PROXIMAL EJECTA AT METEOR CRATER, ARIZONA: DISCOVERY OF IMPACT MELT-BEARING BRECCIAS. G. R. Osinski[1], T. E. Bunch[2], J. Wittke[2], [1]Canadian Space Agency, 6767 Route de l'Aeroport, Saint-Hubert, QC, J3Y 8Y9 (gordon.osinski@space.gc.ca), [2]Geology Department, Bilby Research Center, Northern Arizona University, Flagstaff, AZ, USA.

Introduction: Meteor Crater is one of the world's best known meteorite impact craters and has been the subject of numerous geological investigations over the past century. This structure has been widely acknowledged as being a prototypical simple impact crater [1,2]; however, despite this, recent studies have yielded important new information and some surprises, both about Meteor Crater, and the impact cratering process in general. Hörz et al. [3] provided an extremely detailed study of the ballistically dispersed melt particles or 'beads' and placed constraints on the stratigraphic extent of the melt zone at Meteor Crater for the first time. More recently, evidence for the shock melting of carbonates during the formation of Meteor Crater has been found [4]. Melosh and Collins [5] have also recently suggested that Meteor Crater formed by a low-velocity impact. This may help to explain the old observation that much less melt has been documented at Meteor Crater than would be expected based on current cratering models [6], although the recognition of carbonate-derived melts [4] also partly accounts for the apparent lack of melt. Here, we present the first documentation and preliminary analysis of impact melt-bearing breccias from the ballistic ejecta blanket at Meteor Crater. This has implications for estimating the amount of melt present at Meteor Crater and for reconstructions of the impact event.

Samples and geological setting: Meteor Crater is a well preserved 1.2 km diameter, ~50 kyr. old simple impact crater situated near Flagstaff, northern Arizona (32^o 02' N, 111^o 01' W). The target sequence comprises, in upwards sequence, quartz sandstones of the Coconino Formation, the thin Toroweap Formation (sandstones), interbedded dolomites and sandstones of the Kaibab Formation, and finally, the Moenkopi Formation, a calcite-bearing siltstone [7]. Several types of different impactites have been documented at Meteor Crater. Impact glasses are typically millimeters to centimeters in size. They are often intensely vesiculated and occur are discrete particles, typically found as a lag deposit on the present-day erosion surface [e.g., 8]. They presumablely form part of the ballistic ejecta blanket. Highly shocked and shock-melted sandstones are common in allochthonous crater fill deposits and in the ballistic ejecta deposits [9,10]. Impact breccias are rare at Meteor Crater and are typically poorly consolidated and, apparently, melt-free [7]. The known impact breccias comprise the so-called "mixed breccis" of the buried allochthonous crater-fill and several poorly-exposed outcrops on the inner crater walls [7].

However, we have recently discovered an outcrop of competent impact breccias ~200 m from the southern rim of Meteor Crater (Fig. 1). This lithology outcrops over an area of ~45 m^2 and consists of a fine-grained groundmass containing clasts of <1 mm to 18 cm in size. Clasts from the Moenkopi, Kaibab, and Coconino formations are present. Upon close inspection, small millimeter-size clasts of impact melt glass can be seen.

Figure 1. Outrop of impact breccias ~200 m down from the top of the crater rim on the southern slope. Note the prominent brick-red clasts of Moenkopi Formation siltstone. 10 cm long penknife for scale.

Figure 2. Slab (~4.5 cm across) of impact melt-bearing breccias from the outcrop in Figure 1. Clasts of Coconino (white) and Moenkopi (red/brown) are highly visible, as are millimeter-size particles of melt glass (dark green/black; see arrows).

Analytical techniques: Polished thin sections were prepared and investigated using optical techniques and a JEOL JXA-8900 L electron microprobe (beam operating conditions of 15 kV and 20 nA), equipped with a wavelength dispersive X-ray spectrometer (WDS). Electron microprobe data were reduced using ZAF procedures incorporated into the operating system. Back-scattered electron (BSE) imagery was used to investigate the micro-textures of the various impactites.

Petrography: The samples studied comprise a fine-grained clastic groundmass/matrix, predominantly quartz, calcite, and dolomite (Fig. 2). Backscattered electron imagery reveals that the following components are present as clasts within the impact breccias: (1) lithic clasts from the Moenkopi, Kaibab, and Coconino formations (Figs. 2,3); (2) vesicular silicate impact glass (Figs. 2,3); (3) quartz with PDF's; (4) diaplectic quartz glass; (5) vesiculated SiO_2 glass; (6) calcite spherules; (7) nickel-iron metal grains <0.75 mm in diameter. Vesiculated SiO_2 glasses and calcite spherules are also present as isolated clasts within the silicate impact glass clasts (Fig. 3). Preliminary analysese suggest that the silicate impact glasses are similar to those studied by Hörz et al. [3].

The carbonate spherules comprise microcrystalline calcite and lack pervasive microtwinning. Spherules also occur in samples with unfilled vesicles. These textures are not compatible with a secondary alteration origin for the calcite as vesicles in the glasses remain devoid of calcite, and the glasses are pristine and unaltered. The silicate glasses and calcite, must, therefore, represent impact melt phases (cf., calcite in impact glass clasts studied by Osinski et al. [4]).

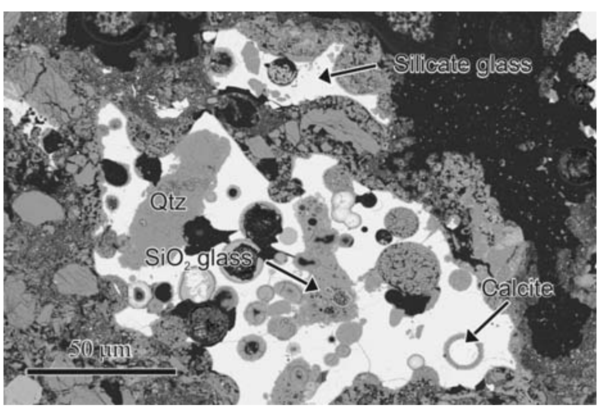

Figure 3. Backscattered electron (BSE) image showing a glassy silicate melt clast with inclusions of quartz, SiO_2 glass (lechatelierite), and calcite globules.

Discussion: This represents the first documentation and study of coherent impact breccias from the ballistic ejecta blanket at Meteor Crater. An important observation is the presence of silicate impact glasses, and shock-melted sandstones and carbonates in these breccias. These impact breccias can, therefore, be classified as melt-clast impact breccias or suevites according to the terminology of Stöffler and Grieve (1996). While the presence of such impactites at Meteor Crater may initially appear surprising, all cratering models for the impact process predict that impact melt should be ejected during the excavation and formation of the transient cavity. As Melosh [12, page 75] notes, "even the lowest velocity ejecta will contain some highly shocked impact melt". Until now, impact glasses have only been recognized as discrete clasts, typically found as a lag on the present-day erosion surface. The recognition of impact melt-bearing impact breccias is, therefore, important for several reasons. Firstly, estimates of the amount of melt present at Meteor Crater may have to be revised upwards, although the lack of exposure hampers estimates of the present and original distribution of these impact melt-bearing breccias. The results of this study also provide further unequivocal evidence for the melting of carbonates [cf., 4] and sandstones [cf., 9, 10] during the formation of Meteor Crater and meteorite impact events in general.

Further work is planned to assess the distribution of these impactites in the ejecta deposits of Meteor Crater and to compare the chemistry of the included glass clasts with those found as a lag deposit on the present-day erosion surface.

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