LOOKING BENEATH AN IMPACT CRATER – NON-DESTRUCTIVE TESTING FOR HYPERVELOCITY IMPACT EXPERIMENTS. D. Moser[1], C. Grosse[1], N. Güldemeister[2], E. Buhl[3], K. Wünnemann[2], T. Kenkmann[3], [1]Technische Universität München, Germany (http://www.zfp.tum.de/, moser@cbm.bv.tum.de, grosse@tum.de), [2]Museum für Naturkunde, Berlin, Germany,[3]Universität Freiburg, Germany.

Introduction: During the impact cratering process, the passage of the shock wave through the target subsurface causes fracturing and comminution of rock material. Understanding the details of the subsurface damage zone in experimental craters can give insights into the formation of planetary-scale craters and their geophysical signatures. Within the framework of the MEMIN research group, impact experiments into sandstone targets were carried out (Figure 1) [1, 2]. Subsurface damaging of the targets was measured nonintrusively [3] and preliminary results are presented below. The comparison with numerical simulations and an optical evaluation is an important step for the validation of the non destructive testing methods.

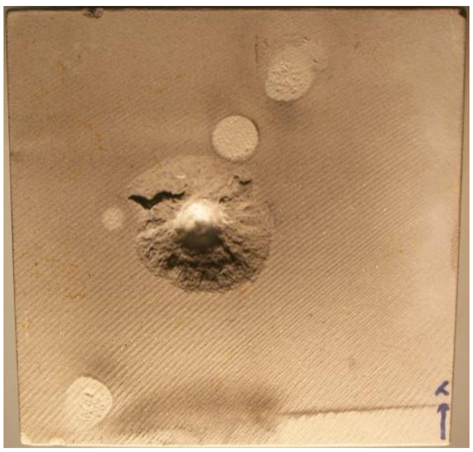

Figure 1: View of the target surface of an experimental impact crater, formed by a 67 mg steel projectile at 5 km/s. Target size: 20cm x 20cm x20cm.

Method for non-destructive measurements: To get an overview of the damage zone beneath an impact crater it is necessary to use several comparative measurement techniques [3], one of which is discussed here. For the MEMIN project the interior of the targets was analyzed before and after the experiments. For these measurements we used ultrasonic (US) tomography and computer tomography (CT) (in cooperation with the Bundeswehr Research Institute for Materials, Fuels and Lubricants, Munich).

The change in P-wave velocity of the damage zone can be resolved with US. However individual cracks (see Figure 2a) can not be resolved. Because CT has a higher resolution than US we identify several cracks, but due to the density and volume of the target, only major cracks > 140 µm (for a target cube with 20 cm edge length) are visible. Combination of the two tomography methods can give a more detailed image of the damage zone. By using diffraction techniques [4] additional information can be obtained using a velocity background model to calculate scatting hyperbolas for each grid-point. [3]

One of the aims of these non-destructive measurements is to give information on the distribution of damage as constraints for numerical modeling of the impact experiments without having to cut open the target and causing unintended additional post-impact damage.

Ultrasonic tomography: The target we discuss is a Seeberger sandstone with 20 cm edge length, a weight of 16.614 kg and a density of 2.076 g/cm^3. The mean P-wave velocity before the impact was 2750 m/s. The steel projectile had a mass of 0.0670 g and a velocity of 5000 m/s. It generated an impact crater with a volume of 8.8 cm^3 and 1 cm depth (Shot Nr. 5124 on block A3 in [1]).

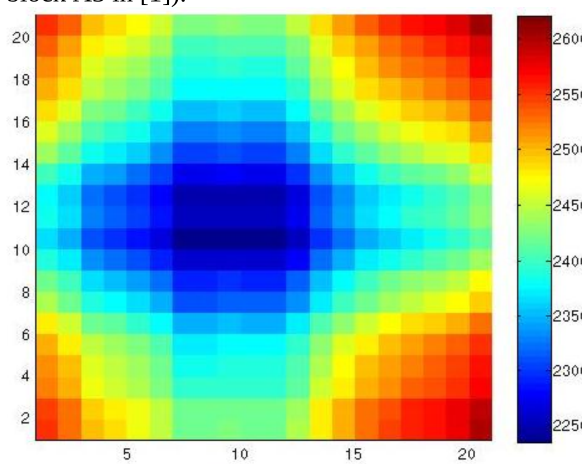

Figure 2 a: Slice in 3 cm depth underneath the impact crater, parallel to the target surface, shown in Figure 1. The slices are 20cm x 20cm with a 1 cm grid. High P-wave velocities are colored red (units in m/s). Dark blue colors in the center identify the crater.

For the tomography we used two modes of ultrasonic sensors with piezo-elements. One sensor functions as an ultrasound transmitter and one sensor as a receiver, which then measures the time-signal to determine the local P-wave velocity of the target. If we have P-wave information at every point at the target from each adjacent point (transmitted by the sensor) we can show a tomography of the damage zone of the target. First results for a simple ultrasonic “tomography" are shown in Figure 2a, 2b and 2c. Here we measured a 1 cm step-size grid alongside three surfaces. In Figure 2b und c a large error occurs at greater depths, due to using the mean value of two perpendicular measurements.

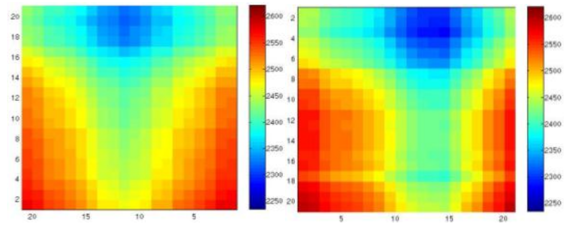

Figure 2 b & c: Each plot shows one slice perpendicu-lar to the target surface located slightly outside of the crater rim. Same grid and color map as in Figure 2a.

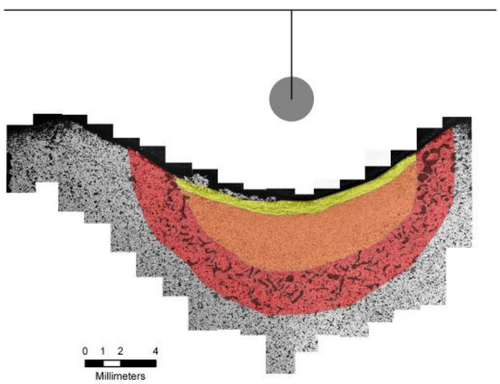

Figure 3: Cross-section of a crater produced under similar conditions. Different deformation zones are shown in colors and were mapped based on SEM images. The deepest compaction features (red zone) have been recognized ca. 2 cm beneath target surface. For details see [7].

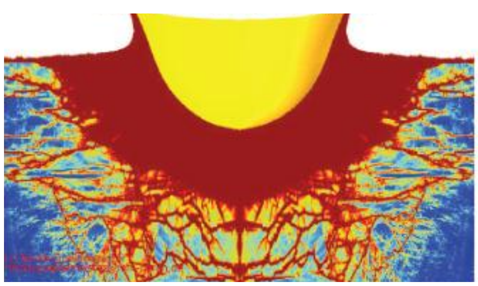

Figure 4: Numerically modeled damage zone of an impact crater. (Wünnemann K., 2Museum für Naturkunde, Berlin)

The three slices in Fig. 2 intersect each other at the point x= 14 cm, y= 6 cm and z= 3cm. The coordinates of the deepest point of the excavated crater are at x= 11.7 cm, y= 10.5 cm and z= 1 cm. The slice in Fig. 2a is located 3 cm below the target surface and is thus only shows the crater subsurface, not the actual crater. Similarly, slices in Fig. 2b&c are also located outside of the crater. Lower P-wave velocities (dark blue in Figure 2), show more intense target damage, while high P-wave velocities (red in Figure 2) represent undamaged areas. This simple "tomography" gives an outline of more detailed results that we intend to produce in the future.

Discussion and conclusion: The current, preliminary results give an outline for a full ultrasonic tomography. But we can clearly see a low velocity zone underneath the crater that extends to 5-10 cm depth by measurements performed parallel to the target surface. The velocity reduction decreases below 5 cm depth, but is still measureable. These results are compatible with the results of [5]. The damage zones mapped by SEM microanalysis of a cross-section of a crater formed under the same impact conditions (Figure 3) reach a maximum depth of about 2 cm underneath the crater surface, or 3 cm beneath the target surface. The reduction of P-Wave velocities at even greater depths is thus presumably related to grain boundary cracking not visible in SEM images. With a higher density of transmitter-receiver measurements we expect to create a higher resolution image of the damage zone underneath the experimental impact craters of the MEMIN project similar to the experiments of [6]. In combination with other nondestructive testing methods described in [3] and additional visual damage characterization [7] we expect to give detailed constraints of subsurface damage for numerical modeling as shown in Figure 4 [8], and thus a better understanding of damage processes at a planetary scale.

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