets.

Discussion: Two different mechanisms produced the characteristic morphological features of the craters. Cratering begins with the formation of a transient cavity [e.g. 6], and in our experiments, remnants of this cavity are preserved in the central depression. This depression is formed by material compression, grain comminution and excavation flow. The morphology of the outer spallation zone is the result of localized tensile failure and ejection of larger fragments of unshocked material that were uplifted when the shock wave was reflected at the target surface to form a release wave.

Excavation of the transient crater using steel and iron-meteorite projectiles impacting into dry targets results in parabolically to cone-shaped central depressions that have roughly the same depth and radius (Fig. 3). In wet targets, these central depressions are slightly flatter, which is also reflected in the likewise flatter morphologies of their host craters. Even more pronounced are the differences in outer spallation zone morphologies between dry and wet targets (Fig. 3). The main orientation of tensile failure planes in dry sandstone targets is 10-20° from the target surface towards the crater centre (comparable to those in gabbro [3]), whereas in wet sandstones, the dominant failure plane is subparallel to the target surface. Possible explanations for this difference include (1) the reduction in effective stress due to the built-up of a pore pressure, which shifts the Mohr circle towards smaller pressures and allows tensile fracturing, and/or (2) preferential accumulation of water in the horizontal sandstone layers and hence weak surface-parallel horizons.

At higher velocities, the craters become increasingly larger as more energy is applied to the system. From transient crater reconstructions through fitting parabolas to the large central depression, it appears that spallation becomes increasingly more influential on final crater dimensions since the assessed percentage of the transient crater volume of the final crater decreases with increasing impact velocity.

Conclusions: Increasing impact velocity and impact energy as well as increasing target pore-space saturation result in increasingly larger craters. Morphologically, the craters in dry and wet sandstones are distinct in that (1) the latter are comparatively wider and shallower with d/D below 0.19, whereas dry craters have ratios almost consistently above this value, and (2) their spallation zone morphologies differ significantly. However, an identification of “dry” versus “wet” targets based upon spallation zone morphology alone is precluded by the fact that high-velocity, low-density projectiles impacting into dry sandstone targets also produce terraces in the spallation zone just like the lower velocity, high-density projectile impacts into pore-space saturated targets.

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