DEFORMATION STYLES AT UPHEAVAL DOME, UTAH IMPLY BOTH METEORITE IMPACT AND SUBSEQUENT SALT DIAPIRISM. R. G. Daly and S. A. Kattenhorn, University of Idaho Department of Geological Sciences (daly6823@vandals.uidaho.edu; simkat@uidaho.edu).

Introduction: Upheaval Dome is a ~5.5 km wide circular topographic depression in Canyonlands National Park, Utah (Fig. 1). Upturned beds around the feature indicate a structural dome located above salt layers in the Pennsylvanian aged Paradox Formation. Its ambiguous origin, either as a salt diapir or a meteorite impact, has been debated for the last 75 years. Recently, planar deformation features (PDFs) were discovered at the dome. Based on current field work we propose two methods of deformation present at the dome: meteorite impact and subsequent salt diapirism.

Based on field and aerial photograph analysis, we have identified and characterized both dynamic and slowly-formed deformation features around the dome. Clastic dikes are representative of the dynamic injection of fluidized material into the surrounding rock, and fractures with dendritic branching patterns may represent dynamic fracturing; however, multiple sets of regular, planar fractures (joints and deformation bands) are common around the dome and point to a slow growth process. We hypothesize that although the discovery of PDFs may seem to be the end of the argument concerning the origins of the dome, post-impact and potentially long-lived salt flow beneath the crater may still have had an effect on the formation of the feature (Fig 2).

Previous Work: The origin of Upheaval Dome has sparked controversy since it was first viewed in the late 1920s. The discovery of planar deformation features (PDFs) at the dome provides strong evidence that it was formed by meteorite impact [1]. They are microstructural planar lamellae that form parallel to specific crystallographic planes in a shocked quartz crystal [2]. Because they are distinct from deformation lamellae produced by other geologic processes they are diagnostic of meteorite impact [2].

Other research that supports a meteorite impact origin for Upheaval Dome has centered on comparisons of the structure of the dome to documented aspects of impact crater morphology in general. Upheaval Dome resembles a complex impact crater in that it has a central uplift surrounded by a depressed ring [3]. Seismic surveys completed at the dome [4, 5] suggest that there is no evidence of salt within 500 meters of the surface of the dome, and that meteorite impact is the main deformation process at the dome. However it has been suggested that the relief observed in the Paradox formation beneath the dome (Fig. 2) may be due to post impact salt flow [4] and, as such, we advocate that diapirism may have had an influence on the deformation present at the dome.

Observations: Field work has focused on observing brittle deformation in and around the ring syncline. This area is pervasively deformed and as such affords many varied examples of brittle failure. This work complements the extensive research done in the central uplift of the dome [6]. Many different morphologies are present, such as joints, deformation bands, and shear fractures. There is also variation within each morphology. Many shear fractures are planar and regularly spaced; however, there are also many sets with a distinct curvilinear shape, the orientation of which varies between each individual fracture. Likewise there are many planar deformation bands, but also many with anastamosing morphologies and distinct truncations suggesting concurrent growth. The mutiple morphologies present at the dome suggest different mechanisms of formation, which may indicate a dynamic impact event followed by a slowly evolving salt diapir. Understanding the formation mechanism, or mechanisms, of the deformation bands present is an especially pertinent question, as it has been suggested that they formed dynamically instead of through progressive shearing over time [7], as is the commonly understood cause.

Just as there are variations within the morphology of a single type of feature in a single lithology, there are also variations in the morphology of features from one lithology to another. Certain lithologies seem to focus deformation, and exhibit a higher frequency of deformation bands that also exhibit prominent positive relief. It is known that different formation mechanisms create different fracture morphologies [8], but lithology may also be a defining factor.

Data Analysis: Data collection sites were spatially georeferenced in ArcGIS. To determine whether such fractures are related to dome formation or are products of a regional stress field, we isolated local from regional deformation by removing three regional fracture sets from the overall dataset. Remaining fracture orientations in tilted beds were then back-rotated to determine original formation orientations.

We categorize the different fracture morphologies observed at the field site as either dynamic or slowly-formed through progressive shearing. Clastic dikes, previously documented at the dome [3, 9], are features formed by the dynamic injection of fluidized material into rock.

Fractures formed by ongoing shearing may have been formed by the movement of salt in the Paradox Formation after meteorite impact. Thin section analysis of these fractures will provide key information about their mode of formation.

Preliminary petrographic results show evidence of grain size reduction and change in rounding and aspect ratio in shear zones. Also present at the grain-size scale are fractures within single grains, undulatory extinction, fluid inclusions and planar lamellae. High temperature silica polymorphs, as well as microstructural pseudotachylyte, are other features that will be searched for in thin section analysis.

Conclusions and Future Research: Field observations lead us to conclude that both dynamically and slowly formed features are present at Upheaval Dome, supporting the hypothesis that subsequent salt movement added to the deformation caused by meteorite impact. However, many questions remain to be answered.

The attempt to unveil any dominant fracture pattern at the dome proves to be a challenge. Work at Vredefort Dome [10] has shown that different deformation features form at various periods in the creation of an impact crater. It is possible that multiple fracture orientations could have formed at different points during the creation of the transient crater, creation of the central uplift, and collapse of the central uplift. However, it is also possible that some fractures formed after beds had already been deformed by the impact, supporting the idea that subsequent deformation may have been caused by salt movement. However, we do see fractures radial and circumferential to the dome, as would be expected for a meteorite impact or with the intrusion of a cylindrical body, somewhat analogous to a salt diapir.

There is very strong evidence that a meteorite impact occurred at Upheaval Dome; however, the dynamics of salt flow and the differences in overburden created by an excavated crater would promote movement of salt in the Paradox [11]. It is important to remember that Upheaval Dome does not represent an impact crater, but an eroded dome that is 1-2 km beneath the original crater. The lack of salt present at the surface of the dome does not rule out deformation of the Paradox Formation in the subsurface. As a result there are numerous non dynamic planar sets of regularly spaced faults and fractures in addition to those formed by the regional stress field.

This study underscores the importance of distinguishing between deformation at an impact site that was formed by the meteorite impact itself, and deformation formed post-impact by other processes. In this case there may be a history of salt flow that, without careful observation, is obscured by the effects of the impact event.

A compelling question raised by the existence of Upheaval Dome is the effect of a meteorite impact into layers of salt. This feature provides the only known opportunity to study such a scenario. With this question in mind, we advocate that strong evidence for a meteorite impact does not necessarily rule out salt movement as a deformation process at Upheaval Dome.

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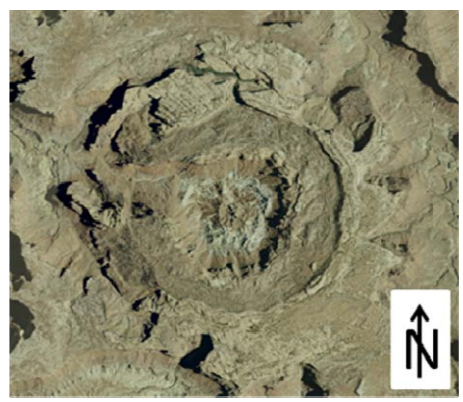

Figure 1. Aerial view of Upheaval Dome, Canyonlands National Park, Utah.

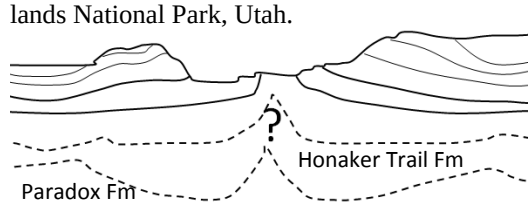

Figure 2. Conceptual cross-section of salt diapirism created by meteorite impact at Upheaval Dome. Figure not to scale. Modified after [4].