FORMATION AND KINEMATIC EVOLUTION OF CRATER PITS: ANALOG MODELING. Thomas Kenkmann[1] Ruprecht Zwiessler[1], Hannes Krietsch[1], Institute of Earth and Environmental Sciences, Albertstrasse 23-B, 79104 Freiburg, Germany; Thomas.kenkmann@geologie.uni-freiburg.de

Introduction: The Earth´s atmosphere is an effective protection shield against small-sized asteroids. Depending on their strength, stony meteoroids up to ~100 m usually start to fragment and decelerate during their passage through the atmosphere. These bodies impact the earth´s surface at terminal velocity or retain only a fraction of their initial cosmic velocity. Such impacts are often insufficient to generate shock waves. The cratering process is fundamentally different from real hypervelocity impacts. A recent example for such an impact is the Carancas event on September 15, 2007 that produced a 14 m crater pit [1]. Impacts that are insufficient to create shock waves also occur on planetary bodies without atmospheres in the form of secondary craters, e.g. [2]. However, not all secondary craters are sub-sonic craters. Usually crater pits form in the unconsolidated granular surface rocks like the regolith. To better understand the kinematic evolution of such crater pits in unconsolidated material, we performed experiments with analog material at the University of Freiburg. The cratering processes are recorded with stereo cameras and particles are traced with a particle image tracking-system (PIS).

Methods: The experimental setup consists of a Plexiglas box (40 x 40 x 20 cm) filled with glass beads of 420-840 µm grain size (Fig. 1). Glass beads were dyed with different colors and filled into the box in horizontal layers. The friction coefficient µ for the glass beads is ~0.43. A 6.35 mm spring-driven air gun is mounted perpendicular to the target surface. Projectiles have a diabolo shape and a mass of 2 g. Calculated impact speed and energy are 86.6 m/s and 7.5 J, respectively. For quarter-space experiments the box is reduced to its half size (20 x 40 x 20 cm) with the impact trajectory running parallel to the front plexiglass pane. Two ImagersCMOS Cameras (49Hz) record the impact from above or, in case of quarter-space experiments, from the side. Diameter, depth, and the displacement were determined for each frame.

Results: Figure 2 shows the impact of a lead projectile into sand. Initially a deep V-shaped cavity develops whose penetration depth grows propotionally to the diameter (Fig. 3b) until a maximum depth of about 6 cm is reached after 50 ms. The horizontal marker beds are deflected downward near the penetration hole. This cavity strongly deviates from the parabolical shape of transient cavites that result from hypervelocity impacts. Figure 2 highlights the subsequent modification of this deep cavity and displays the particle vector field. There is no upward motion recorded that could be induced by an elastic rebound or by buoyancy forces. Failure occurs along the flanks of the steep cavity walls. Initially these have slopes of ~60°. The subsequent flank collapse reduces the slope angle to ~25°, which corresponds to the angle of repose of the material. The depth-diameter ratio decreases from 1 to less than 0.2. The final cross section through the crater shows a strongly deformed penetration channel whose depth corresponds to the radius of the final crater pit.

Relevance : The crater pit of the Carancas crater is 10^2 times larger than the experimental crater and has a similar depth-diameter ratio of 0.18 [1]. The scaling factor, *S*, that is important to relate nature with experiments is given by: $S = (C\,\rho_m\,a)/(C_m\,\rho\,g)$, with C and C_m being cohesion in nature and model, ρ and ρ_m being material density in nature and model, and g and a being gravity in nature and model, respectively. Using data for cohesion and density of the Carancas target [1] with that of the material in use, a scaling factor of 100 seems reasonable. The major chunk of the meter-sized impacting meteoroid was never found at Carancas. In accordance to our analog modeling we propose that it may rest at several meters depth beneath the original target surface. However, the penetration depth is a function of the density contrast between projectile and target, which is higher in our experiments than at Carancas.

Reference: [1] Kenkmann, T. et al. (2009) Met. Planet. Sci. 44: 985-1000. [2] Robbins, S. J. and Hynek, B. M. (2011). Geophy. Res. Lett.

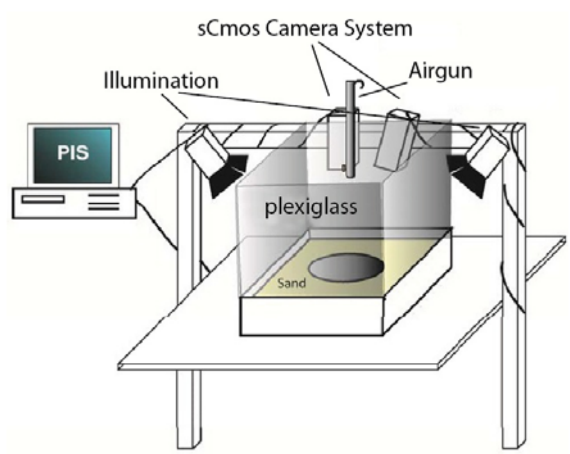
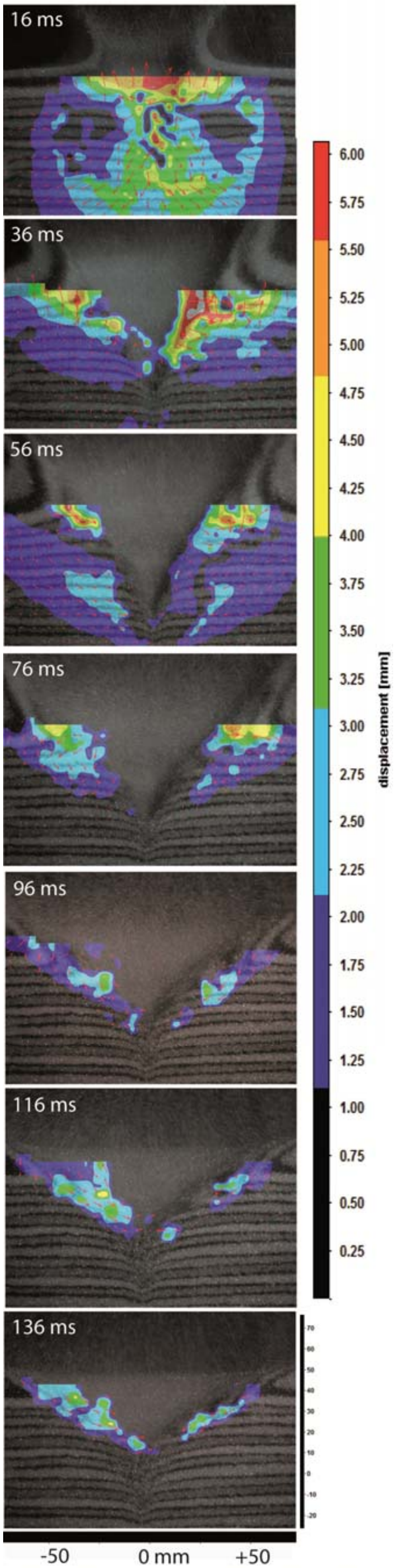


Fig. 1 Experimental set-up. An airgun is mounted above the sandbox, shooting perpendicular into the target. Two cameras film the crater evolution from above or from the side for a quarterspace experiment.



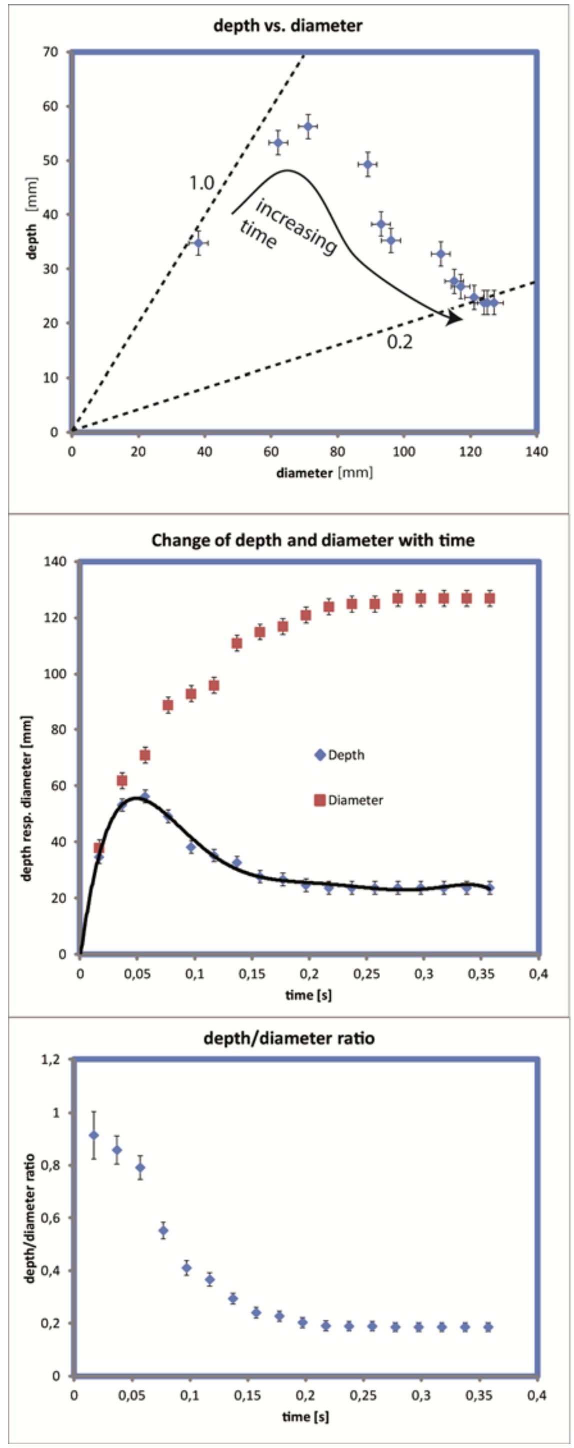


Fig.3 Change of depth and diameter with time. During excavation depth and diameter increase at approximately the same rate. The depth-diameter ratio steadily decreases from ~1 to less than 0.2.

Fig.2 Kinematic evolution of the crater formed in glass beads. The penetration hole is modified into a pit with a depth-diameter ratio of 0.2. Color coding shows the magnitude of displacement between two frames (20 ms). The flow ends after ~300 ms.