DIFFERENTIAL VERTICAL AND RADIAL DISPLACEMENT ALONG FAULTS IN THE CRATER WALL DURING THE FORMATION OF METEOR CRATER, AZ. C. Adeene Denton[1,2,3] and David A. Kring[2,3], [1]Rice University, 1600 Main Street, Houston, TX, 77005, [2]Lunar and Planetary Institute, 3600 Bay Area Blvd, Houston, TX, 77058, [3]NASA Solar System Exploration Research Virtual Institute.

Introduction: The excavation phase of crater formation uplifts lithologies in the crater wall, producing a topographically high rim that is further heightened by overturned impact debris. In the case of Barringer Meteorite Crater (a k a Meteor Crater), that uplift was influenced by pre-existing tectonic joints in the target rocks (e.g., [1]). Motion along those joints produced near-vertical faults [2] that created differential motion parallel to the joint systems. The outcome is a square-shaped crater in plan view rather than a circular one. While those faults are well-known [2-5], the motion accommodated along them has not been studied in any detail. To address that issue, we collected structural data and remapped the fault structures in the southeast corner of the crater to determine the types of motion that occurred during the crater-forming process and how they affected the overall morphology of the crater.

Study Site: Meteor Crater is a simple crater ~1.2 km in diameter excavated from mostly horizontal strata consisting of the Coconino Sandstone (~220 m), sandy Toroweap Fm (3 m), dolomitic Kaibab Fm (~80 m), and the sandstone and siltstone of the Moenkopi Fm (2-10 m) [2, 6]. All of these units are visible in the southeast corner of Meteor Crater.

Description of Sections: The crater wall in the study area contains three separate blocks, referred to here as A, B, and C, that are separted by two large faults, F_1 and F_2 (Fig. 1). Both faults branch, F_1 near the base of the exposure and F_2 near the top. The strata in block A were uplifted 45 m higher than block B along F_1, which represents the largest near-vertical offset in the crater walls [2, 3]. Due to this offset, a significant amount of Coconino strata is exposed in block A, which is unusual in the walls of the crater. Above the Coconino is a 40 m section of Kaibab, which represents only the lower half of the Kaibab stratigraphy present in the target area, followed by a blanket of Kaibab and then Coconino ejecta. The uplifted strata in block A have an average dip of 35º as measured in the field and the exposed face of block A has a steep slope of 46º as measured from a 25 cm-resolution LiDAR-derived slope map [7].

Block B is between faults F_1 and F_2 and is heavily deformed; the strata, as measured at the Toroweap-Kaibab contact, were uplifted 78 m relative to their pre-impact positions. Coconino is exposed at the base of the block, but not as extensively as in block A. Above the Coconino is 56 m of shattered Kaibab, which contains several radial, conical, and concentric fractures [5] and smaller faults with gouge that reflect motion along those planes. The upper Kaibab in the target area contains a white sandstone marker bed, which is evident in block B, but does not continue across F_1 into block A. Above the Kaibab lays overturned Kaibab and Coconino ejecta. Moenkopi is not exposed in either blocks A or B and presumably is hidden within the overturned Kaibab. The strata in block B have an average dip of 46º and the exposed face of block B has an average slope of 42º.

Block C lays on the lower side of F_2 and is the most similar to the rest of the crater's wall. It is much less deformed than blocks A and B, and the strata were uplifted less (69 m) from their pre-impact elevations. Toroweap and a small amount (<1 m) of the uppermost Coconino are visible at the base, followed by a complete 80 m section of Kaibab, then Moenkopi bedrock and Moenkopi ejecta. The sequence is capped by Kaibab and Coconino ejecta. An exposure (C' in Fig. 1) of Moenkopi caught between two branches of F_2 is not as complete; most of the basal Wupatki Mbr is missing and the overlying Moqui Mbr is thin. The uplifted strata in block C have an average dip of 14º and the exposed face of the block has an average slope is 35º.

Relative Motion: The vertical offsets along the two main faults, F_1 and F_2, are significantly different. The offset along F_1 was previously measured to be 45 m [2]. We measured 7.3 m of offset along F_2 at the base of blocks B and C; at the top, most displacement (8.2 m) was carried by the right branch of F_2, with only 0.9 m along the left branch.

The relative motion along both F_1 and F_2 is the same: right lateral. Block B is caught between F_1 and F_2, and the differential motion between the two faults rotated and tilted the Kaibab strata, lifting the eastern edge of the block ~5 m higher than the western edge, and shattering the strata throughout the block. A section of Moenkopi in block C is caught between the branches of F_2 (C'). A stereographic analysis of strike-dip data indicates the strata were folded by both vertical and radially-directed drag along the left branch of F_2, rather than a simple overturning of the rim sequence.

Differential motion along the near-vertical faults in the crater wall has been qualitatively described before [2-5]. Our measurements indicate there is also an important radial component of motion along the faults. The stratigraphic differences between blocks B and C can be attributed to this radial motion – block B was shoved much farther outwards from the crater center. To keep uplifted Moenkopi bedrock and Moenkopi ejecta hidden inside the Kaibab fold hinge of block B, it must have been displaced radially 1 to 20 m farther than block C along F_2. Furthermore, strata in block A have a much lower dip than in block B, indicating that, though both blocks lack exposed Moenkopi, block B moved farther outwards from the crater center; the displacement between the two is perhaps in the range of tens of meters.

The truncation of the upper Kaibab in block A (Fig. 1) and the missing white sandstone marker bed requires an additional type of structural deformation. As seen elsewhere along the top of the south crater wall [8, 9], the Kaibab here was removed from the upper crater wall when it was sheared radially outward in a sub-horizontal wedge. The shearing could have cut through the upper part of the crater wall sequence in several ways; e.g., by removing both the upper half of the Kaibab as well as the Moenkopi or instead by removing only the upper Kaibab and leaving the Moenkopi intact but hidden. Radial displacement of the upper Kaibab may explain the abnormally thin layer of ejecta on that section of the crater rim and the thickened section of ejecta about 40 m beyond the crater rim that is seen in drilling logs [10, 11].

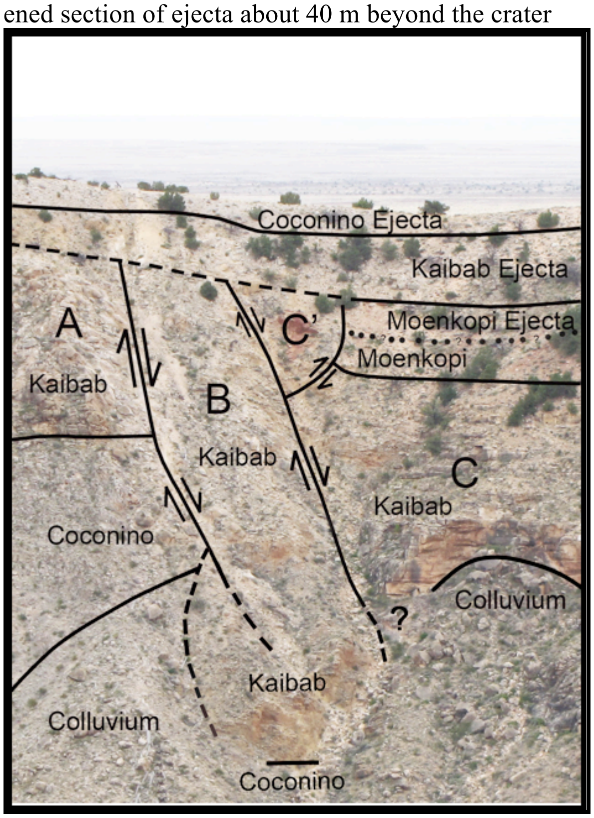

Fig. 1. The southeast corner in plane view. Note the differences in Kaibab thickness between A, B, and C, as well as the increasing presence of Coconino. One to 3 meters of Toroweap occur at the top of the Coconino section.

Consequences of Motion: The effects of vertical and radial faulting in the southeast corner extend to the topographically uplifted rim, which follows an anticline-syncline-anticline pattern that manifests as a trough between two ridges. The pattern can be followed in the Coconino ejecta, which remains visible across the entirety of the corner despite changes in rim elevation. Any backwards thrusting in block A that removed the upper half of the Kaibab could have uplifted the rim. The rim also appears to be radially differentiated, with rim sections offset with respect to the crater center. While one of these offsets appears to align with F_1, the emphasis may be an erosional artifact rather than tectonic influence. The southeast corner is defined by the unique combination of tear and radial faulting in its walls, which in turn helps define the crater's square-like shape.

The faults do not appear to extend upwards into the ejecta (indicating motion along those faults stopped before ejecta was emplaced), and are buried beneath colluvium near the crater floor. Overall, vertical and radial motion along fault planes in the southeast corner has drastically affected the stratigraphy, shattering and in some cases removing sections of rock completely. Shoemaker [2] mapped the near-vertical fault structures, but motions that occurred along those and other faults surfaces during the excavation of the crater were much more complex than previously appreciated.

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