SHATTER CONES FROM THE MEMIN IMPACT EXPERIMENTS. J. Wilk[1] and T. Kenkmann[1]. [1]Institute of Earth and Environmental Sciences – Geology; Albert-Ludwigs-Universität Freiburg, Albertstrasse 23B, 79104 Freiburg, Germany (jakob.wilk@geologie.uni-freiburg.de)

Introduction: Shatter cones are the only known macroscopic feature considered as evidence for shock metamorphism. Conveniently identifiable in the field, they play an important role for the discovery and verification of impact structures. Nonetheless is the occurrence of shatter cones heterogeneous throughout the crater record and evidently bound to material parameters and boundary conditions. Most authors link the formation of shatter cones with the trailing end of the shock wave [1-3]. However, all existing models are problematic in combining the various surface characteristics, from the conical shape to the horsetail hierachical striation patterns of shatter cones, for that their precise formation mechanism and timing remains enigmatic.

In our study we attempt to constrain the boundary conditions of shatter cone formation by means of impact experiments and aim at a thorough qualitative and quantitative description of the shatter cone geometry. The geometry offers critical tests for the debated shatter cone formation models.

Methods: The cratering experiments have been carried out at the Ernst-Mach Institute in Freiburg with two-stage light gas guns and cubes of sandstone, quartzite, limestone and tuff under dry and wet conditions [4]. By hand picking and stimulated fracturation of the crater subsurface we thoroughly examine the ejecta of our experiments and the crater itself. We carried out morphometric analyses of the millimeter to half centimeter sized conical fragments with curved and striated fracture surfaces using white light interferometry (WLI) and SEM. of. For SEM analysis we used a Zeiss Leo 1525 field-emission scanning electron microscope at the ALU Freiburg. WLI analyses were conducted with a Bruker AXS Contour GT-K0 white light interferometer. The WLI method is an optical non-contact, non-intrusive technique for characterizing surface topography, allowing to measure (i) apical angles of master cones and their sub-cone apices, (ii) the groove-ridge wavelength and amplitude of striated cone surfaces, (iii) the bifurcation distance of fractures and (iv) the curvature of cones on a µm to nm scale.

Results: We recovered several fragments from the MEMIN cratering experiments, showing slightly curved and conical geometries marked by fine striations typical for shatter cones, which is along with the hierarchical horsetailing of the striation patterns distinctive for shatter cones. The 14 shatter cone fragments recovered so far, were found in the ejecta of experiments with 20 to 80 cm sized target cubes of sandstone, quartzite and limestone. They were impacted by aluminum, steel and iron meteorite projectiles with velocities ranging from 4.6 to 7.8 km/s. The projectile sizes ranged from 2.5 to 12 mm in diameter and produced experimental peak pressures of 46 to 86 GPa. The fragments were recovered from intensively crushed material with reduced porosity which has a brightened appearance in comparison to the undamaged rock. The 3D scans (fig.1) and the resulting 3D models with µm-accuracy display morphologies coherent with shatter cones of various terrestrial impact craters. SEM analysis of the MEMIN fragments showed vesicular melt films alternating with smooth polished surfaces (fig.2).

In addition to the conically fractured and striated ejecta fragments, radial sub-cone ridges pointing to the crater center have also been found on bedding planes in the subsurface of a 40 cm sized cube of sandstone in a pilot experiment. The block was impacted by a 10 mm Campo del Cielo meteorite projectile with an impact velocity of 4.76 km/s.

Discussion: We are currently try to constrain the shock pressure interval, and the shock duration the fragments have experienced with the help of numerical models of crater formation. The occurrence of shatter cone fragments in the ejecta of the MEMIN experiments advocates for a formation of shatter cones in the rather early stages of crater formation and after grain crushing and porosity reduction. The targets of the MEMIN campaign were purposely chosen very homogenous in order to limit the effects of larger inclusions or millimeter-sized heterogeneities to the propagation of the shock wave. In this perspective we see a limited contribution of heterogeneities to initiate the formation and control the shape of shatter cones in our experiments. We hypothesize the vesicular melt films observed with SEM predominantly form at strain releasing steps and suggest that shatter cones are probably mixed mode fractures. The thorough description of the horsetailing shatter cone geometry will offer critical tests for the debated shatter cone formation models.

Acknowledgement: Our sincere thanks go to the German Research Foundation (DFG) for funding our project (KE 732/22-1), which is part of the DFG research unit FOR-887: "Experimental Impact Cratering: The MEMIN program".

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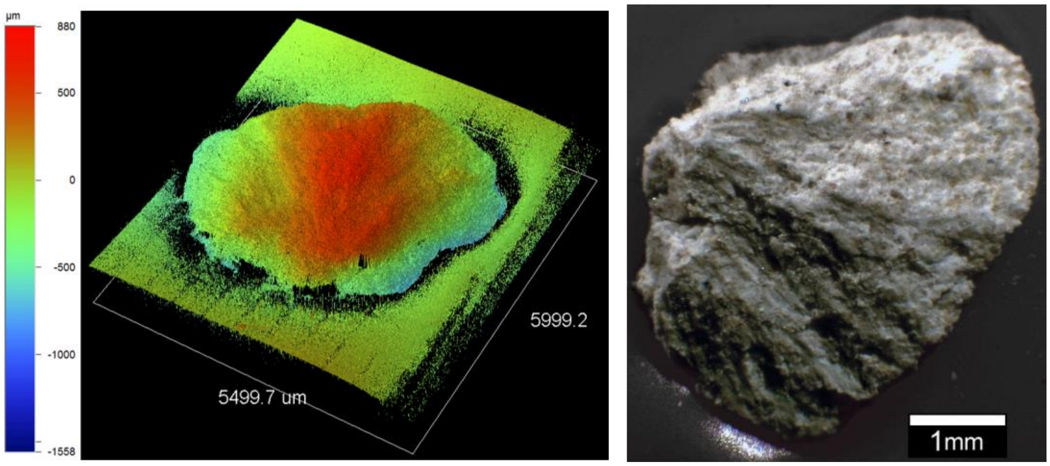

Figure 1: left - WLI scan with the Bruker AXS Contour GT-K0 of the fragment shown to the right, note the curved fracture sur-face and fine diverging striae. right - Fragment recovered from the ejecta of a 20 cm sized sandstone cube impacted by an aluminum projectile.

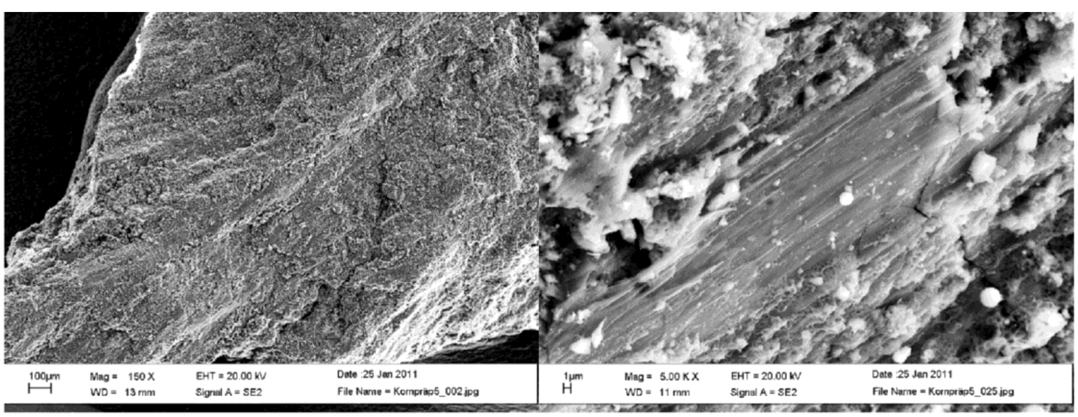

Figure 2: Micrographs showing the shatter cone fragments surface with distinctive striae and steps (SE mode with 20 kV). Note step wise alternation of melt films with smooth polished surfaces. The fragments where also recovered from a sandstone block impacted with 6.97 km/s by aluminum with a resulting maximum Hugoniot Pressure at impact of about 66 GPa.