ORGANIC CARBON FROM THE HIAWATHA IMPACT CRATER, NORTH-WEST GREENLAND.

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Introduction: Impacts on Earth affect its carbon cycle, life and climate, but well-preserved craters containing appreciable amounts of carbon are few. Here we report on impact-related organic carbon in the recently discovered Hiawatha crater 31 km in diameter [1], concealed under the Greenland Ice Sheet at 78°30' N, 66° W in Inglefield Land, North-West Greenland.

Analytical methods: Optical microscopy, scanning electron microscopy with backscattered-electron (BSE) imaging and Raman spectroscopy of hand-picked grains from glaciofluvial sample HW21-2016; see [1] for details.

Organic carbon in glaciofluvial sand from the Hiawatha crater: Glaciofluvial sand (sample HW21-2016), deposited no earlier than 2010 near the terminus of Hiawatha Glacier that drains the cratered area [1], predominantly consists of rock-forming mineral grains from the bedrock Palaeoproterozoic migmatitic paragneisses, as well as a wide range of impact-affected grains including shocked quartz, impure mineral glasses and microbreccias likewise with shocked quartz. Many of the latter grain types contain appreciable amounts of organic carbon. Grains of almost pure glass, grains with microliths in a glassy matrix, as well as grains composed of microcrystalline magmatic aggregates are commonly dark brown to almost black in colour irrespective of their chemical composition as reported in [1], contain dispersed graphitic carbon with low ordering, and in many grains the silicate microliths possess distinct graphitic coats about 1 µm thick [1]. Raman spectrography of glass grains in uncoated thin sections typically first yields a weak and very broad carbon band, which then abruptly intensifies and narrows on continued analysis and remains distinct also if the laser beam intensity is subsequently reduced. This observation seems to suggest that the carbon is initially finely dispersed in the glass, but that the energy delivered by the laser beam increases the local ordering and/or crystallinity of the carbon.

Microbreccia grains with tiny angular fragments of silicate minerals, including shocked quartz, may have a glassy matrix (Fig. 1) or a matrix consisting of a mixture of clayey material and very fine-grained carbonaceous matter with low ordering as determined by Raman spectroscopy. Other grains contain both silicate mineral particles and angular fragments of coal up to ~70 µm long with very low reflectance (R_0 = 0.2–0.5, Fig. 2). Some microbreccia grains with mixed clayey and carbonaceous matrix contain numerous amalgamated ellipsoidal to spherical subparticles ranging in size from ~5 to 125 µm, identifiable as an apparent circular arrangement of incorporated mineral splinters in thin or polished sections.

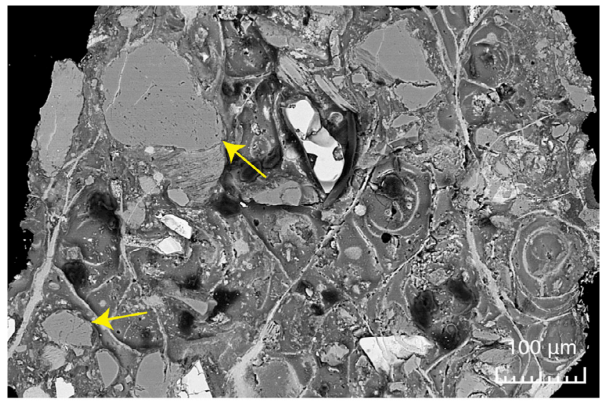

Fig. 1. Glassy microbreccia with fragments of quartz with shock lamellae (arrows), feldspar and garnet. The glassy groundmass displays onionshell-like perlitic microtexture, is partially devitrified and contains tiny carbonaceous particles. SEM-BSE image.

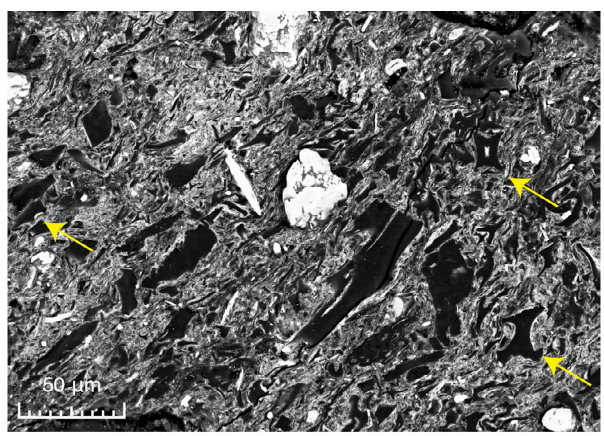

Fig. 2. Microscopic angular fragments of coal, commonly with concave shapes suggesting shrinkage (arrows), and silicate mineral particles in a matrix of very fine-grained clayey and carbonaceous material. SEM-BSE image.

Sand-sized charcoal fragments: In sample HW21-2016, occasional fragments of charcoal contain intricate vacuolated structures, some with higher reflectance up to R_0 ~3.5. There are also carbonaceous particles with massive appearance, vitreous lustre and high reflectance ('glassy' or 'glass-like' carbon using coal nomenclature). Larger fragments of charcoal up to ~2 cm in size were picked out directly from the ice at the tip of the Hiawatha Glacier where the sand was collected. An unpublished attempt to date the charcoal with the ^{14}C method showed that it is older than 50 ka.

The larger pieces of charcoal contain short, irregular shrinkage cracks that taper out in all directions, confirming that the charcoal fragments are drived from thermal alteration of wood. Many pieces are solid, coalified wood fragments with low reflectance ($R_0 \leq 0.5$) displaying regular rows of blocky, even-sized cells with bordered pit pairs. Cell walls are fibrous partially degenerated spiralled microstructure. Alternating layers of spring and summer wood each up to a dozen cells high and well-preserved bark layers also occur. The combination of all these cell structures is diagnostic for conifers, most likely *Pinus* or *Picea*. Some pieces contain a greatly expanded bark layer, where the expanded bark cells contain numerous spherical voids of different sizes, apparently caused by rapid expansion and escape of volatile material prior to complete coalification.

A few charcoal pieces contain poorly preserved wood cells with distinct perforation plates, a characteristic of the angiosperm genus *Betula*. Other pieces consist of fine-grained, conglomerate-like masses of disintegrated and partially downgraded organic material. Still other pieces contain both wood fragments and such fine-grained organic material. Groups of fungus cells are common in all investigated varieties of charcoal, whereas inspection in UV light only revealed very sporadic remnants of plant spores and/or algae, and no leaf cuticula at all. Silicate grains are virtually absent.

Discussion and conclusions: Most terrestrial impact structures only contain traces of organic carbon. This may be related to their target compositions, lack of preservation in eroded craters, and airblast removal of vegetation and unconsolidated deposits in young craters. A rare exception is the breccia of the Gardnos crater in Norway with up to ~1 wt.% finely dispersed graphitic carbon, considered to be derived from local Ordovician Alum shale [2]. The presence of a large variety of organic carbon in different forms in the Hiawatha impactite grains is therefore highly unusual. The carbonaceous matter includes finely dispersed, poorly ordered graphite in shock-melted silicate mineral glasses, discrete, structureless coal particles in microbreccias, and recognisable grains of charcoal displaying different states of thermal alteration. Some of this carbon might even have been sublimated and mixed with shocked and melted bedrock material above the surface of the crater.

The source of organic carbon: What are the source and age of the organic carbon? The cell structures and signs of shrinkage and bark expansion in the charcoal clearly indicate that the source is subfossil, >50 ka gymno- and angiosperm wood, as opposed to previously buried, compacted and thermally matured lignite. Gymnosperm trees are extinct in northern Greenland but were present in eastern North Greenland during a warm period ~2–2.5 Ma ago. The estuarine Kap København Formation in Peary Land preserves a large variety of plant debris including *Larix*, *Picea* and *Pinus* [3]. In the context of the Hiawatha crater it is important to note that no charcoal has been found among the plant debris in the Kap København Formation, despite the detailed studies of the latter [3, 4]. Furthermore, in Washington Land adjacent to Inglefield Land subfossil tree trunks up to 10 cm in diameter with remains of bark and twigs have been found at altitudes up to 370 m above sea level in river beds draining the Greenland Ice Sheet [5] (i.e. the tree trunks are not driftwood). We infer that open tundra vegetation with small trees was also growing in the Hiawatha target area ~2–2.5 Ma ago and, like in Washington Land, some of the tree trunks were preserved during the subsequent glaciations, maybe embedded in shallow sedimentary deposits on the crystalline bedrock. The thermal record in well-preserved pieces of Hiawatha charcoal (including desiccation cracks and bark expansion) is ascribed to impact-induced heating of subfossil wood in the periphery of the crater, with or without open wildfires.

The large variety of Hiawatha impactite grains containing terrestrial organic matter with a likely age between 2.5 Ma and 50 ka support the conclusion in [1] that the crater itself is not much eroded and very young, and the possibility of an age of less than 50 ka remains open.

Acknowledgements: We gratefully thank the coauthors of [1] for their contributions to establish the Hiawatha crater itself.

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