SYSTEMATIC COLLECTION AND ANALYSIS OF METEORITIC MATERIALS FROM METEOR CRATER, ARIZONA; Jeffrey S. Kargel[1], Peter Coffin[2], Michael Kraft[3], John S. Lewis[4], Carleton Moore[5], David Roddy[1], Eugene M. Shoemaker[2], and James H. Wittke[2]; [1]USGS, 2255 N. Gemini Dr., Flagstaff, AZ 86001, email: jkargel@iflag2.wr.usgs.gov

Overview. We have started a systematic collection and analysis of meteoritic materials from Meteor Crater, Arizona. Since our earlier report **[1]**, we have found 47 small fragments of the Canyon Diablo iron meteorite. We also have collected impactite lapilli; oxidized meteorite fragments; and materials we call amalgamated meteoritic/lithic fragments (AMLs), which consist of target rocks fused with and impregnated by oxidized meteoritic iron. The composition of the impactite lapilli is consistent with admixture of about 3 parts Kaibab Formation (siliceous dolomitic limestone) and 1 part oxidized meteorite. In addition, the lapilli contain microscopic spherules of Ni-rich metal (up to 90% Ni), which can only be explained by partial oxidation of Canyon Diablo metal. Our interpretation of the lapilli is that the impact event melted and devolatilized rocks of the Kaibab Formation (siliceous limestone and dolomite), which mixed with molten meteoritic metal. If impact-heated metal droplets or vapor condensates attained about 3500 K, then CO_2 released from the Kaibab Formation may have thermally decomposed to CO and O_2 and caused partial oxidation of the metal.

The project. Collected meteoritic materials are documented at USGS and then curated by Carleton Moore at the Center for Meteorite Studies at Arizona State University. Representative samples are being analyzed petrographically and chemically by James Wittke and collaborators at Northern Arizona University. Much of the field and laboratory work is being conducted by undergraduate students (Michael Kraft and Peter Coffin) working under the guidance of Jeffrey Kargel, David Roddy, and Eugene Shoemaker at USGS.

Meteorite collection and description. Although Meteor Crater has long been an excellent source for meteorites, extensive collecting by others (both legal and illegal) has "picked over" the area so well that surface meteorites are now hard to find. Field procedures used by this team include selection of areas deemed most likely to contain meteorites, establishing a collecting grid, use of a metal detector to locate meteorites, and careful documentation of the exact location and the physical appearance and mass of each find. We calibrate the metal detector to detect only unoxidized metal and to "tune out" more abundant oxidized metal, such as AMLs and "shale balls." To date we have found 47 small, strongly magnetic meteorite fragments near the east rim and south of the crater. The largest weighs 33.5 g, and the total mass is about 300 g. Two of the 47 fragments were found on the surface. The others were buried up to 10 cm, which is about the maximum depth at which small metal fragments can be detected with our instrument.

The meteorite fragments collected vary considerably in shape and texture, but these differences do not appear to be related to discovery location. About 12% of the fragments have irregular shapes and seem to be bent or twisted; these may be pieces of shocked shrapnel. Most fragments, however, are equidimensional and have "cupped" surface features that we infer were caused either by ablation during entry or by weathering while sitting near the surface. A few fragments are slightly oxidized and plate-like.

Impact melting of carbonates and oxidation of metal. Impactite lapilli from Meteor Crater are aerodynamically shaped, centimeter-size masses of highly vesicular glass; they contain spheroidal blebs of Ni-rich metal 5–300 μm in diameter. Impactites collected during this study from several locations appear identical to some described previously by Nininger **[2]**. Millimeter-size vesicular glass spherules adhere to many lapilli and some are partly embedded in microcraters, indicating an accretion process. The lapilli are dominated by silicate glass but also contain grains of unmelted quartz and Ni-rich metal blebs (up to 90% Ni). Glass and metallic blebs of five lapilli were analyzed by electron microprobe. Both materials are chemically heterogeneous. The average glass composition is consistent with admixture of about 1 part oxidized meteorite and 3 parts decarbonated Kaibab Formation (with or without some Moenkopi or Coconino Sandstone). Metallic blebs contained in the lapilli have an average composition around 70% Ni + 30% Fe, although they vary widely in Ni/Fe.

The Canyon Diablo impactor penetrated three major formations: the Moenkopi Sandstone, the Kaibab Formation, and the Coconino Sandstone. The only source for large amounts of CaO and MgO is the carbonates of the Kaibab Formation. The fact that the analyses have sums close to 100% without CO_2 means that there was nearly complete devolatilization of impact melted carbonates. The upper Kaibab Formation also contains a large

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amount of SiO_2, enough that the Kaibab Formation may have been the principal contributor of target rock to the five analyzed lapilli. The meteorite is the only major source of Fe and Ni to the lapilli, although these metals must have been oxidized. Our interpretation is that the glass was derived by impact melting and devolatilization of the Kaibab Formation and admixture with melted, oxidized meteorite in the approximate mass ratio of 3 parts Kaibab to 1 part meteorite. High-temperature (~3500 K) oxidation of Fe can explain the glass/metal fractionation of Fe and Ni and the formation of Ni-rich metal. This process involved (1) impact shock heating of Kaibab Formation carbonates and release of CO_2, (2) thermal dissociation of CO_2 into $CO + {}^1/_2O_2$, and (3) high-temperature (3500 K) oxidation of Fe, leaving residual Ni–Fe metal. This proposed mechanism recalls Nininger's **[3]** explanation accounting for Meteor Crater's Ni-rich metallic spheroids and his visualization of "a towering cloud of metallic vapor rising above the crater" following the impact. Nininger believed that Earth's atmosphere was responsible for the partial oxidation of metal spheroids. Whatever the actual oxidation process, Fig. 1 shows that smaller metallic blebs were more strongly affected by oxidation, as indicated by their more strongly fractionated and elevated Ni/Fe ratios.

Conclusions. Our chemical analyses to date have focussed on studies of impactite lapilli and their included microspheroids of Ni-rich metal. Our interpretation is that impact shock heating and decarbonation of the Kaibab Formation caused partial oxidation and chemical fractionation of Canyon Diablo metal. Admixture of the refractory residue of the Kaibab Formation and oxidized meteorite produced impactite glass made of CaO, MgO, SiO_2, Al_2O_3, FeO, and NiO. Millimeter-size glass spherules and metal microspherules accreted while still molten to form centimeter-size lapilli, which then rained from the ejecta plume onto the surface of the ejecta blanket surrounding the crater.

Meteorites collected during this project are being curated at the Center for Meteorite Studies (Arizona State University) and are available to other researchers by contacting Carleton Moore. Other meteoritic materials, including impactite lapilli, AMLs, and "shale-ball" fragments are available by contacting the first author. We invite collaboration including chemical and petrographic studies of these materials.

Acknowledgements. This work has been done in cooperation with the Barringer Crater Company and Meteor Crater Enterprises. Support for Michael Kraft and Peter Coffin and partial funding for analytical expenses is from the NASA Summer Intern and Undergraduate Researcher programs.

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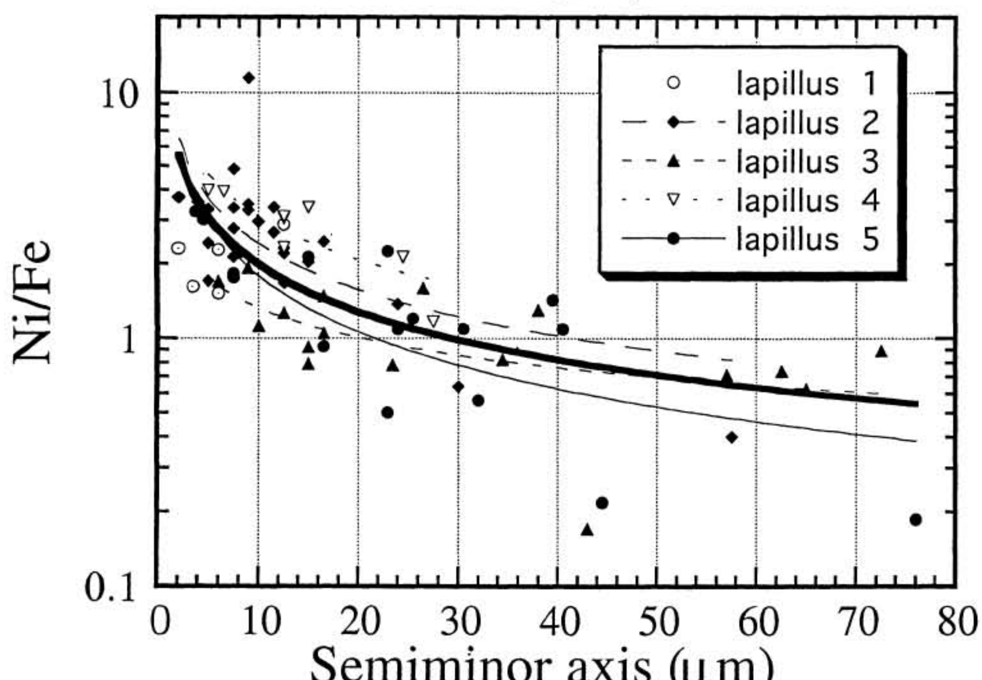

Fig. 1. Correlation of the size and Ni/Fe ratios of spheroidal metallic inclusions in 5 impactite lapilli. Each symbol represents one metal bleb.