ANALOGUE MODELING OF THE COLLAPSE OF AN OVER-HEIGHTENED CENTRAL PEAK: CLUES TO THE PEAK-RING FORMATION AT CHICXULUB?

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Introduction: Peak rings form during the gravitational collapse of large impact craters. The current IODP-ICDP expedition 364 to the Chicxulub impact structure, Mexico, [1,2] was aimed to shed light on structure and formation of a peak ring, and how rocks can be weakened to allow them to collapse and form relatively wide, flat craters. Different models try to explain the formation of peak-rings, summarized in [3]. Here we use analogue modeling to analyze the kinematics of the collapse of an over-heightened central peak in order to study peak-ring formation. In analogue experiments [4] materials like sand or glass beads are used to simulate geological processes on a laboratory scale. Both materials are used to simulate the brittle lithosphere. A scaling factor relates analogue materials to nature.

Experimental set-up: A 3D-printed cast was used to bring analogue material in the shape of an over-heightened central uplift. We used a snapshot of Gareth Collins 2D numerical simulation of the Chicxulub crater formation, very similar to [1], when the central peak reached its highest point. Assuming axial-symmetry we obtained a digital elevation model of the numerical crater. This was then printed out with a 3D-printer as a negative of the crater. The cast has a scale of 1:586'400 ± 6'000. Next, a box to hold the analogue material was manufactured around the cast. The front is made of plexiglass. An aluminum plate at the bottom can be removed to open up the filling-hatch. This allows a complete fill-out of the shape of the cast by turning the box upside down, with the lid held in place by two lashing straps (Fig. 1). To assess the effects of acoustic fluidization a subwoofer was installed beneath the box. Both, frequency and amplitude were varied independently and systematically to generate the vibrations in this study. A sinusoidal audio signal was generated on a computer. This signal was delivered to the speaker with a 50 W subwoofer amplifier, as illustrated in Figure 1. The analogue materials used were glass beads of three different grain sizes. These mechanically characterized materials have been successfully employed in previous experiments [4]. The cast was then quickly lifted and the central peak collapsed. The flow field was recorded in cross-sectional view with a camera at a distance of 80 cm (Fig. 1b). This camera is controlled by the PIV-software DaVis by LAVISION. The kinematics of the collapse was analyzed with the help of particle image velocimetry, revealing a downward and outward collapse of the central uplift. For the particle image velocimetry open source software called PIVlab was used. To characterize the intensity of collapse we determined height H and diameter D of the central peak after collapse. The latter was defined by the lowest points of the annular trough after the experiments. These values were normalized by the initial values H_0 and D_0, respectively. The normalized ratio of height to diameter R_n is given as: $R_n = (H D_0)/(D H_0)$. A low value corresponds to a wider and/or flatter remaining peak and indicates an intense collapse. In total 63 experiments were conducted with three different grain sizes, each tested thoroughly with four different frequencies (50, 80, 110 & 140 Hz) and two different sound volumes for each frequency plus experiments without the speaker being active. The viscosities of a fluidized granular material were independently determined with a PCE-RVI2 (V1R) rotational viscometer by PCE instruments.

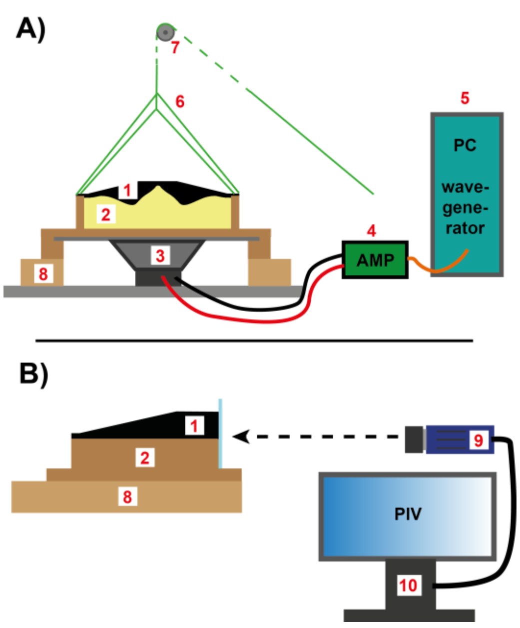

Fig. 1 Experimental setup: 1) crater cast, 2) box filled with analogue material, 3) speaker, 4) amplifier, 5) wave generator, 6,7) lift.

Results: The fluidization produced by the subwoofer had a significant influence on the collapse of the central uplift, notably in the shape of the remaining central peak as well as in the kinematics of the collapse

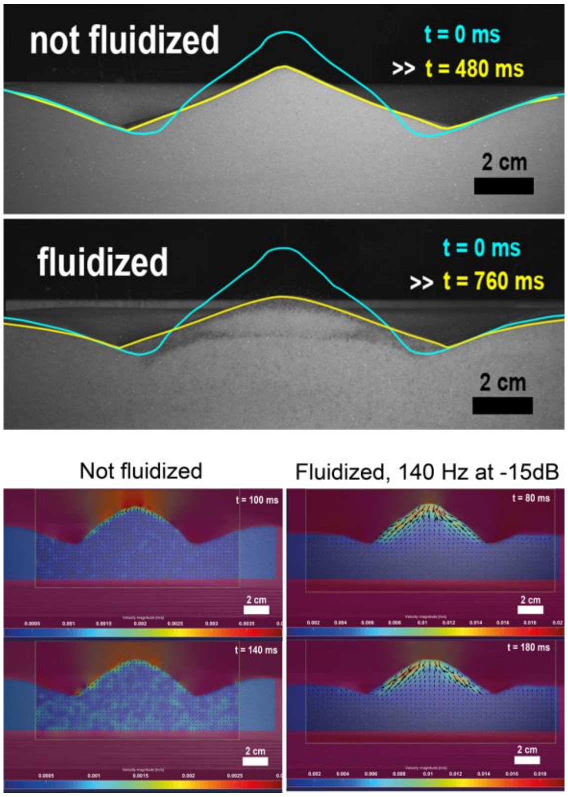

Fig. 2 Comparison of a non-fluidized and fluidized experiment.

as made visible with particle image velocimetry (Fig. 2). Fluidization reduces the height of the remaining central peak and tends to level the morphology: the top of the central peak is not pointy and the slopes are straight, compared to the outcome of an experiment without fluidization. Also, mass movement comes to a halt notably earlier without fluidization. Without fluidization the collapse remains an entirely superficial process, the mass movement is restricted to the outermost layer of the central peak in the form of landslides.

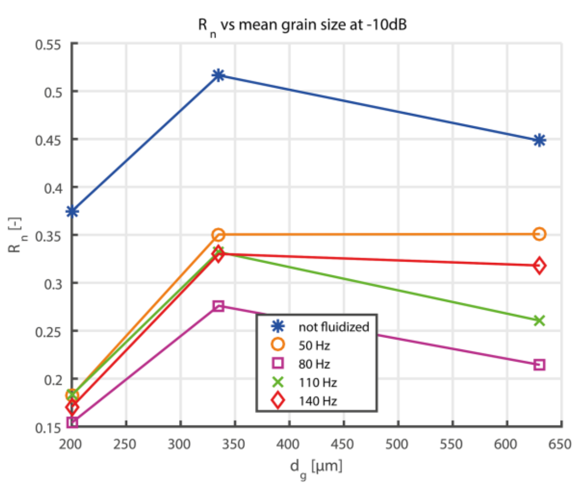

Fig. 3 R_n is plotted as a function of grain size and frequency.

When fluidized, the movement is evidently much more extensive and material deeper inside the central peak is involved (Fig. 2). Also, the maximum velocity achieved is almost three times as high.

Values of R_n are significantly greater for the experiments where the glass beads were not fluidized across all three different grain-sizes (Fig. 3). The grain size itself has a significant influence on R_n as well: the smallest grain size produced the flattest remaining peaks while the intermediate grain size produced the steepest (Fig. 3). The coarsest glass beads have R_n values somewhere in between. While there appears to be a weak trend towards smaller R_n values for higher frequencies, there are many exceptions and with the available data the relationship between frequency and R_n remains inconclusive. A higher sound volume generally produced lower R_n values, 50 Hz was always the least effective frequency at fluidizing the material, and at the higher volume (-10 dB) 80 Hz was the most effective frequency across all grain sizes (Fig. 3).

Discussion: No peak ring could be reproduced in the analogue experiments. A flattened central peak remained instead as the final product of the collapse in the analogue experiments. The resulting morphology is similar to an intermediate stage of the collapse in the numerical model of G. Collins [1]. Like in the numerical model, the collapsing central uplift shows a downward and outward motion and overthrusts the annular trough, though the particle trajectories are partly different. The assumption of a static starting point, as done for the analogue model, is a shortcoming, which might cause that we are not able to accurately reproduce the final stage of the cratering process. In the numerical simulation [1] the crater wall still moves inwards when the uplift reaches its highest extent. Furthermore, at the point of reversal from uplift to collapse of the central peak (our starting point), an equilibrium between the buoyancy force driving the upwards movement and the gravitational force exists. This is not the case in the analogue model, where only the downwards force acts on the glass beads. The results from the viscometer measurements show that the viscosity increases with time, thus fluidized glass beads are rheopex. This may prevent a further collapse and peak ring formation in our experiments.

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References: [1] Morgan, J. V., et al. (2016) 354(6314), 878-882. [2] Morgan, J. V. et al. (2018) Proceedings of the International Ocean Discovery Program 364. [3] Baker, D. M. H., et al. (2016) Icarus, [4] Aschauer, J. & Kenkmann, T. (2017). Icarus 290, 89–95.