IMPACTS INTO SALT BASINS: THE ROLE OF SALT MOBILIZATION IN CRATER MODIFICATION AND DEFORMATION. S. A. Kattenhorn and R. G. Daly, Department of Geological Sciences, University of Idaho, Moscow, ID 83844-3022; simkat@uidaho.edu.

Introduction: Crater modification immediately after a relatively large impact event results in a central uplift and rings of deformation of target rocks around the crater center. This process may take several minutes, during which dynamic deformation occurs in the target rocks in response to the shock wave. This deformation is commonly manifested at both the outcrop scale (e.g., pseudotachylyte, shatter cones) and the microstructural scale (e.g., planar deformation features, PDFs, in quartz grains), and provides a means to identify whether or not a suspected impact feature is, in fact, the result of a meteorite impact.

An example of where such evidence has been used to infer an impact event is at Upheaval Dome in southeastern Utah, U.S.A. [1]. This circular feature (Fig. 1) in the Paradox Basin (which is underlain by ~1500 m of Pennsylvanian evaporites), has long been a topic of debate regarding its origins, whether as an impact feature or the result of salt diapirism within the Paradox Basin. The discovery of PDFs [1] favors an impact cause; however, an impact into target rocks that are underlain by highly mobile material (in this case, salt), raises the issue of the importance of such lithological heterogeneity in affecting crater morphology over time scales much longer than the crater modification process immediately after impact. We present evidence that Upheaval Dome and its associated deformation was greatly influenced by salt mobility for an extended period after the impact event. We advocate that such long-term effects may be important for crater modification on other solar system bodies where mobile materials exist below the target rocks, whether these be salt deposits (e.g., Mars [2]) or ductile ice (e.g., icy moons partial to convection-driven diapirism, such as Europa [3] and Enceladus [4]).

Upheaval Dome: Upheaval Dome is a ~5.5 km-wide circular topographic depression in Canyonlands National Park, Utah. Upturned beds around the feature indicate a structural dome located above salt layers in the Pennsylvanian Paradox Formation. Its ambiguous origin has been debated since 1927. The absence of conventional dynamic deformation features such as pseudotachylyte and shatter cones in the siliciclastic rocks that define the circular structure, led many to suggest that Upheaval Dome was not caused by impact. Instead, the feature was variably suggested to be the result of unloading [5], volcanic activity [6], and salt diapirism [7,8,9]. The last of these formed the main counterargument to the dome having formed by meteorite impact, which was nonetheless a widely favored model [10].

Recently, planar deformation features (PDFs) were discovered at the dome [1], which provide diagnostic evidence for meteorite impact. We present field observations that indicate that dynamic deformation during the initial meteorite impact event was overprinted by deformation related to a long-lived period of salt mobility ultimately induced by the impact event.

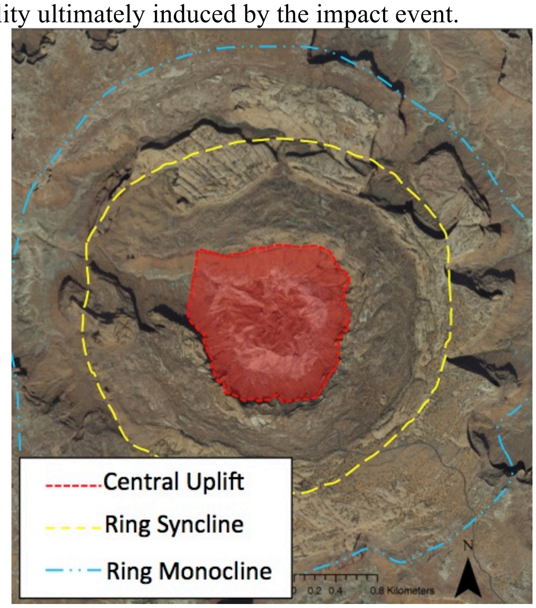

Figure 1: Aerial view of Upheaval Dome, showing its circular geometry defined by ring folds. The central uplift is comprised of Permian units that overlie deeper salt deposits.

Overall Structure: The main structural features of upheaval Dome (Fig. 1) are: (1) an inner central uplift, in which beds have been concentrically thrust upon one another; (2) a ring syncline, which circles the central uplift; and (3) a surrounding ring monocline, where folded beds transition to almost horizontal layers outside of the main structure. This multi-ring appearance superficially bears a resemblance to complex craters. The bowl-shaped crater-like appearance of the feature is a purely geomorphic effect, however, caused by removal of more easily eroded units at the center of the structural dome during uplift of the Colorado Plateau. The circular folding around the structure could also have been produced by diapiric rise of salt into the overlying stratigraphy.

Models that examined the impact event at Upheaval Dome [1] suggest an impact into a Late Cretaceous landscape, meaning that up to 2 km of the stratigraphy is missing since the impact occurred into what would have been a shallow marine setting (the Mancos Sea). Upheaval Dome is thus simply the deeply eroded root of a much larger impact crater. The deep level of erosion may explain the lack of classic impact features such as shatter cones and pseudotachylytes.

Deformation Features: A combination of field mapping and observation, aerial photograph interpretation, and petrographic analysis, was used to identify and characterize both dynamic and slowly-formed deformation features at Upheaval Dome. Shear fractures and deformation bands are both found in abundance at Upheaval Dome in both radial and concentric orientations that are separate from fractures created by the regional stress field. These two distinct forms of shearing deformation within the same lithology ostensibly reflect disparate formation conditions. They are differentiated by unique morphological characteristics, both in outcrop and in thin section. We interpret shear fractures to represent dynamic deformation features associated with the impact event. Deformation bands formed later during long-lived salt diapirism below the original impact site.

Deformation bands (DBs) are tabular, localized deformation features, generally <3.5 millimeters in width, that accommodate offset across a zone of distributed shearing (i.e., no discrete slip plane). This zone is characterized by altered porosity, grain fracture, and grain size reduction. DBs are tectonic features that are exceptionally common in granular materials such as siliciclastic rocks and are well described in the scientific literature [11]. DBs have a multi-stage evolution starting with a stage of increased dilatancy (in which porosity has increased in comparison with the host rock) as individual grains roll and slide against one another. Progressive shearing then leads to a reduced porosity and cataclasis, creating compactional deformation bands (in which porosity has decreased in comparison with the host rock). At Upheaval Dome, DBs show a multi-stage formation (dilatant to compactional to cataclastically sheared) and provide no evidence to suggest that they formed anything other than slowly (i.e., not within the dynamic time-frame of an impact), through progressive shearing over time.

Shear fractures are also ubiquitous around the dome, have a central displacement discontinuity (i.e., a slip surface) within a damage zone a few tenths of a mm wide (i.e., an order of a magnitude less than a DB). Cataclasis of the host rock appears to be the result of motion along the slip surface. This geometry is different to the DBs in the region and is uncharacteristic of DBs in general. The outcrop appearance also differs from the DBs, tending to break the rock mass into polygonal blocks a few cm wide and with negative relief features (whereas DBs tend to be positive in relief). We therefore infer that these features represent a different style of brittle deformation to the DBs. The high frequency, close spacing, and central slip surface of shear fractures suggest that they were formed dynamically.

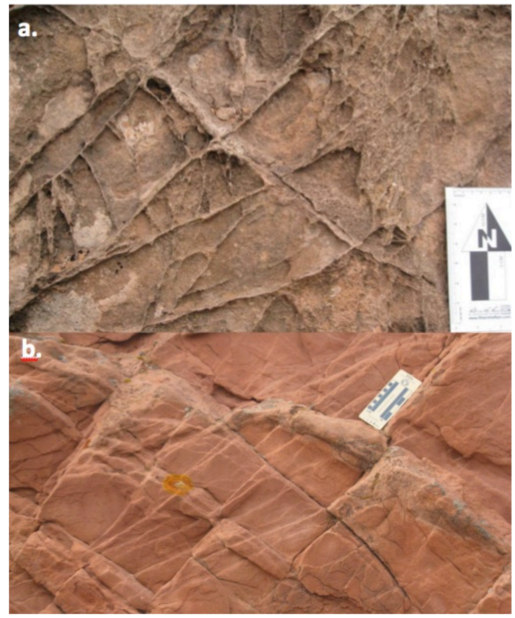

Figure 2: (a) Deformation bands in Kayenta Sandstone at Upheaval Dome. (b) Shear fractures in Kayenta Sandstone.

Conclusion: The wide variety of different fracture types within specific rock units at Upheaval Dome suggest that different formation mechanisms and driving stresses existed at different points in time. The available evidence suggests that both meteorite impact and post-impact salt diapirism contributed to the development of Upheaval Dome, lending credence to both existing hypotheses for the creation of the structure. Ultimately, however, the dome is unlikely to have formed without a triggering meteorite impact event. Similar crater modification may have occurred elsewhere in the solar system where target rocks are underlain by mobile materials.

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