A METEORITE EJECTA LAYER AT THE BASE OF MID-PALEOCENE LAVAS, WESTERN SCOTLAND.

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A new meteorite impact layer: We report the youngest recorded meteorite impact event from the UK, located at the base of the mid-Paleocene basaltic lavas on the Isle of Skye, western Scotland [1]. We present mineralogical and textural evidence for impact-derived shock metamorphism at ~30 GPa. This layer is unrelated to a previously reported impact deposit on the Scottish mainland which is of Precambrian age [2] and is somewhat younger than the end-Cretaceous (K-Pg) impact event. The impact deposit contains unmelted fragments of the impactor. The nature of the unmelted minerals suggests that the event was caused by impact of a highly reduced body which may have been an enstatite chondrite meteorite.

Field relations: Evidence for a meteorite impact is found in two locations, 7 km apart in the southern part of the island of Skye. At Site 1 on the Strathaird peninsula, a meteorite ejecta layer 0.9 m thick overlies mid-Jurassic sedimentary rocks and is overlain by 70 m of mid-Paleocene lavas. The layer comprises ~95% matrix, with a fabric similar to that of a welded ignimbrite.

Site 2 is on the B8083 road, SSW of Broadford. Here, the ejecta layer is 2.1 m thick, crudely stratified, with a 0.25-0.9 m thick lower pumiceous-like unit resembling un-welded ignimbrite. This unit lies unconformably on Cambro-Ordovician dolostone and grades upwards into a coarser 1.2 m thick unit which is clast-supported with sporadic blocks of basalt. One basalt block in this unit has been dated using the ^{40}Ar-^{39}Ar method at 61.54 ±0.42 Ma.

Nature of the impact layer: The layer at site 1 is extremely fine-grained and contains quartz, orthoclase and clay minerals, plus granitic and basaltic lithic lapilli. Streaked domains are deflected around crystals and lapilli. Common accessory phases are rutile, monazite, zircon and rare chromite. Glass shards representing bubble walls are present.

At site 2, the lower layer is also fine-grained with glass shards, quartz and K-feldspar, with lithics of arkosic sandstone and gneiss. The upper unit at this site contains sub-rounded lapilli and blocks of quartzite, arkosic sandstone and basalt.

Mineralogical evidence for a meteorite strike: Reidite (high-pressure polymorph of zircon) occurs sporadically within both sites. Individual zircon crystals are sub-rounded, ≤250 µm long, zoned and contain reidite shock lamellae (identified by Raman microscopy). Rare anhedral baddelyite (ZrO_2) is found in association with reidite and may be a breakdown product. U-Pb dating of the zircons shows ages between 3227 and 294 Ma, with peaks at 2800-2600 Ma and 1800-1600 Ma. These ages correspond well with known geological events in the basement of western Scotland. We interpret the zircons as being derived from the local clasts of basement Lewisian gneiss and Torridonian arkosic sandstone. The ages have not been reset by shock or transformation to reidite. The presence of Paleocene-aged zircons has yet to be confirmed.

Additionally, grains of V-rich osbornite (TiVN) and Nb-rich osbornite-type phase (TiNbN) have been identified (Figure 1), often in clase spatial association with barringerite. A previously unrecognized osbornite-like phase V-Nb-osbornite has also been found as inclusions within native Fe which contains trace amounts of Si, Ni and Cu. This phase may be a carbonitride, as it contains 11 wt% C.

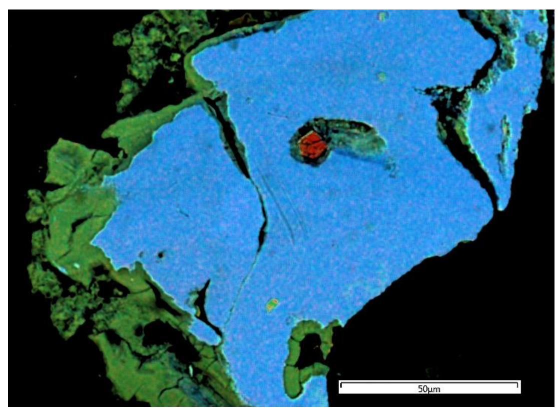

Figure 1. False-colour X-ray image of osbornite (in red) inside Fe(Si) metal fragment (in blue), mantled by iron oxide (green). Site 1, Skye.

Barringerite $(Fe,Ni)_2P$ appears as rare inclusions within native metal fragments at both sites (Figure 2). Alabandite (MnS) is also present. Microscopic iron spherules (up to 40 µm diameter) are found at both sites. Some are carbon-bearing, with silicon-bearing cores, mantled by FeO rims (Figure 3). Some of the spherules are vesiculated and have ferrosilicate glass mantles. These spherules are extremely similar to those reported from the Wabar impact deposit [3] and indicate rapid crystallization under conditions of low oxygen fugacity. Matrix quartz grains occasionally display planar deformation features, evidenced as parallel, multiple undeformed planes and some have been converted to diaplectic glass.

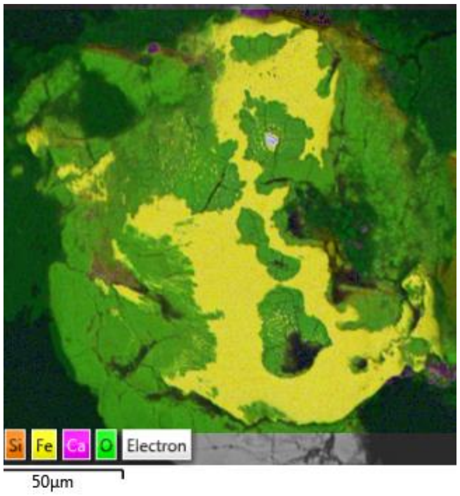

Figure 2. Native metal fragment (yellow) with inclusion of barringerite (grey).

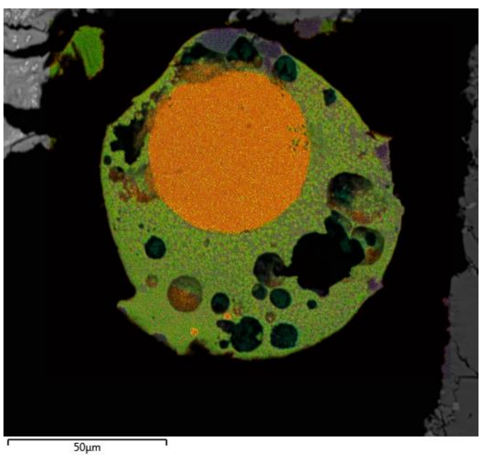

Figure 3. A false-colour X-Ray image of an Fe(Si) microsphere (orange) surrounded by vesicular Fe-silicate glass.

Discussion:

Mineralogy. The exotic mineralogy and matrix composition of the layers at both sites are extremely similar. Both sites contain reidite, barringerite, native iron spherules, and an array of phases related to osbornite. Pure osbornite (TiN) is extremely rare, and has been found in cometary dust, in carbonado diamonds and as inclusions in rare terrestrial ophiolites and eclogites. The composition of some grains in the Skye layers is similar to that of V-bearing osbornite from comet 81P/Wild2 [4]. Barringerite in the layers has a low-Ni but high-Cr composition similar to that of andreyivanovite (FeCrP) from the Kaidun meteorite [5].

Age of impact. The impact event must have taken place prior to the earliest eruptions of basalts which lie above the impact layer. These lavas belong to the lowest units of the Main Lava Series, dated elsewhere in the region at 60.00 ± 0.23 Ma. The impact must therefore pre-date this, and must post-date the age of the basaltic block found in site 2 (61.54 ± 0.42 Ma). Thus the age is bracketed at mid-Paleocene, and cannot easily be reconciled with the end-Cretaceous impact event.

Nature of the impactor. The unusual mineralogy of the impact layer (Si- and C-bearing iron, barringerite, alabandite, osbornite and related nitrides and carbides) strongly suggests that the impactor was very reduced. These minerals are either extremely rare or unknown in the terrestrial environment, and certainly never found in association. However, these highly reduced minerals are commonly found mainly in enstatite chondrite meteorites, so it is most probable that the impactor was an enstatite chondrite. It is unusual to find unmelted crystals from the actual impactor within an ejecta layer, and their preservation may be related to their refractory nature.

Conditions of shock metamorphism. The presence of reidite shock lamellae in zircon implies instantaneous shock pressures in excess of ~30 GPa. Features such as planar deformation lamellae and diaplectic glass in quartz crystals indicate similar pressures (30-50 GPa).

Conclusions: This is the first report of a mid-Paleocene meteorite impact in western Scotland. The event coincided with the onset of extensive magmatism of the British Paleogene Igneous Province, but whether there is a connection between the two events is not yet clear. Furthermore, the extent of the ejecta layer throughout the region has not yet been established, nor has the impact crater been identified.

References: [1] Drake S. M. et al. (2017) *Geology* , *https://doi.org/10.1130/G39452.1*. [2] Parnell J et al. (2011) *J. Geol Soc., 168*, 349-358. [3] Gnos E. et al. (2013) *MAPS, 48*, 2000-2014. [4] Chi M. et al (2009) *GCA 73*, 7150-7161. [5] Zolensky M. et al. (2008). *Am. Min. 93*, 1295-1299.

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