UPHEAVAL DOME IMPACT STRUCTURE, UTAH, E. M. Shoemaker, U.S. Geological Survey, Flagstaff, AZ 86001, and K. E. Herkenhoff, Caltech, Pasadena, CA 91125.

Upheaval Dome, a spectacular scenic feature in Canyonlands National Park, Utah, first noted in 1927 [1], is at the center of a circular structure about 5 km in diameter. Complexly faulted, uplifted rocks of the dome are surrounded by a structurally depressed ring of rocks that is also complexly faulted. McKnight, who mapped Upheaval Dome at a scale of 1:62,500 and gave the first detailed description [2], considered that the structure might be of cryptovolcanic origin; however, he favored the hypothesis that the central uplift and surrounding structural depression were the result of salt flow in the underlying Paradox Formation of Pennsylvanian age. Bucher, on the other hand, firmly advocated a cryptovolcanic origin [3]. Boon and Albritton suggested that many structures originally interpreted as cryptovolcanic in origin by Bucher are of impact origin [4]. Shoemaker [5,6] earlier supported the interpretation of Bucher, on the basis of deformation observed near the center of the dome and the results of geophysical surveys by Joesting and Plouff [7]. In the last two decades, however, the evidence has become compelling that Boon and Albritton were right. A reexamination of the structure at Upheaval Dome in the light of current knowledge about impact craters, therefore, seems appropriate.

The rocks exposed at Upheaval Dome include, in stratigraphic order upward, the Moenkopi and Chinle Formations and the Wingate Sandstone of Triassic age, the Kayenta Formation of Triassic (?) age, and the Navajo Sandstone of Triassic (?) and Jurassic age. In addition, clastic dikes [5,6] composed of crushed grains of quartz derived from the White Rim Sandstone Member of the Cutler Formation of Permian age are intruded near the center of the structure. Exposures are superb, and deep canyons permit mapping of the structure in three dimensions to an extent not possible at any other known impact site.

Our 1983 field work revealed that most of the strongly deformed rocks at Upheaval Dome are bounded by a series of listric faults that had not been recognized earlier. Thinning of the Wingate, observed by McKnight on the east side of the structure [2] and by J. H. Stewart on the south side [7], is due chiefly to its truncation by these faults. Beds of the Wingate, Kayenta, and Navajo are displaced toward the center of the structure along the listric faults. Around the periphery of the structure, the faults dip at relatively low angles toward the center, and displacement is normal or nearly parallel with the bedding. Nearer the center, the faults flatten and then rise on the flanks of the central uplift, where displacement becomes reverse. From the deepest part of the annular structural depression inward, each formation generally rests with fault contact on the subjacent formation. On the flanks of the central uplift, beds of the Kayenta are duplicated by many thrust faults that are basically branches of the rising listric faults. The apparent thickness of the Kayenta is locally more than doubled by this thrusting. Still closer to the center of the structure, the Wingate has been deformed by convergent flow into tight and open folds [5,6,8] that plunge away from the apex of the dome. At the center of the dome, beds of the Moenkopi are highly deformed and are duplicated by many small thrusts.

The convergent displacement of the rocks at Upheaval Dome is similar to that observed in impact structures at Sierra Madera, Texas [9] and at Gosses Bluff, Australia [10]. Displacement above the listric faults probably is due chiefly to collapse of a large transient cavity produced by impact. This style of deformation is incompatible with the stresses that occur in the rocks above salt diapirs, where observed displacement is divergent.

Beneath the listric faults, the exposed section of beds from Moenkopi through Kayenta is deformed in a broad structural dimple, the margin of which extends in most places slightly beyond the preserved limit of the listric faults. Such a dimple is expected to develop in soft stratified rocks at considerable depth beneath large impact craters, as a result of downward and lateral flow of the rocks engulfed by shock. Growth of the central uplift at Upheaval Dome, which includes rocks that lie below the listric faults, may be the result partly of early convergent flow in the shock wave during opening of the transient cavity, and partly of late-stage collapse of the cavity. The presence at depth of the Paradox Formation, which contains beds of salt and shale of low yield strength, may have facilitated development of both the structural dimple and early growth of the uplift at the center of the dimple.

On the northeast and west sides of the structure, the Wingate is locally in contact with the Chinle along nearly horizontal faults. These faults occur well below the listric faults. Tilting of the Wingate toward the center of the structure and truncation at the base of the Wingate of its progressively higher beds toward the center of the dome suggest either that the Wingate has been thrust outward over the Chinle or that relatively plastic beds of the Chinle have flowed inward beneath the Wingate. We interpret this displacement as having occurred during passage of the shock wave.

Preliminary petrographic study of the clastic dikes near the center of the dome shows that the dike material has been shock metamorphosed. The dikes are in contact chiefly with the lowermost units of the Moenkopi; the material of the dikes has clearly been derived from the immediately subjacent White Rim Sandstone. Under the hand lens, however, the dike material is much finer grained than normal White Rim Sandstone and less than 20% of the original detrital sand grains have survived. Under the microscope, the dike rocks are found to consist largely of sharp angular shards of quartz ranging from 10 to 100 μm across. Relatively few grains with planar features or lamellae of probable shock origin were found. The observed metamorphism corresponds approximately to that of class 1b shocked Coconino Sandstone at Meteor Crater, as defined by Kieffer [11].

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Exposure of the structural dimple that lies below faults related to collapse of the transient cavity indicates that the dome has been deeply eroded. The dimple is 5.2 km in average diameter, and the diameter of the transient cavity probably exceeded that of the dimple by 20% to 30%. If we assume a depth-to-diameter ratio of 1:5 for the transient cavity, its initial depth probably was about 1.3 to 1.4 km. At least 1 km of strata has been removed by erosion since the dome was formed. If the final collapsed crater was 30% larger than the transient cavity [12], the final crater diameter probably was about 8 to 9 km. Upward extrapolation of the outermost listric faults to this diameter suggests that about 2 km of rock has been eroded from the region around the crater [Fig. 1]. Restoration of this thickness of strata implies that the impact occurred near the end of Cretaceous or in Paleogene time.

Upheaval Dome is in the north-central part of the Colorado Plateau, a region of about 3.4×10^{5} km^{2}. The average age of the Phanerozoic strata exposed on the Plateau, weighted by area of exposure, is 1.6×10^{8} yr. Adopting an estimated rate of production of impact craters ~10 km in diameter of 2.4×10^{-14} km^{-2} yr^{1} for the late Phanerozoic [12], about one impact structure corresponding to a crater in this size range should be exposed on the Colorado Plateau, provided that there has been no loss by erosion of a structure this large. The strata are nearly flat lying across 95% of the Plateau, and large structural anomalies are exceptionally easy to detect. As the bedrock exposures are among the best in the world, it is unlikely that an eroded structure corresponding to an impact crater on the order of 10 km in diameter would have been missed in the course of the geologic mapping of the region. Upheaval Dome approximately fulfills the statistical expectation for a large impact structure on the Colorado Plateau, and no other candidate impact structure of its size has been found. It was precisely this calculation that triggered our investigation.

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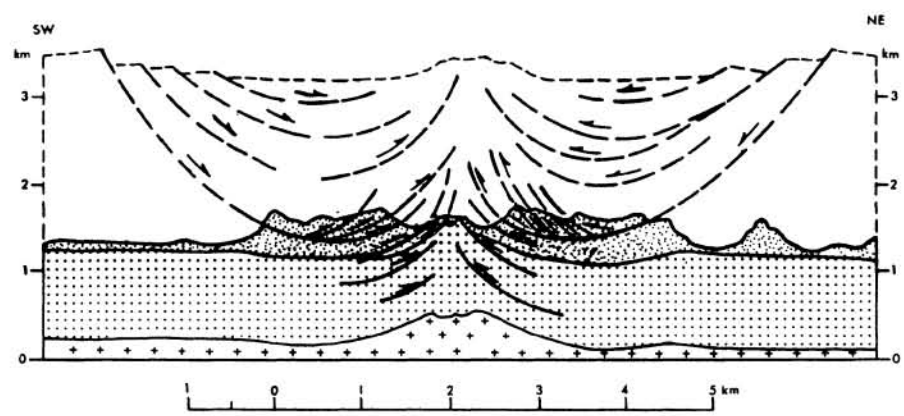

Figure 1. Schematic cross-section through Upheaval Dome, modified after [2]. Paradox Formation shown with crosses; Pennsylvanian rocks above Paradox and Permian rocks shown with coarse stipple; Mesozoic rocks shown with fine stipple.