The Upheaval Dome impact crater, Utah: Combining structural and numerical data to constrain age, diameter, and amount of erosion.

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Introduction: Upheaval Dome is located in southeastern Utah on the Colorado Plateau. The circular structure represents the remnant of a deeply eroded complex impact crater and provides spectacular insights into the architecture of a crater floor. By combining structural and numerical data we try to constrain the structure in time and space.

Pressure estimates: Shatter cones in sandstones of Moenkopi Formation described by [1] are not fully developed and partly ambiguous. Sets of subplanar microstructures in quartz of the White Rim Sandstone, documented by [1] and [2] are frequent and most commonly represent planar fractures. Up to date we failed to present PDFs with SEM and TEM. This suggests that the presently exposed rocks were affected only by a strongly attenuated shock or pressure wave, most likely below 5 GPa. We found a method to define a lower pressure limit more precisely for the rocks of the innermost part of the central uplift, based on the recognition of deformation mechanisms [3] that are experimentally calibrated with respect to pressure:

The complex occurrence and geometry of the White Rim Sandstone (Fig.1) indicates an almost complete loss of internal coherence during deformation. The sandstone displays extreme thickness variations, blind terminations and frequent embranchments at nodular-like points. This, together with discordant contacts to the country rock, shows that the sandstone builds up a network of dykes that were emplaced and injected during formation of the central rise. Microstructural analyses revealed that the macroscopically ductile appearance is achieved by distributed cataclastic flow. Beside inter- and intragranular fracturing, dislocation pile-ups, dislocation arrays and tangles indicate additional dislocation glide activity in quartz of the White Rim Sandstone during deformation. The undeformed White Rim Sandstone is pure in composition, has a grain size of 140 µm, and a porosity of 19 %. The distributed cataclastic flow was initiated by grain crushing, collapse of pore space, and subsequent intergranular shear. The grain size of the deformed sandstone is 46 µm and contains >40 % comminuted matrix and minor porosity. In accordance to experimental data for a very similar sandstone (Berea sandstone)[4] it is suggested that a high effective confining pressures, in excess of 250 MPa was necessary to cause this flow. At shallow crustal levels (the maximum possible depth of burial of the White Rim Sandstone on the Colorado Plateau is 3 km, corresponding to ~80 MPa) such a high confining pressure cannot be realized by the lithostatic overburden. However, this pressure can be built up transiently by an attenuated pressure pulses during an impact process.

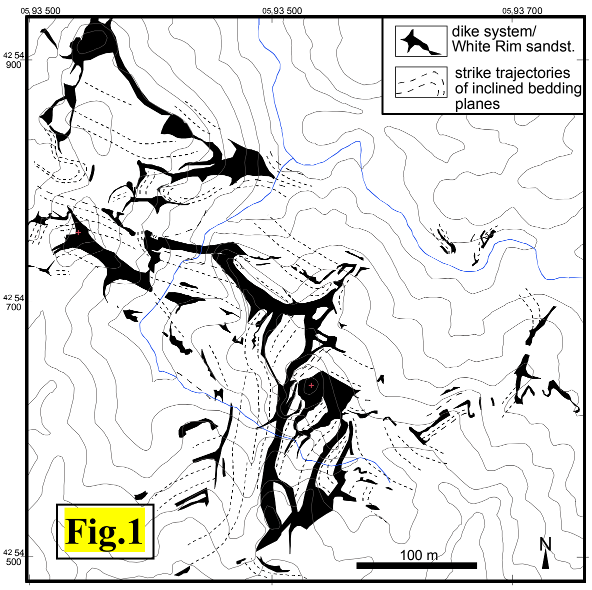

Fig.1

We can conclude: At the present depth below the crater the shock wave attenuated to magnitudes below the Hugoniot elastic limit of quartz but was still well above any possible lithostatic pressure of this region.

Other structural constraints: Triassic and Jurassic layers of the crater display a strata thickening towards the center of the dome and a strata thinning towards its rim (Fig.2). They are a consequence of convergent inward flow during crater collapse. The systematic change in thickness obeys a power law function of the form: $h/h_0 = A\,R^{y}$, with h being the thickness of a layer at a radius R from the impact center, h_0 being the initial layer thickness, and y being a power law factor. The amount of thickening increases from footwall to hangingwall units. Geological cross sections constructed across Upheaval Dome show that the distance of the axis of the ring syncline to the center of the structure increases from footwall to hangingwall units from 1.4-1.5 km (Moenkopi F.) to 1.7-1.8 km (Navajo sandstone) in both NNE-SSW and WNW-ESE profiles.

Fitting a numerical model to the structure: Our pressure estimates and the above mentioned structural features represent the frame numerical models have to be fitted to. Using the 2-dimensional multimaterial Eulerian SALE-B code we simulate the crater formation due to a vertical impact of a spherical asteroid

500 m in diameter with the velocity of 12 km s^{-1}. According to a standard scaling law the impact should produce a complex crater ~7 km in diameter. The mechanical model includes brittle damage, thermal softening and acoustic fluidization of the target [4]. The model allow us to record initial shock compression and the following rock displacement. Fig. 3 demonstrates the final geometry of initially flat strata in the target.

The model shows that in order to achieve a shock compression below 5 GPa in the presently exposed rocks, the Permian-Triassic boundary (white and red strata in Fig. 4) has to be ~2 km below the ancient surface when the bolide struck the Earth. A radius distance of the ring syncline axis of 1.4-1.8 km as observed at Upheaval Dome is found to occur at a depth of 1.6-2.0 km in the best fitted model (Fig. 3).

The strongest increase in layer thickness toward the center of the structure occurs in the numerical model at a depth of 2.075 km (Fig. 2). However, this increase is limited to the immediate vicinity of the center of the structure (below 500 m), in contrast to Upheaval Dome, where an increase in layer thickness is already observed at 1-2 km, pending on the layer. The reason for this discrepancy is not yet clear to us but may depend on the rheological input parameters of the model.

Combining model and observation, the White Rim Sandstone (Uppermost Permian) was at a burial depth of ~2 km when the impact occurred at Cretaceous times during deposition of the Mancos shales (most likely the Emery Sandst. Member). The initial diameter of the Upheaval Dome impact was about 7.5 km.

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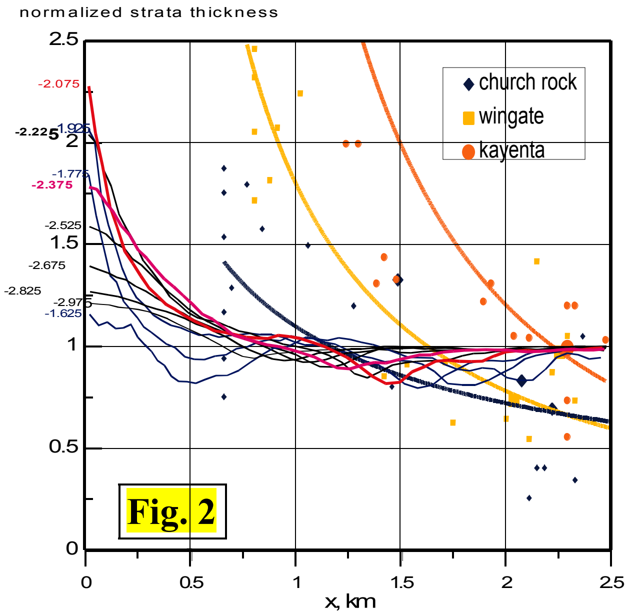

Fig. 2

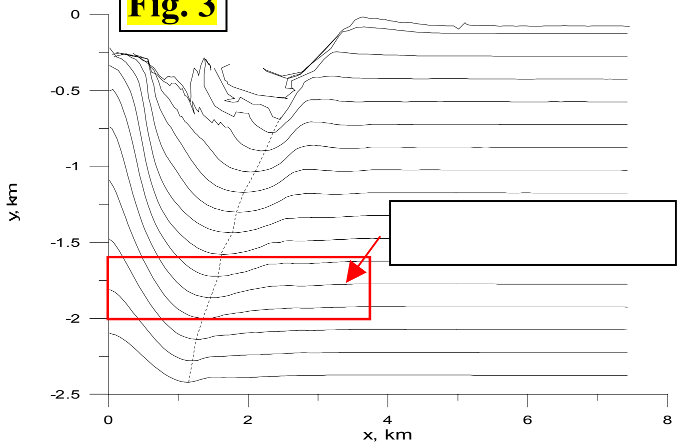

Fig. 3

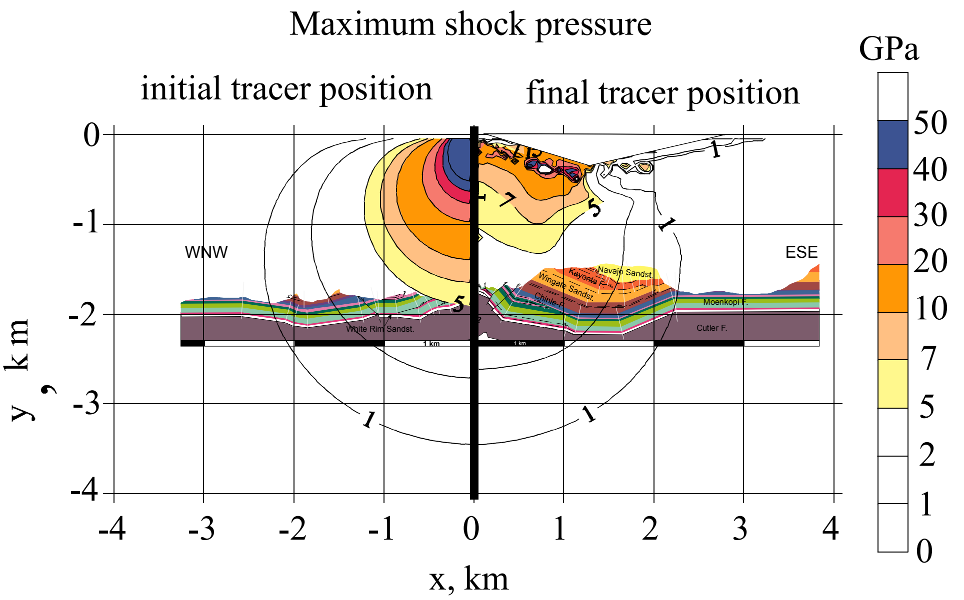

Fig. 4