NEWLY DISCOVERED METEOR CRATER METALLIC IMPACT SPHERULES: REPORT AND IMPLICATIONS. M. G. Chapman[1], [1] U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ 86001; mchapman@usgs.gov.

Introduction: This report documents the discovery of large (3 mm to 1.5 cm) metallic particles 82 km from Meteor (Barringer) impact crater, on a high plain west of the Little Colorado River. The particles are nonvesicular and extremely spherical. Their location indicates that the Meteor Crater impact predated the deep cutting of the Little Colorado River. In addition, these spherules may have implications for the origin of the Mars "blueberries" at the Opportunity Landing Site.

Discussion: Micron-size metallic spherules within impact glass of the Henbury and Wabar Craters were first discovered in 1933 [1]. Larger, but still very tiny (up to 40 µm in diameter) metallic spherules have long been known to occur within black glass blebs in vesicular impactite silica glass lapilli of Meteor Crater ejecta [2,3,4,5,6]. The vesicular lapilli are mostly small, ranging in size from 3-4 mm in diameter [6] to rare larger clasts about 2 cm in diameter [7]. They commonly contain grains and lithic clasts of unmelted quartzose sandstone (from the target Coconino Sandstone [7]), and are found very proximal to the crater rim (within a few km; [2,6,7]). The Canyon Diablo impactor was a Fe-Ni bolide, but the spheroid melt droplets are enriched in Ni relative to the bulk composition of the meteorite and the enclosing vesicular impact glass is enriched in iron [3,4,5,6,7]. The bolide Fe was oxidized by the impact and more readily incorporated into the glass than Ni [7].

A private collector donated another type of metallic Meteor Crater spherule to the USGS Field Center. The sample consists of about 50 spherules, that are larger than those reported within vesicular glass lapilli, but still small (ranging in diameter from 2-3 mm in diameter). These spherules were collected within 1-2 km of the crater rim about 30 years ago (Fig. 1). They have relatively rough surfaces (Fig. 1) and about 80% of them attract to a magnet, indicating a high content of iron. Petrographically, the spherules contain lithic clasts of silt- to fine sand-sized quartzose sandstone, less than about 8% of grains are shocked to variable degrees within a nonvesicular, dark matrix. The matrix is a melted mixture of reflective metal and brownish-orange glass. Because the particles were found lying on the ground, presumably their rough outer surface is due to removal of hematized iron by exposure to the elements.

Recently, this author collected extremely spherical, very dark brownish-blue particles (resembling musket balls) from a thin (< 0.5 m thick) gravel far from Meteor Crater. This fluvial sheetwash deposit is Recent in age and overlies the much older Triassic Chinle Formation, about 70 km north of Flagstaff. The collection site is west of the Little Colorado River, on a high plain between Black Point and Grey Mountain, Arizona—a distance of about 82 km from Meteor Crater. The spherules range widely in size, from 3 mm to 1.5 cm (Fig. 2). The spherules can form doublets (symmetric and asymmetric) and clumps. One spherule has a central cleavage crack and another shows a triple-joint fracture. Several hemispherical spherules were also found, most have central hollow pits (2-5 mm in diameter) and others are solid. Unlike the smaller, high-iron, near-rim spherules--only 1 particle out of 29 attracted to a magnet. The surfaces of the spherules are extremely smooth with some silt-sized pits and a sheen that can be slight and dull to almost polished. Grains could not be observed in hand sample. Petrographically the spherules show silt-sized (below the resolution of the Microscopic Imager Camera on the Opportunity Rover) lithic grains of quartzose sandstone, less than about 8% of which are shocked to variable degrees. The grains are within a nonvesicular, dark matrix, that is a melted mixture of reflective metal and brownish orange glass. Because the majority of the spherules don't attract to a magnet, the metal is likely enriched in Ni and very low in Fe. The hollow pits may have held iron-rich cores that were hematized and removed. The spherules are coated with a very thin transparent glass rind, which is presumably a fusion crust that may account for their sheen. Their preserved high degree of sphericity may be due to this protective crust and their location within a fluvial gravel. Ejecta from Meteor Crater had a likely maximum extent of <10 km and at present is eroded. Therefore, the eroded ejecta was apparently incorporated in a fluvial system that freighted the more durable parts about 70 km to the collection site, mixing the various sizes of the spherules together (on a pristine ejecta blanket local spherules might likely have a unimodal size distribution). As this area is topographically higher and on the opposite side (west) of the Little Colorado, the Meteor Crater impact had to predate the deep dissection of this River.

These spherules may have implications for the origin of the Mars "blueberries" at the Opportunity Landing Site. By comparison, the surface of pedogenic nodules are usually rough, particles are much less spherical than the Mars blueberries, and locally they vary widely in size (Figure 3). When pedogenic nodules undergo weathering (grain plucking) they become even rougher. The sphericity and smoothness of the newly discover Meteor Crater "pearls" is similar to that the blueberries. The blueberries are fairly unimodal in size—a relation expected on a non-eroded ejecta blanket. Mars is a very different surface from that of the Earth, covered by many more impact craters than Earth; many craters are huge. If a large Fe bolide impacted the Martian crust, perhaps an adequate portion of the iron may have survived oxidation to form spherical Fe-rich melt droplets.

Conclusion: Within a thin fluvial gravel, 82 km from Meteor (Barringer) impact crater, 3 mm to 1.5 cm nonvesicular metallic spherules have been found. No chemistry has been performed (microprobe work is planned), but the spherules match the internal attributes of other, smaller melt droplets found near the rim of Meteor Crater. The large spherules were eroded from the ejecta blanket and moved northwest across the Colorado Plateau by a fluvial system, before the incision of the Little Colorado River. The smoothness and sphericity of these Meteor Crater "pearls" is very similar to that of the Martian "blueberries" at the Opportunity Site. Therefore, their discovery may have implications for the origin of the Mars "blueberries."

References: [1] Spencer L. J. (1933) *Mineral Mag., 23,* 387–404. [2] Ninenger H. H. (1956) *Arizona's Meteorite* Crater, American Meteorite Laboratory. [3] Mead C. W. et al. (1965) *Amer. Mineral., 50,* 667–681. [4] Brett R. (1967) *Amer. Mineral.,* 52, 721-733. [5] Blau P.J. et al (1973) *JGR*, 78, 363-374. [6] Kelly W. R. et al (1974) *Geochimica et Cosmo. Acta*, 38, 533-543. [7] Kargel J. S. et al. (in progress).

Figure 1: Impact spherules found near rim of Meteor Crater; scanned thin section on right.

Figure 2: Newly discover impact spherules found 82 km from Meteor Crater; scanned thin section on right.

Figure 3: Pedogenic spherules; Calcite-micrite nodules from Chinle Formation on left (scanned thin section to far left); sandstone-hematite nodules from Page Sandstone on right.