LITHOSTRATIGRAPHIC ANALYSIS OF THE METEOR CRATER EJECTA BLANKET. A. L. Gullikson[1], T. A. Gaither[2], and J. J. Hagerty[2], [1]Northern Arizona University, 625 S. Knoles Dr, Flagstaff, AZ, 86011, [2] U.S. Geological Survey, Astrogeology Science Center, 2255 N. Gemini Drive, Flagstaff, AZ 86001

Introduction: Barringer Meteorite Crater (hereafter referred to as Meteor Crater) is a 180 m deep, 1.2 km diameter, bowl-shaped depression located in north-central Arizona [1]. This impact crater is thought to have formed ~50,000 years ago [2,3] by the impact of the ~100,000 ton iron-nickel Canyon Diablo meteorite, roughly 30 m in diameter, which struck at a speed that has been estimated to be anywhere between 12 and 20 km/sec [4-7]. The crater and surrounding rim have since experienced limited erosion, providing one of the best preserved, young impact craters on Earth [8-10]. Recent sample analyses and numerical models [e.g., 12-19] indicate that the formation of Meteor Crater was much more complex than previously thought. Current models are insufficient for explaining certain aspects of the impact melting process, target rock-projectile mixing, siderophile element fractionation trends, and ejecta blanket formation processes, and require further investigation to understand newly identified complexities.

These issues are being investigated through the use the USGS Meteor Crater Sample Collection, housed on the campus of the USGS Flagstaff Science Center. The samples in this collection consist of over 2,500 m of drill cuttings from 161 well-documented drill holes into the ejecta blanket of Meteor Crater. Our work utilizes these drill cuttings to study the composition and spatial distribution of impact-generated materials associated with the ejecta blanket, in an effort to better understand the complexity of cratering processes and products. We are integrating observations of impact melt geochemistry, metallic inclusion and spherule compositions, and a detailed stratigraphic and sedimentological analysis of the ejecta deposits.

Lithostratigraphic Analysis: The morphology of Meteor Crater and its ejecta blanket, as well as the composition and distribution of impactite lithologies, result from the complex interplay of processes that occurred during impact. The continuity of the inverted strata within the ejecta blanket led Roddy et. al [8] to use the term "overturned flap" to emphasize the well-ordered inversion. Although Shoemaker and Kieffer [1] characterized the internal structure of the ejecta blanket as consisting of mainly blocky, fragmented beds that are continuous, but lie in an inverted stratigraphic order, it is now clear that this idealized model of the continuous ejecta blanket is complicated by local complexities within the debris [11] that were only briefly acknowledged by [1] and [8]. Our recent results [16-19] indicate the ejecta formation process involved a greater degree of mixing between lithologic units than expected by the "overturned flap" characterization.

We are formulating a detailed, field-based model for crater excavation and ejecta emplacement processes through a detailed lithostratigraphic analysis of the internal structure of the ejecta blanket. The extent of lithologic mixing within the ejecta blanket is being quantified by identifying ejecta facies that represent contrasting mixtures of target rock lithologies (i.e., Coconino, Kaibab, Moenkopi formations), impact melts, metallic spherules, and Canyon Diablo meteorite fragments. Using these data and RockWorks software, we are constructing detailed stratigraphic and lithologic columns that emphasize not only overturned flap morphology, but mixed-lithology facies and the relative abundances of impact melts, metallic spherules, and Canyon Diablo meteorite fragments. Using these detailed stratigraphic and lithlogic columns, RockWorks is being used to interpolate surfaces, and create a fully visualized subsurface from which we can generate fence diagrams, cross sections, and isopach maps. These derived products will provide a representation of the complete ejecta blanket, including possible internal structures and lateral and vertical variations in lithologic composition. These products will be ingested into the project database and will be used to inform new models for the excavation/transient crater stage of the impact process.

Methods. Drill cuttings from several drill holes along four transects are being analyzed. These transects, consisting of 4 – 5 drill holes per transect, extend from the crater rim in a northwest, northeast, southwest and southeast fashion (Figure 1). Drill holes typically ranged in depth from several meters to 50 meters [18], with cuttings collected at 1 ft intervals. For our lithostratigraphic analysis, drill cuttings were sampled every 5 ft until Moenkopi bedrock was reached. Sample aliquots for each depth interval ranged from 100 g for sandy samples to 200 g for pebble/grain dominant samples. In order to obtain representative splits for analysis, samples for each depth interval were first re-homogenized, and then subsampled using the cone-and-quarter method [20]. Mass and volume of the splits were then recorded. Unused material was placed back into the sample collection.

Representative splits were dry sieved and separated into seven size fractions (U.S. Standard sizes 3½ - 140). It was previously noted that a fine powder coats many of the grains, causing difficulty in classifying material to their appropriate lithologies [16,17]. In order to remove this coating, the three largest size fractions (3½, 10, and 18) were rinsed thoroughly with deionized water and dried under a heat lamp for several hours.

We assigned each sample a facies description according to the proportions of its major and minor lithologic components. We sorted clasts into their respective lithologies (Coconino, Kaibab, and Moenkopi), and sandy and smaller size fractions (i.e. sizes 35, 60, 120, and < 120) were described as being Coconino-derived, Kaibab-derived, or Moenkopi-derived based on color and texture. Volumes of each lithologic component were measured and then converted to percentages of the total sample volume. Ejecta facies are therefore based on contrasting percentages of Coconino, Kaibab, and Moenkopi lithologies, as well as the proportion of clasts versus sand.

After all sample volumes are recorded for the selected depth intervals for each drill hole, we will enter data into RockWorks, which is being used to generate detailed lithostratigraphic columns.

Results: The northwest transect and one drill hole from the southwest transect have been completed. The four drill holes that were analyzed for the northwest transect were (moving from the rim outward) 56, 60, 62, and 64. Drill hole #56, closest to the crater, is comprised of shocked Kaibab material from the depth interval 0' – 1' down to 40' - 41'. The final depth that was analyzed from this drill hole was 44' – 45', which transitioned into Moenkopi. The samples from this drill hole were all sand-dominant. Drill hole #60 is comprised of mostly unshocked Kaibab material from a depth of 1' – 15', with 1 – 10% Moenkopi sand and clasts mixed in. Moenkopi bedrock is reached by 19'. The upper portion of this drill hole (1' – 3') is clast-dominant, transitioning into sand-dominant material for the majority of the drill hole, until entering into Moenkopi bedrock. Drill hole #62 and #64 reflect similar characteristics. From a depth of 0' – 11' both drill holes are comprised of Kaibab material and at 15', both transition into Moenkopi. There is some mixing occurring between Kaibab and Moenkopi at this depth. Drill hole #62 has 60% Kaibab and 40% Moenkopi clasts and drill hole #64 has 30% Kaibab and 70% Moenkopi clasts. Both drill holes are clast-dominant until reaching a depth of 20', which is the depth at which Moenkopi bedrock is the main lithology.

Drill hole #39 (closest to the rim) has been completed for the southwest transect. This drill hole is comprised of Coconino ejecta from 0' – 14', then transitioning into Kaibab from 18' to 78'. This drill hole was analyzed down to a depth of 83', which' consists of Moenkopi bedrock from 80' - 83. Drill hole #39 is sand-dominant, with little to no mixing observed in the depth intervals studied.

Discussion: The ejecta facies of the northwest transect samples generally reflect single lithologies (i.e., ejected Kaibab and Moenkopi) and contain little to no impact melt, lechatelierite, or metallic spherules. This suggests minimal mixing of target lithologies and impact generated materials in the northwest portion of the Meteor Crater ejecta blanket. Based on previous observations of drill cuttings from the southwest and southeast portions of the ejecta blanket, we predict that more complicated (mixed) facies will be revealed through our ongoing lithostratigraphic analysis of drill holes in these transects.

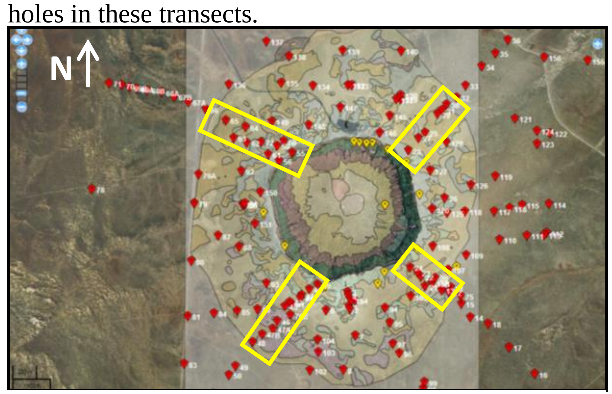

Figure 1. Map view of Meteor Crater using the USGS Interactive Map. Red points show all drill holes. Yellow boxes highlight transects chosen for study, though not all drill holes within the highlighted section are used for the lithostratigraphic analysis.

References: [1] Shoemaker E.M., and Kieffer S.W. (1974) *Guidebook to the geology of Meteor Crater*, Arizona, Publ. 17, 66 pp; [2] Nishiizumi K., et al. (1991) *Geochim. Cosmochim. Acta*, *55*, 2699; [3] Phillips F.M., et al. (1991) *Geochim. Cosmochim. Acta*, *55*, 2695; [4] Shoemaker E.M. (1960) Impact mechanics at Meteor Crater Arizona: unpublished Princeton PhD Thesis, 55 pp; [5] Melosh H.J. (1980) *Ann. Rev. Earth Planet. Sci*, *8*, 65; [6] Melosh H.J. and Collins G.S. (2005) *Nature*, *434*, 156;
[7] Artemieva N. and Pierazzo E. (2009) *Meteor. Planet. Sci.*, *44*, 25; [8] Roddy D.J., et al. (1975) *Proceedings of the Sixth Lunar Science Conference*, *3*, 2621; [9] Grant J.A., and Schultz P.H. (1993) *J. Geophys. Res.*, *98*, 15,033; [10] Ramsey M.S. (2002) *J. Geophys. Res.*, *107(E8)*, 5059;
[11] Kring D.A. (2007) *Lunar and Planetary Institute LPI Contribution No.* 1355; [12] Hörz et al. (2002) *Meteor. Planet. Sci.*, *37*, 501; [13] Mittlefehldt et al. (2005), *GSA Special Paper*, *384*, 367; [14] Osinski et al. (2008) *Meteor. Planet. Sci.*, *43*, 1939; [15] Artemieva N. and Pierazzo E. (2011) *Meteor. Planet. Sci.*, *46*, 805; [16] Gaither et al., (2012) *LPSC 43*, abstract #1601; [17] Hagerty et al. (2012) *75th Annual Meeting of the Meteoritical Society*, abstract #5296; [18] Hagerty et al., (2010) *LPSC 41*, abstract #2213; [19] Hagerty et al., (2011) PCC 2, abstract #1109; [20] Lewis D.W. and McConchie, D. (1994) *Analytical Sedimentology*, 197 pp.