MELTING AND VAPORIZATION OF A STEEL PROJECTILE IN MESO-SCALE HYPERVELOCITY CRATERING EXPERIMENTS.

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Introduction: Impact breccias and crater floor fractures of terrestrial meteorite craters can contain residues of the projectile which are important to decipher the nature of impactors. The emplacement of projectile residue is attributed to either a very early stage of the crater forming process or to later extensional fracturing during central uplift formation [1]. The mechanism by which the emplacement occurs is unconstrained. It could be either emplaced in a vapor phase, as melt droplets or as fine graind solid material. Here, we present first results of hypervelocity cratering experiments [2-4] using steel projectiles and sandstone targets. A large relic of the projectile was recovered and delicate fragments were found at various sites within ejected clasts and crater floor.

Experiments: Two shots have been carried out with a novel and powerful two-stage light gas gun developed at the Ernst-Mach-Institute Freiburg, Germany (EMI) [4]. We fired CrMo-steel spheres (10 mm Ø, 4.1 g; Fe: 97.3 - 98.2 wt%, Cr: 0.8 - 1.1 wt%, Mn: 0.4 - 0.6 wt%, Mo: 0.15 - 0.25 wt%, C: 0.28 - 0.33 wt%, Si:0.15 -0.3 wt%, P: <0.035 wt%, S: <0.04 wt%) with ~5300 ms^{-1} onto blocks of so-called Seeberger sandstone (block size: 100 x 100 x 50cm, grain size: 169+/-8 µm; porosity: 12-20 vol.%)[2, 3]. The experiments were performed under dry (*Exp. 2808)* and wet (*Exp. 280;9* ~44 vol% water saturation) conditions.

Results: Details of the experiments and the obtained craters are given in a compagnion abstract by Kenkmann et al (this volume), and by [2-4]. Estimates of the peak shock pressure in the cratering experiments yielded 50-60 GPa for a very small volume at the projectile-target interface. In *Exp 2808*, 2.84 g of the projectile were recovered from a fiber board mounted ~55 cm above the crater. In *Exp. 2809* no projectile remnants were found in the bunker. The relic (Fig. 1) most likely represents the rear half of the projectile that was spalled when the shock wave was reflected as a rarefaction wave. This relic is a strongly deformed half sphere with a disrupted and highly serrated fracture plane. SEM inspection of this surface shows indications of brittle fracturing (Fig. 2a) under tensile stresses. However, fracturing is intimately linked with melting. Delicate melt filaments bridge the open fissures (Fig. 2a). They indicate a rather low viscosity of the melt. Bubbles and droplets (Figs. 2b, c) indicate a temperature near the liquid-vapor transition of the steel. Striated shear planes exist edgeways of the projectile (Fig. 3a). They contain tiny spheroids. Foam textures of bursted spheroids indicate boiling (Fig. 3b). They may result from shock and shear heating. Preliminary analyses of the composition of melt and spheroids of the projectile relic indicate an iron composition. However, a loss in iron, and admixture of elements like C, Si, Al, and Ca seems to occur and suggests a certain degree of vaporization of target material. In particular phyllosilicate coatings around quartz grains of the target may contribute to this admixture as they are the first phases becoming mobilized and melted upon shock.

Metallic particles, interpreted as residues of the projectiles, were collected from the catched ejecta and the fine-grained material decorating the crater floor surface with a bar magnet. Differences in the abundance of projectile residues have not been established yet in the experiments. Metallic particles collected comprise among others spheroids, similar in shape to spheres produced in gas welding, delicate paramagnetic apophyses (Fig. 4a) and other metallic fragments (Fig.4b) . The branches in Fig. 4 intimately pervade the fine-grained sandstone target and weld the grains. Their one-dimensional expansion is in contrast to an assumed injection process along early fractures, because fractures usually have two-dimensional extensions. The compositional variety of the residues is large and exceeds the range defined by the compositional endmembers projectile, quartz, and pyllosilicate. C is locally enriched.

Discussion: Melting and vaporization of parts of the projectile is in contrast to the proposed maximum shock pressure of 50-60 GPa in the experiments and may indicate local excursion in pressure and temperature within the projectile and near the projectile-target interphase. While the role of water for impact vaporization in our experiments is unclear up to now, the variability and element loss of many analyses may indicate the formation of hydrocarbons, hydrous silicates and hydrous iron oxides; in accordance to [5, 6].

References: [1] Kearsley et al. 2004. MAPS 39, 247-265. [2] Kenkmann et al., 2006. LPSC 37#1587 [3] Wünnemann et al. 2006. ESTEC-Conf. Nordwijk. [4] Schäfer, et al 2006. ESA SP-612 [5] Mittlefehldt, D.W. 2005, In Kenkmann et al (eds) GSA SP 384, 367-390. [6] Gerasimov, M. V. et al., 2002. Deep sea research II, 49, 995-1009.

Fig. 1 Relic of the projectile, Exp 2808, width ~1 cm

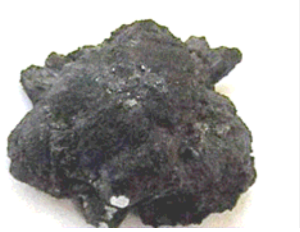

Fig.2a Open projectile fissure decorated with melted iron

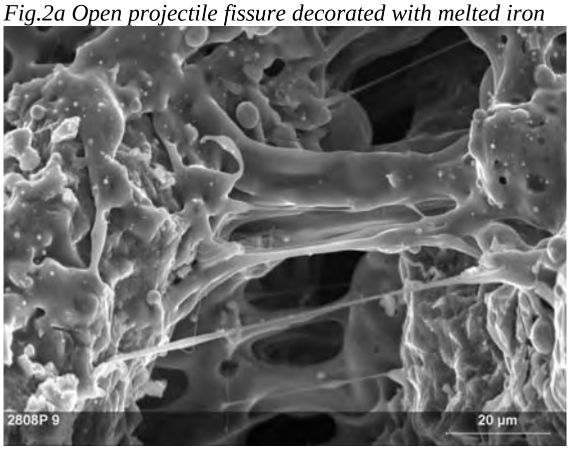

Fig. 2b Bubbles at the projectile surface suggest boiling

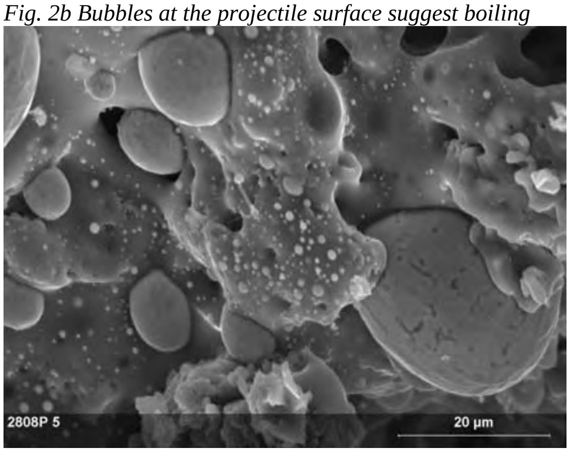

Fig. 2c Delicate melt filaments at the projectile surface

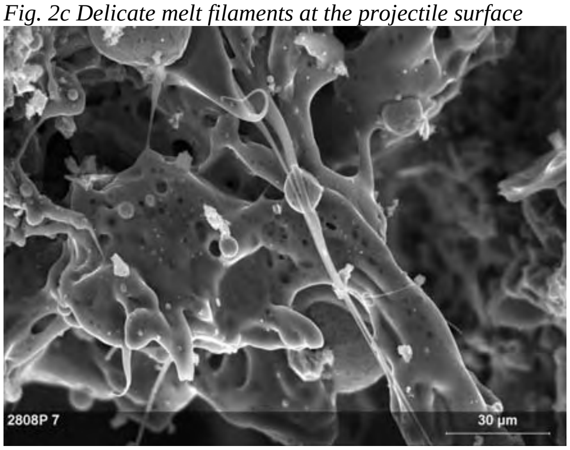

Fig.3a Striated shearsurface edgeways of the projectile

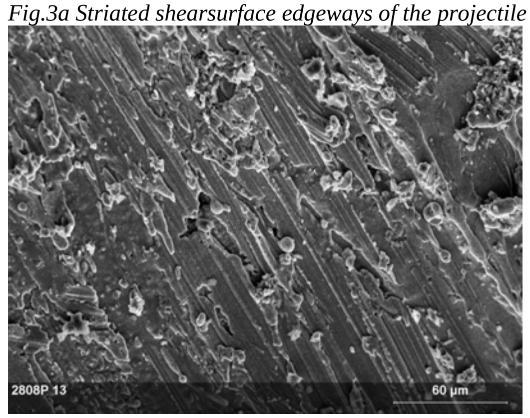

Fig. 3b Shear planes contain spheroids with foam textures

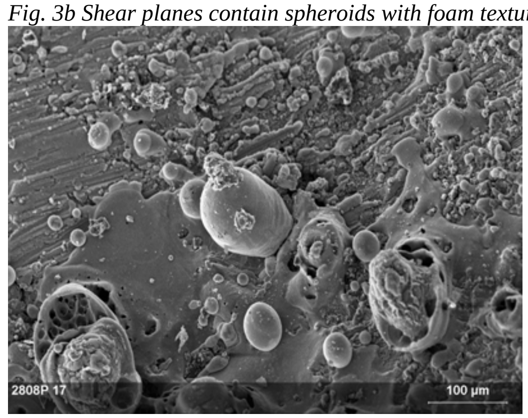

Fig. 4a. Paramagnetic iron-rich apophyses in fragments of the crater floor surface

Fig. 4b. BSE-SEM image of metallic fragment