DISTRIBUTION OF DISCONTINUOUS KAIBAB EJECTA NORTH OF METEOR CRATER, ARIZONA.

D. A. Kring[1,2], C. Atwood-Stone[3], A. Boyd[4], J. Brown[5], L. Corley[6], N. Curran[7], C. Davis[8], K. Korman[9], A. Maine[10], F. McDonald[7], S. Montalvo[11], R. Nuno[12], S. Oezdemir[13], K. Rathbun[14], N. Rhodes[15], H. Susorney[16], D. Weiss[17], and M. Zanetti[18], [1]Center for Lunar Science and Exploration, USRA Lunar and Planetary Science Institute, 3600 Bay Area Blvd., Houston, TX 77058 USA (kring@lpi.usra.edu), [2]NASA Solar System Exploration Research Virtual Institute, [3]Univ. Arizona, [4]Arizona State Univ., [5]Univ. New Brunswick, [6]Univ. Hawaii at Manoa, [7]Univ. Manchester, [8]Univ. Western Ontario, [9]Temple Univ., [10]Northern Arizona Univ., [11]Univ. Puerto Rico at Mayaguez, [12]Univ. California Los Angeles, [13]Univ. Vienna, [14]Univ. Iowa, [15]Univ. Texas at El Paso, [16]Johns Hopkins Univ., [17]Brown Univ., [18]Washington Univ.

Introduction: Shoemaker's classic map of Meteor Crater [1] provides a clear picture of the continuous ejecta blanket, but the map is complete to only 1 crater radii and extends to only 1.75 crater radii in two limited areas. No attempt was made to map discontinuous ejecta. He later suggested [2] that a Moenkopi ridge north of the crater was once covered with ejecta, but that the material was redeposited as Pleistocene colluvium and alluvium. In contrast, Grant and Schultz [3] briefly described distal ejecta lobes on the southern flank of that same ridge (see their Fig. 12). To clarify the origin of that material, we mapped the entire Moenkopi ridge and adjacent areas. That mapping indicates there is a significant amount of discontinuous Kaibab-rich ejecta far beyond the area originally mapped by Shoemaker [1].

Description of Mapped Lithologies: The bedrock in the area is the Moqui Member of the Moenkopi Formation [2], which forms a ~20 ft (6 m) high ridge that is cross-cut by vertical pre-impact tectonic joints. Two-hundred-six measurements of the bearings of those joints indicate a dominant set at 117 ± 2.1º and two minor sets at 20-40º and 150-155º. The dominant set is consistent with the orientation of joints measured elsewhere in the vicinity of the crater [4,5]. Joints exposed on the edges of the ridge can be traced with vegetation lines across the top of the ridge and the landscape beyond the base of the ridge (as in [5]). Those vegetation lines are used to map bedrock Moenkopi in areas of shaly Moenkopi scree, in contrast to Shoemaker who mapped such areas as alluvium.

On top of the Moenkopi are twenty-two patches of ejecta that are dominantly Kaibab (Fig. 1), but which also contain Moenkopi fragments and meteoritic material. Some of the patches were once laterally continuous deposits, but have been dissected by erosional channels. The Kaibab debris ranges in size from <5 mm to boulders ~3 m in diameter. Also entrained in the debris are (a) cobbles of lithified breccia similar to the Kaibab-Moenkopi breccia seen in the crater walls at the Permian-Triassic boundary (Chapter 15 of [6]) and (b) Moenkopi, although the proportion of Moenkopi deposited with the Kaibab is difficult to assess because the material landed on Moenkopi. The pebble-rich Kaibab veneers are a few centimeters to 20 cm thick, with Kaibab cobbles and boulders rising above the surfaces for total thicknesses up to 3 m.

Fig. 1. (top) Kaibab ejecta on a ~6 m high Moenkopi ridge ~1.2 km beyond the crater rim. (bottom) Discontinuous ejecta can be nearly 100% Kaibab (as seen here), although it also contains cobbles of the Kaibab-Moenkopi boundary breccia and pebbles of Moenkopi (as seen outside the frame of this image).

Additional Kaibab-rich veneers lie northwest and northeast of the Moenkopi ridge. The Kaibab could potentially be a partially deflated surface, but it cannot have been transported by colluvial or alluvial processes, because there are no topographically higher source regions, unless one appeals to the distant crater rim on the other side of a stream channel that Shoemaker [2] implied existed prior to the impact. Whether these materials were once part of a continuous ejecta blanket or remnants of discontinuously deposited ejecta is unclear. They lie, however, 2 to 3 crater radii beyond the crater rim, whereas the continuous ejecta around craters of a similar size on the Moon only extends to an average of 1.3 crater radii beyond the crater rim [7].

South of the Moenkopi ridge, we encountered the north edge of the area mapped by Shoemaker [1]. He mapped a Pleistocene alluvium surface surrounded by bedrock Moenkopi, both of which are slightly north of material he mapped as Recent alluvium. The older alluvium in this location is characterized by a Moenkopi-rich surface and isolated, but abundant, pebbles, cobbles, and boulders of Kaibab on topographic highs. His Moenkopi bedrock is characterized by red soil and a few Kaibab rocks that may have been carried from the topographic highs. The surface slopes towards the Recent alluvium channel. Thus, it appears Shoemaker thought drainage cut through the Pleistocene alluvium to underlying Moenkopi. His Recent alluvium is even muddier and in a flat wash.

In contrast, we are mapping his older alluvium as discontinuous Kaibab ejecta on bedrock Moenkopi. We interpret the surface as bedrock Moenkopi because it is covered with shale fragments (with no silt or mud) and vegetation lines that indicate joints in bedrock Moenkopi are virtually at the surface [5]. We are interpreting his Moenkopi as an alluvium channel, because it is composed of silt and clay-size particles on a slope that is feeding debris from the Moenkopi ridge to the current/Recent alluvium channel.

The distribution of these lithologies in the mapped area is shown in Fig. 2.

Source of Excavated Debris: In the model of overturned ejecta developed at Meteor Crater (e.g., [8]), material at the outer edge of the continuous ejecta blanket or in discontinuous ejecta deposits at greater distances should be derived from near the center of the crater along relatively shallow excavation streamlines. As described above, the Kaibab-rich debris contains clasts from a marker bed, the Kaibab-Moenkopi boundary breccia horizon, indicating some of the distal ejecta is derived from ≤10 m below the target surface, consistent with the excavation model.

Deposition of Ejecta: Assuming a ballistic trajectory with a 45º ejection angle, material landing near the southern base of the Moenkopi ridge would have had a velocity of 360 to 430 km/hr and a horizontal radial component of 250 to 300 km/hr. Thus, once the material landed, it could have skated 100 m or farther across a Moenkopi landscape that had already been winnowed by the shock wave and air blast [9]. Thus, it is possible that debris flowed up and over the ridge. We did not, however, find any scour marks on the underlying bedrock.

Conclusions: Kaibab ejecta occurs far beyond the limits previously mapped. The material is often on topographic highs and mantling Moenkopi bedrock and, thus, appears to be primary ejecta rather than transported colluvial and alluvial deposits. Surveys beyond the area in Fig. 2 identified several other Kaibab ejecta deposits that need to be investigated.

Acknowledgements: We thank the Barringer Crater Company and Meteor Crater Enterprises for hosting the Field Training and Research Program at Meteor Crater and gratefully acknowledge the financial support provided by NASA's Solar System Exploration Research Virtual Institute through the LPI-JSC Center for Lunar Science and Exploration.

References: [1] Shoemaker E. M. (1960) *Internat. Geol. Congr. XXI Session,* Copenhagen, 418–434. [2] Shoemaker E. M. and Kieffer S. W. (1974) *Guidebook to the Geology of Meteor Crater, Arizona*. ASU Center for Meteorite Studies Publ. No. 17. [3] Grant J. A. and Schultz P. H. (1993) *JGR, 98*, 15033–15047. [4] Roddy D. J. (1978) *Proc. LPSC 9th*, 3891–3930. [5] Kring D. A. (2015) *LPS XLVI,* Abstract #1036. [6] Kring D. A. (2007) *Guidebook to the Geology of Barringer Meteorite Crater, Arizona*. LPI Contrib. No. 1355, 150 p. [7] Moore H. J. et al. (1974) *Proc. Lunar Conf. 5th*, 71-100. [8] Roddy D. J. et al. (1975) *Proc. LSC 6th*, 2621–2644. [9] Kring D. A. (1997) *Meteoritics & Planet. Sci., 32*, 517–530.

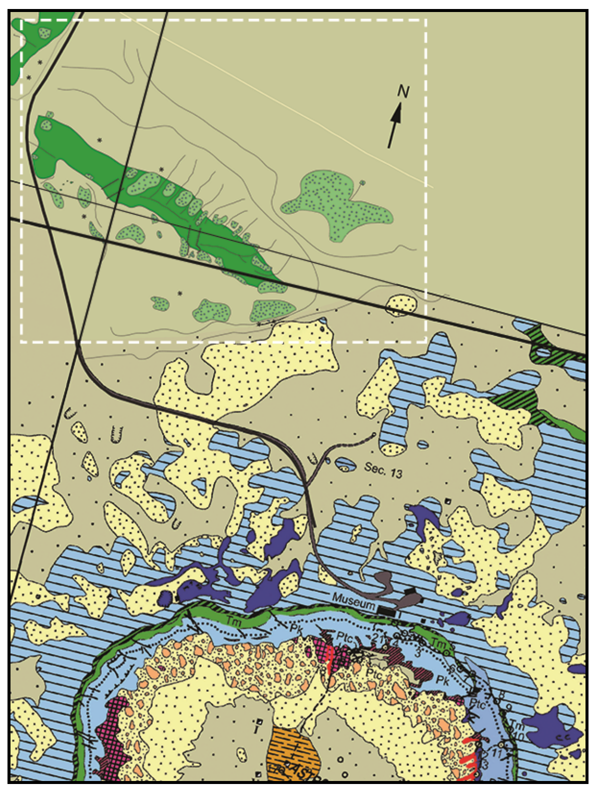

Fig. 2. Preliminary map (within dashed line box) of the discontinuous ejecta deposits north of the crater rim. Solid green is Moenkopi bedrock and blue stippled pale green is Kaibab-rich discontinuous ejecta on Moenkopi bedrock.