THE USGS METEOR CRATER SAMPLE COLLECTION: RESULTS AND INSIGHTS. J. J. Hagerty[1] and T. A. Gaither[1], [1]USGS Astrogeology Science Center, 2255 N. Gemini Drive, Flagstaff, AZ 86001, email: jhagerty@usgs.gov

Introduction: The USGS Meteor Crater Sample Collection (MCSC) has been completely curated, documented, and inventoried and is now available for use by the science community. Please visit the following website for more details and to request samples: http://astrogeology.usgs.gov/geology/meteor-crater-sample-collection. In the following sections we present information on new additions to the collection and new discoveries that have resulted from a series of microbeam and bulk rock characterization analyses.

Additions to the Collection: In addition to the rotary drill samples from the ejecta blanket of Meteor Crater, we have also accessioned materials donated by Dr. Fred Hörz (NASA Johnson Space Center). The Hörz samples were used in the early 2000s to conduct trace element studies of Meteor Crater samples and they have provided important information about the range of impact melt compositions found at Meteor Crater [1-3]. These samples are also available for request (primarily in small powdered aliquots).

While inventorying the drill cuttings from USGS drilling program we also identified 47 boxes of drill core from Meteor Crater. With the assistance of Dr. David Kring, we determined that 31 of the 47 boxes were drilled on the southern rim and flank of Meteor Crater between January 26 and March 30 of 1966. The remaining 16 boxes were collected at the nearby SP Crater (a volcanic cinder cone) as part of NASA's Apollo astronaut training program. These cores were collected to provide unshocked examples of Moenkopi, Kaibab, and Coconino materials and to serve as a baseline for investigating the effects of shock on target rock at Meteor Crater. These drill cores still need to be fully characterized and their metadata need to be ingested into the USGS MCSC database; however, once fully documented, these samples will also be made available to the science community.

Results and Conclusions: As part of the curation process, we also conducted a series of analyses that allowed us to identify and characterize a subset of samples from the ejecta blanket. The data collected from these analyses were used to constrain the processes that led to the formation of the ejecta blanket.

Ejecta blanket characterization. Bulk rock and thin section analyses indicate that there are no significant differences in siderophile element content between ejected and in-situ units of the Moenkopi Formation. Because of the physical effect of the drilling process on in-situ Moenkopi (i.e., breaking up originally intact rock into small, angular fragments), the contact between the original target surface and ejected Moenkopi was significantly blurred. Although we were unable to pin-point the contact between the two units, our documentation of the thicknesses of individual layers of Coconino and Kaibab ejecta revealed an unexpected level of complexity in their formation that requires further exploration.

Distribution of lithic and metallic spherules. We established a generalized distribution of metallic spherules within the ejecta blanket, and demonstrated via hand sample and scanning electron microscope (SEM) characterization, that sedimentary concretions (i.e., Moqui marbles) at Meteor Crater are distinctly different from impact-derived materials in terms of external morphology, internal textures, and mineralogy. Therefore, these samples are not likely to represent analogs for investigating the impact origin of martian blueberries as has previously been suggested [e.g., 4].

Distribution of impact melt fragments. Initial estimates have been made of the lateral and vertical distribution of impact melts and meteoritic fragments at Meteor Crater and our assessment of these data reveals that, in the NE, SW, and SE transects, impact melts are concentrated within a zone ~270-300 m from the crater rim, at depths of 2-4 m [5]. We find that impact melts are rare nearer to the rim and further out than ~300 m. Only trace amounts (i.e., < 2%) of impact melts are present at depths of 0-2 m and deeper than ~4 m, although intact melt clasts are found as deep as 10.5 m. Our examination of impact melt distribution indicates that the zone of greatest impact melt abundance (2-4 m deep) is dominated by Kaibab ejecta, with variable contributions from the Coconino and Moenkopi Formations. We suggest that this zone of high impact melt concentration is an original feature of the ejecta blanket, while the melt fragments in the upper 2 m were subjected to alluvial and/or colluvial processes.

Lechatelierite (i.e., shock melted Coconino Sandstone) is common, if not pervasive, within deeper portions of the ejecta blanket [5]. Inclusions of lechatelierite within impact melt clasts indicate that shock-melted Coconino Sandstone may have had a larger role in mixing processes that occurred during melt formation than suggested previously by [1]. Quantification of the volume of lechatelierite within the drill hole samples will likely lead to an upward revision of the volume of Coconino Sandstone-derived impact melt ejected from the transient crater [5].

Additionally, we observe carbonate lithic inclusions and carbonate melt globules within several impact melt fragments, which contrasts with the near-absence of carbonate materials noted in other studies [i.e., 1-3]. The presence of these carbonate phases supports the assertion of Osinski et al. [6] that the role of carbonate melting during impacts into sedimentary target rocks is more important than previously established.

Additionally, the presence of lechatelierite and carbonate materials within impact melt clasts suggests other volatiles, such as water, may have played a greater role in the final compositions and characteristics of the impact melts. The presence of water in the melt-clast mixture would have the effect of quenching impact melts before lithics could be assimilated into the melt, terminating melt flow and mixing and preserving the lithic clasts, lechatelierite, and immiscible carbonate melt spherules [e.g., 6].

Bulk rock analyses of ejecta. Previous bulk rock analyses of ejecta deposits reveal that siderophile elements are heterogeneously distributed and do not demonstrate clear patterns [1-3]. In contrast, our investigation reveals that mixing within the ejecta blanket may have been quite active and the overturned/inverted stratigraphy model is not necessarily applicable throughout the entirety of the ejecta blanket (i.e., there are major portions of the ejecta blanket where individual layers cannot be delineated). Given these findings, it is clear that a different strategy is required to investigate the physical and compositional aspects of the ejecta blanket. As such, we will conduct an intensive lithostratigraphic analysis of the sample collection. The sorted samples resulting from this analysis will be made available to interested researchers.

Microbeam analyses of impact melts. Microbeam analyses of impact melts have provided new data that conflict with previous interpretations for the production and geochemical evolution of a variety of impact melt fragments and inclusions. Figure 1 shows a backscattered electron image of an impact melt glass from Meteor Crater. Within this single sample we see several different and complex phase relationships. For instance, there are two different types of matrix, alteration of the glass, inclusion of meteoritic material, rapid growth/crystallization of pyroxene and olivine grains, and evidence of volatiles in the form of large spherical vesicles. These relationships are indicative of a complex interplay between target rock, the Fe-Ni impactor, and impact melt.

One of the most intriguing issues surrounding this and other impact melts from Meteor Crater is the production of the acicular, skeletal olivine grains from non-mafic sedimentary target rock. Hörz et al. [1] initially identified the acicular pyroxene grains in several samples and proposed that the dolomite and quartz-rich target rock combined with the iron-rich impactor to yield an ultramafic melt that rapidly crystallized olivine and pyroxene. Though the assertion of Hörz et al. [1] represents the most reasonable explanation, the measured ratios of Fe and Ni in the samples complicates the interpretation (i.e., many of the meteoric inclusions are enriched in Ni, as noted by [3]).

Further analysis of these samples will allow us to delineate the chemical fractionation and crystallization processes that produced the observed trends within the inclusions, glasses, and bulk particles. These analyses will help link the degree of fractionation of the glasses to the degree of fractionation measured in the metallic inclusions. Our investigative results will constrain projectile-target mixing and fractionation processes, and will allow us to determine if and how the compositions of metallic inclusions compensate for the fractionated glass compositions.

Acknowledgements: This work is supported by NASA through the Planetary Geology and Geophysics program via grant NNH09AK43I.

References: [1] Hörz et al. (2002) *Meteor. Planet. Sci.*, 37, 501-531; [2] See et al. (2002) NASA/TM-2002-210787, 23; [3] Mittlefehldt et al. (2005), *GSA Special Paper*, 384, 367-390; [4] Knauth et al., (1995) *Nature*, *438*, 1123; [5] Gaither et al., (2012) *LPSC 43*, abstract #1601; [6] Osinski et al. (2008) *Meteor. Planet. Sci.*, *43*, 1939.

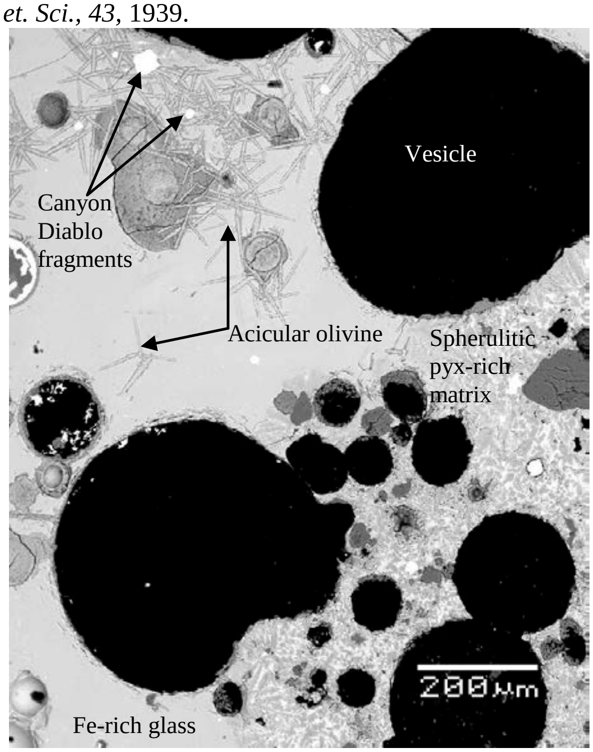

Figure 1. Backscattered electron (BSE) image of an impact melt glass from the USGS Meteor Crater Sample Collection (Drill hole #13).