COMPOSITIONAL CONTRADICTIONS RECORDED WITHIN IMPACT-GENERATED MATERIALS FROM METEOR CRATER, ARIZONA: IMPLICATIONS FOR CRATER FORMATION.

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Introduction: Meteor Crater is a 180 m deep, 1.2 km diameter, bowl-shaped depression on the southern edge of the Colorado Plateau, located in north-central Arizona [1]. This impact crater is thought to have formed ~50,000 years ago [2,3] by the impact of a 100,000 ton iron-nickel 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].

Historically, the Meteor Crater impact has been described as having a small amount of impact melt compared to other craters of similar size [1,4,6]. The apparent paucity of impact melt has been attributed to a combination of factors including the volatile content of the sedimentary target rock and the velocity of the impactor [7,11]. Nevertheless, numerical modeling [12], along with data from the USGS Meteor Crater Sample Collection (MCSC) [13,14], indicates that at least some of the “missing” melt may be finely distributed throughout the ejecta blanket in the form of previously unidentified, small (< 3 cm) particles and fragments.

Numerous studies [e.g., 11-21] have collected and analyzed impact-generated materials from Meteor Crater. The results of these analyses indicate that materials produced by the impact come in many forms including: meteoritic fragments, spherules of meteoritic melt, compositionally variable impact melt glasses, lechatelierite, ballistically dispersed melt bombs (~cm-sized) composed of mixtures of melted target rock and melted projectile, and carbonate fragments and spherules [13,14] (**Figure 1**). Despite decades of research on these materials [e.g., 11,15-21], the formation mechanisms, compositional range, and relationships between the impact-derived materials have not been definitively established and in some cases widely discrepant or contradictory results have been presented.

Contradictions Documented in Previous Work: Beginning with observations presented by Nininger [15], researchers have been perplexed by the variety and composition of materials produced by this “simple” impact crater [e.g., 11, 15-21]. Below we list a series of observations that illustrate the compositional complexity documented in samples from the crater.

- Fe-rich impact melt glasses contain rapidly crystallized acicular olivine and pyroxene grains (**Figure 1**) [e.g., 11, 20], which is intriguing given that the only significant source of iron required for the production of these minerals is from the Canyon Diablo impactor [11]. While the presence of mafic minerals is indisputable, the timing and efficacy of possible iron vaporization, condensation, and subsequent incorporation into impact melts is unclear. The incorporation of iron into impact glasses appears to require significant fractionation of iron from other siderophiles like Ni and Co [11]; however, the bulk composition of silicate impact glasses show little to no evidence of fractionation of the Fe/Ni ratio relative to the Canyon Diablo impactor [20].
- Although bulk glasses show little fractionation, analyses of projectile-derived materials within impact melt particles appear to show evidence of Fe-Ni fractionation as a function of depth within the target rock (i.e., melts from the upper portion of the sedimentary sequence show no fractionation [20], while deep-seated melts show fractionation [11]). The apparent discrepancy may be related to the degree of oxidation and removal of Fe from the projectile component within the impact melt particles [e.g., 18].
- The presence of carbonate lithic fragments and melt spherules within impact melt glasses indicates that impact melt temperatures were not as high as previously assumed (i.e., carbonates were not completely volatilized) (**Figure 1**) [e.g., 21].
- Previous compositional modeling [e.g., 11,20] indicates that the major zone of impact-induced melting did not include significant amounts of Coconino Sandstone; however, the pervasive occurrence of lechatelierite within impact melt glasses [e.g., 13] indicates that shock-melted Coconino Sandstone likely had an important role in the melting and mixing processes that occurred during the formation of the crater.
- The bulk composition of impact melt glasses shows significant variability (more so than expected for a crater of this size), which indicates that mixing and homogenization were inefficient at best. Conversely, the occurrence of projectile-derived metallic inclusions in almost every melt sample indicates that melt mixing was very intense [11].

In an effort to resolve some of these contradictions and in turn, to place new constraints on the formation of Meteor Crater, we are conducting a series of microbeam analyses of impact-derived materials from the USGS MCSC. The materials from this unique sample suite provide geologic context for impact-generated lithologies and span the entire extent of the ejecta blanket. This sample suite has been completely curated, documented, and inventoried and is available for use by the science community. For more information, please visit the following web page: http://astrogeology.usgs.gov/facilities/meteor-crater-sample-collection.

Analytical Methodology and Results: Electron microprobe analyses of materials from Meteor Crater were conducted on the JEOL JXA 8200 electron microprobe at the University of New Mexico's Department of Earth and Planetary Sciences. Impact melt glasses, melt breccias, and meteoritic fragments were analyzed at 15 kV, 20 nA, with a 1 µm beam, for major and minor element composition (including Fe and Ni). A combination of natural and synthetic mineral and glass standards were used for calibrating our analyses.

Preliminary results show that meteoritic materials (i.e., fragments and melts) from the ejecta blanket of Meteor Crater show significant fractionation of Fe and Ni compared to the Fe/Ni ratios measured in the Canyon Diablo meteorite (i.e., Fe/Ni = 13.2). The 25 meteoritic fragments and inclusions analyzed in this study thus far have shown widely discrepant Fe/Ni ratios, ranging from <0.1 to well over 1,000. Only one sample has an Fe/Ni ratio of 13. While these results are intriguing, they are limited, and therefore additional analyses are being conducted. A comprehensive lithostratigraphic analysis of drill cuttings from the USGS MCSC is underway, which will lead to the selection and analysis of impact-derived materials from the entirety of the Meteor Crater ejecta blanket.

Conclusions and Future Work: Further analysis of samples from the USGS MCSC 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/or how the compositions of metallic inclusions compensate for the fractionated glass compositions.

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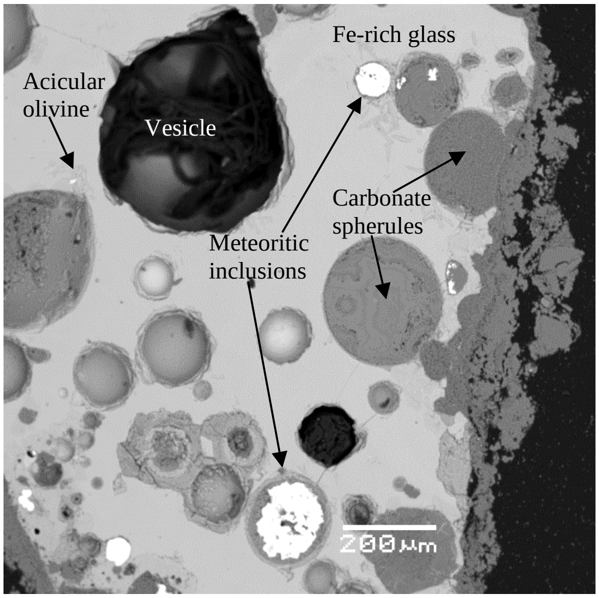

Figure 1. Backscattered electron (BSE) image of an impact melt glass from the USGS Meteor Crater Sample Collection (Drill hole #68).