TRACES OF FALLBACK BRECCIA ON THE RIM OF BARRINGER METEORITE CRATER (a.k.a. METEOR CRATER), ARIZONA. D. A. Kring[1,2], L. Angotti[3], M. Bouchard[4], B. Byron[5], N. Chinchalkar[6], S. De Graaff[7], T. Déhais[7], L. Glaspie[8], J. Hedgepeth[9], M. Hughes[4], P. Kaskes[7], J. MacArthur[10], M. McGregor[11], C. Ross[12], K. Stacey[13], S. Suarez[14], C. Verhagen[15], and T. M. Erickson[16], [1]Center for Lunar Science and Exploration, Lunar and Planetary Institute, Universities Space Research Association, Houston TX 77058 (kring@lpi.usra.edu), [2]NASA Solar System Exploration Research Virtual Institute, [3]Case Western Reserve University, [4]Washington University in St. Louis, [5]University of Texas at San Antonio, [6]Auburn University, [7]Vrije Universiteit Brussel, [8]Northern Arizona University, [9]University of Western Ontario, [10]University of Leicester, [11]University of New Brunswick, [12]University of Texas at Austin, [13]University of Texas at Dallas, [14]University of Houston, [15]Rutgers University, [16]Jacobs–JETS, NASA–JSC.

Introduction: Barringer Meteorite Crater (a.k.a. Meteor Crater), Arizona, is one of the youngest and best preserved impact craters on Earth. For that reason, it provides a baseline for similar craters formed in the geologic past, formed elsewhere in the Solar System, and illuminates the astronomical and geological processes that produce them. The crater has not, however, escaped erosion completely. While Shoemaker [1] mapped a breccia with fallback components inside the crater, he did not locate it beyond the crater rim. He only found remnants of that type of debris in reworked alluvium [1; see also 2]. Fallback breccia and any base-surge deposits have, thus, been missing components in studies of material ejected beyond the transient crater rim.

Relics of that type of material began to emerge (**Fig. 1**) in a new mapping effort. In a series of NASA-sponsored student training and research programs, fallback material and related ejecta mechanics are being systematically documented [3-8]. Here, we present the latest results, which indicate traces of fallback breccia survive on the crater rim.

Figure 1. *Fragments of red Moenkopi siltstone (foreground), from the uppermost impact target unit and a proxy for fallback ejecta, are located among Kaibab boulders near the summit of the crater rim. From [7].*

Mapping: The impact event excavated and ejected Coconino sandstone, Kaibab dolomite, and Moenkopi siltstone around the crater. An ~8,500 m^2 area of that ejecta was re-mapped in the vicinity of Whale Rock (**Fig. 2**) on the west side of the crater. This area was previously described [1] as Kaibab ejecta and alluvium. In the current study, we documented the locations of Moenkopi blocks in both of those domains, conducted representative 1-m^2 point counts of surface components (e.g., Moenkopi, Kaibab, Coconino), and surveyed the surface for other relics of fallback ejecta (e.g., impact melt particles).

Figure 2. *Portion of area mapped near Whale Rock (far left). This area was previously used to ascertain [9,11] an approximate age of the crater (c. 50 ka) and erosion rates (e.g., between 50 and 23 ka, as shown). Although the area is mapped as Kaibab ejecta, it contains blocks of Moenkopi ejecta. From [7].*

Results: A series of ejected blocks of Moenkopi were documented along the entire mapped region (**Fig. 3**). Blocks ranged in size up to exposed lengths of 0.9 m. Importantly, these blocks are near the rim crest at elevations up to 48 m above bedrock Moenkopi in the crater walls. Nine representative 1-m^2 surface surveys reveal a small clast content that is dominated by Kaibab, contains 1.5 to 23% Moenkopi, and contains only rare Coconino. A drift survey across the surface of the area located two fragments of vesicular impact melt (clearly distinguishable from volcanic detritus that contaminates the crater region) within a few meters (**Fig. 3**) of the crater rim crest.

Figure 3. *Locations of ejected Moenkopi blocks (orange points) and impact melt particles (red rectangles) topographically above Moenkopi bedrock in the crater wall (burgundy strata on right). Additional fragments of Moenkopi occur on the ejecta blanket farther to the left and were likely transported downslope by erosion of fallback ejecta. West crater rim in the vicinity of Whale Rock (far left), looking obliquely south to north.*

Discussion: Moenkopi blocks near the rim crest, far above bedrock exposures in the crater wall, must be ejecta because rock does not erode uphill. The Moenkopi ejecta is stratigraphically above Kaibab ejecta and is, thus, part of a fallback unit, rather than the main unit of Moenkopi ejecta that underlies Kaibab ejecta (e.g., Fig. 7.4 of [7]). We cannot completely discount the possibility the Moenkopi blocks are transported by humans as it was used as building stone around the crater, but we note the blocks are usually buried and often from the shaley member of the Moenkopi, which is not used as a building stone. Impact melt particles in the same area seem to confirm a fallback origin for the deposit, although we are again mindful the surface has been disturbed by visitors.

While the Moenkopi blocks and impact melt particles are sitting on top of Kaibab ejecta, they are clearly below the uppermost Kaibab ejecta surface (**Fig. 2**). This suggests the material may be within depressions that existed on the original surface of the ejecta blanket. Alternatively, and perhaps more likely, the debris is slightly displaced fallback breccia that settled downward as the ejecta blanket was being deflated. Because the Moenkopi blocks and impact melt particles are within a few meters of the rim crest, any downslope transport was very small and the debris is very close to where it was originally deposited by the impact. It is perhaps stunning that any fallback ejecta survives in an area where cosmogenic nuclide analyses [9] indicate up to 10 m of erosion into the Kaibab ejecta layer occurred (**Fig. 2**).

Very little Coconino ejecta survives along with the Moenkopi fallback ejecta. Thus, if Coconino was part of the fallback breccia, it seems to have been destroyed. Nor is there a layer of Coconino ejecta that, ideally [10], should have been deposited on top of the layer of Kaibab ejecta and beneath any fallback ejecta. Either Coconino was not ejected in that region of the crater or it was preferentially removed during deflation of the crater rim.

Conclusions: Decimeter-scale mapping reveals blocks of Moenkopi ejecta and impact melt particles in an area previously mapped as Kaibab ejecta. The newly recognized debris indicates traces of fallback ejecta lay scattered on the erosional surface of the continuous Kaibab ejecta layer near the crater rim on the west side of the crater. These traces of fallback breccia augment those found [5,7] on top of Coconino ejecta roughly 100 m from crater rim on the south side of the crater.

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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] Kring D. A. et al. (2011a) *LPS XLII*, Abstract #1746. [4] Kring D. A. et al. (2011b) *LPS XLII*, Abstract #1740. [5] Kring D. A. et al. (2012) *LPS XLIII*, Abstract #1618. [6] Kring D. A. et al. (2015) *LPS XLVI*, Abstract #1186. [7] Kring D. A. (2017) *Guidebook to the Geology of Barringer Meteorite Crater, Arizona (a.k.a. Meteor Crater),* 2nd Edition. LPI Contribution No. 2040, Lunar and Planetary Institute, Houston, 270 p. [8] Schmieder M. et al. (2017) *LPS XLVIII*, Abstract #2180. [9] Nishiizumi et al. (1991) *Geochim. Cosmochim. Acta 55*, 2699–2703. [10] Roddy D. J. et al. (1975) *Proc. 6th Lunar Sci. Conf.*, 2621–2644. [11] Phillips F. M. et al. (1991) *Geochim. Cosmochim. Acta 55*, 2695–2698.