GEOLOGICAL AND GEOPHYSICAL STUDIES OF THE UPHEAVAL DOME IMPACT STRUCTURE, UTAH.

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Introduction: Two vastly different phenomena, impact [1] and salt diapirism [2], have been proposed for the origin of Upheaval Dome, a spectacular scenic feature in southeast Utah. Detailed geologic mapping and seismic refraction data indicate that the dome originated by collapse of a transient cavity formed by impact. Evidence that Upheaval Dome is an eroded impact structure includes: 1) sedimentary strata in the center of the structure are complexly folded and pervasively imbricated by top-toward-the-center thrust faulting, 2) top-toward-the-center normal faults are found at the perimeter of the structure, 3) clastic dikes are widespread, 4) the top of the underlying salt horizon is relatively flat, at least 500 meters below the surface at the center of the dome, and there are no exposures of salt or associated rocks of the Paradox Formation in the dome to support the possibility that a salt diapir has ascended through it, 5) the lack of a gravity anomaly over the structure is consistent with the shallow deformation and flat salt horizon inferred from geologic mapping and seismic studies, 6) fan-tailed fracture surfaces (shatter surfaces) and rare shatter cones are present near the center of the structure, and 7) planar microstructures have been found in samples from the clastic dikes in the center of the dome.

Geologic Mapping: Detailed geologic mapping indicates that the dome formed mainly by centerward motion of rock units along listric faults. Outcrop-scale folding and upturning of beds, especially common in the center, are largely a consequence of this motion. We have also detected some centerward motion of fault-bounded wedges resulting from displacements on subhorizontal faults that conjoin and die out within horizontal bedding near the perimeter of the structure. The observed deformation corresponds to the central uplift and the encircling ring structural depression seen in complex impact craters [3]. The apparent depth of erosion of the structure (between 0.1 and 2 km) suggests that the impact occurred either during the late Jurassic/early Cretaceous or during the late Triassic.

Recent study of the rounded cobbles found at Upheaval Dome that were previously interpreted as “impactites” [1] suggests that they may be a lag deposit of chert nodules commonly found at the top of the Navajo Sandstone in the Canyonlands region [4]. Planar microstructures have been recognized in quartz grains in thin sections of some samples, some of which resemble planar deformation features. Results of our continuing studies of these samples will be reported at the conference.

Seismic Reflection Results: We obtained a 5 km seismic section extending radially from the Dome's central depression using a 320 kg weight-drop source and a 48-channel off-end receiver spread 0.5 km long. The data show clear reflections as deep as 1.5 km. Imaging of the reflection section with velocity filtering and 3-D prestack Kirchhoff migration techniques reveals the geometries of deformed stratigraphy from the surface to the top of the Paradox Formation at 1.2 km depth. Stratigraphic terminations and fault-plane images show the paths of listric faults. We tied our sections to two well logs, one in the ring syncline and one outside the zone of deformation. Listric faults flatten and sole into the clastic formations above the calcareous layers of the Hermosa Formation at 1.0 km depth. At the base of the Hermosa, on the axis of the ring syncline, the Paradox has forced the Hermosa 0.1 km up and broken it with thrust faults. Post-impact relaxation of the crater form may have driven this deeper uplift.

Seismic Refraction Results: Refraction rays passing within 500 m below the center of Upheaval Dome show no evidence of early arrivals. Rays passing below Buck Mesa and Syncline Valley have very early arrivals. There is no evidence of any salt diapir below the center of Upheaval Dome [5]. High velocities at depth ringing Upheaval Dome may be due to: 1) an asymmetric bulge of the top of the Paradox; or 2) to the presence of a relatively low-velocity shattered zone at the center of the structure. A central shattered zone is more consistent with the minor deformation of stratigraphy observed on Buck Mesa. A more complete description of our seismic results can be found at:
http://www.seismo.unr.edu/ftp/pub/louie/dome/index.html

Gravity Survey Results: Joesting and Plouff’s gravity data [7] indicated a positive anomaly associated with the structure. Their figure 4 shows a Bouguer map (assuming a density of 2.5 g cm^{-3}) that indicates a positive anomaly of about 5 mGal; in the text they describe the anomaly as +3 mGal. However, they further state that the anomaly is only about +1 mGal when errors associated with the station elevations are considered.

In light of these uncertainties and to constrain the crustal structure, a gravity survey was conducted. Data were collected at each of the seismic refraction stations, along the access road on the southeast side of the structure, and at scattered locations around and within the structure. The Canyonlands region is one of rugged topography; terrain corrections are required and are significant. Near-station corrections are made by hand, hence there is significant uncertainty in estimating the correction. We estimate that the uncertainty in estimating the near-station topography could correspond to perhaps a milliGal. Thus, in order to attach geologic significance to an anomaly, it must have an amplitude of several milliGals.

Our results suggest that no gravity anomaly exists associated with Upheaval Dome. If a reduction density of 2.67 g cm^{-3} is used (a standard reduction density), a positive anomaly of about 5 mGal is indicated. However, this density is significantly greater than that of the sedimentary rocks exposed at Upheaval Dome. If the reductions are made using a density of 2.3 g cm^{-3} (± 0.1 g cm^{-3}), a value more consistent with the density of the rocks, no Bouguer gravity anomaly is indicated.

The absence of a gravity anomaly is consistent with the seismic data that suggest that the Paradox salt formation is essentially flat beneath the structure and the geologic mapping which suggests deformation is limited to shallow crustal levels. Structural deformation of the clastic rocks above a decollement will not significantly affect the density of those rocks, hence a gravity anomaly would not be expected. The absence of a gravity anomaly at Upheaval Dome, vis-à-vis other impact structures, is consistent with the geology. Gravity anomalies at impact structures typically result from the impact breccia layer within the structure and/or higher density rocks exposed in the central peak, both of which are absent at Upheaval Dome.

Fission Track Analysis: In June 1990 we collected samples of all rock types exposed in the central uplift. We collected the same rock types from the walls of the canyon of the Colorado River along the Shafer Trail, 11 km NE of the center of Upheaval Dome. That locality is far enough from the center of Upheaval Dome to have escaped the effects of shock metamorphism from the presumed impact event, but close enough to offer some assurance that we were sampling the same rock units that we had collected within Upheaval Dome. Of the 10 samples acquired (5 from within Upheaval Dome; 5 from Shafer Trail), only two (one from each locality) yielded enough apatite grains to enable us to determine fission-track ages within acceptable statistical limits. Both of those samples were taken from the Moss Back conglomerate near the base of the Chinle Formation. We returned to those two sites in 1994 and 1995 to acquire more samples.

Samples of Moss Back conglomerate from both localities contain abundant woody material; in samples from within Upheaval Dome much of that wood is fully carbonized. A vitrinite reflectance measurement (undertaken by Gareth Mitchell and Alan Davis, of the Coal and Organic Petrology Laboratory of Penn State University) shows no increase in reflectance over non-carbonized wood, suggesting that the elevated temperature that affected the wood in samples from within Upheaval Dome was of short duration. Petrographic study of samples of Moss Back conglomerate from within Upheaval Dome revealed abundant interstitial glass, partially devitrified, and an abundance of a well crystallized mineral phase that we identified as [Ba(0.75), Sr(0.25)]SO_4, a member of a series between Barite ($BaSO_4$) and Strontianite ($SrSO_4$). This mineral may be synthesized in the laboratory at ~1,000°C [6]. Neither the interstitial glass, the sulfate mineral, nor the carbonized wood was observed in the sample of Moss Back conglomerate collected from Shafer Trail Road.

Even in these two samples, apatite is not abundant, and must be hand-picked from the heavy-mineral fraction. To improve the statistics of the track-length measurements, we will irradiate the samples with neutrons from ^{252}Cf to expose horizontal confined tracks in the interior of the apatite grains to the etchant. We expect to be able to announce a fission-track age, a track-length histogram, and a modeled thermal history for each sample at the meeting.

Summary: Stratigraphic uplift observed in the center of Upheaval Dome is the result of convergent displacement of the wall of a transient cavity formed by hypervelocity impact, not Paradox salt diapirism. Geophysical studies indicate that the top of the Paradox is deformed up to 100 m vertically, but the top of the Hermosa appears undeformed. At least 5 km in diameter, Upheaval Dome is the largest recognized impact structure on the Colorado Plateau.

References: [1] Kriens, B. J. *et al.* (1997) *BYU Geol. Studies, 42,* Part II, 19-31. [2] Jackson, M. P. A. *et al*. (1998) *GSA Bull., 110*, 1547-1573. [3] Wilshire, H. G. *et al*. (1972) *USGS Prof. Paper 599-H*, 42 pp. [4] Pipiringos, G. N. and R. B. O'Sullivan (1975) in *Canyonlands Country: Four Corners Geol. Soc. Guidebook, 8th Field Conference*, edited by J. E. Fassett, pp. 149-156; Peterson, F., and G. N. Pipiringos (1979) *USGS Prof. Paper 1035-B,* 44 pp. [5] Louie, J. N. *et al.* (1995) *Eos, 76*, 337. [6] Mitchell and Davis (1995) pers. comm. [7] Joesting, H. R. and D. Plouff (1958) *Utah Intermountain Assoc. Petrol. Geol., 9th Annual Field Conf.*, 86-92.