SUBSURFACE DEFORMATION OF EXPERIMENTAL HYPERVELOCITY IMPACTS IN NON-POROUS TARGETS.

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Introduction: During hypervelocity impact the crater subsurface experiences pervasive deformation. Fracture propagation and the localization behavior of damage depend on mechanical properties of the rock, i.e., dynamic strength behavior, which in turn must be constrained by the mechanical properties of the rock-forming minerals phases. These patterns also correspond to the variation of the stress field that occurs during the propagation of the shock wave. Where pressures in the order of a several GPa above the Hugoniot Elastic Limit (HEL) are achieved, non-porous rocks fail under compression, due to pervasive shearing under differential stresses [1]. When pressures decrease to around the HEL, more localized, tensile deformation can occur in the target, e.g. radial fractures [2]. Our goal is to determine how impact-induced deformation varies between different mineralogically homogeneous, non-porous rocks and address their potential influence on the resulting crater.

Methods: Two hypervelocity impact experiments into quartzite and marble were conducted, using a spherical 2.5 mm steel and iron meteorite projectile, respectively, with densities between 7.8 – 8.1 g/cm^3 and an impact veloc-ity of ca. 5.0 km/s. The crater surface topography was measured with a 3D laser scanner. Craters were sawn in half and thin sections of the crater subsurface were made to analyze subsurface deformation. Orientations of the deformation features were mapped to infer the deformation mechanisms.

Results: Subsurface analysis of the two craters shows that a common feature of both is the development of sub-concentric tensile fractures directly beneath the crater floor due to dilatancy upon pressure release. The maximum depth of tensile failure below the crater floor varies with target material: quartzite 2.2 d_p, marble 1.5 d_p (projectile diameter). The quartzite target additionally shows localized deformation along discrete, 25 to 180 µm wide zones with subradial orientation relative to the impact point. Target material within these zones has a mean grain size of ~ 1.3 - 2.6 µm and thus is highly comminuted. Additionally, they are commonly surrounded by areas with large fractures. Outside of these fault zones the quartzite target suffered only the formation of narrow radial fractures down to a depth of at least 8.5 d_p.

In comparison, the marble target experienced intensive and pervasive intra- and intergranular fracturing, but did not develop the localized fracture zones seen in the quartzite target. The intragranular fractures show a stong correlation to the natural cleavage of calcite and a high percentage of the intragranular fractures is crystallographically orientated. In combination with the intergranular and tensile fractures they led to a much stronger overall comminution in the marble subsurface than in the quartzite. A further impact-induced deformation feature is microtwinning along crystallographic planes in calcite minerals and results in minor crystal-plastic behavior of the calcite. Close to the crater floor several sets of twins per grain developed, but with increasing distance to the crater floor their abundance decreases to a depth of ~2 d_p.

The depth of observable deformation features in quartzite extends down to ~ 11.4 d_p, compared to only 3.6 d_p in the marble target. In both targets, the deformation in the most proximal, highly comminuted area underneath the crater floor seems to be controlled by shear deformation. Such a dominance of one deformation mechanism over others cannot be established in the deeper regions of the crater subsurface.

Discussion: The compressive and subsequent tensile stress fields generated in the shock wave are demonstrated by distinct deformation featuers in both target materials. The strong grain comminution in the localized deformation zones in quartzite indicates compressive failure due to shearing under differential stresses. The apparent absence of deformation in the neighboring areas of the shear zones is probably attributed to the lack of cleavage in quartz. The radial fractures are suggested to form due to hoop stresses in the elastic decay regime [2]. The less localized and more pervasive deformation in the marble target on the other hand can be attributed to the weaker crystal strength of calcite. The excellent rhombohedral cleavage and the possibility of twin formation led to a stronger absorbtion of impact energy by the formation of cleavage fractures and twins. Thus, the shock wave is more effectively dampened than in the quartzite.

Conclusions: First results of SEM microscopy of impacted quartzite and marble target subsurfaces reveal great differences in impact induced deformation mechanisms between the two non-porous target materials. The origin of these differences seems mostly to be found in the dynamic mechanical properties of the main rock-forming minerals. Further investigations will be performed to validate these preliminary results.

References: [1] Ai H.-A. and Ahrens T. J. (2004) Meteoritics & Planet. Sci, 39, 233-246. [2] Poelchau M. H. et al. (2015) LPSC Abstract #2447.