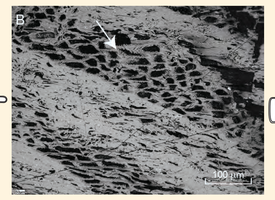
Organic carbon from the Hiawatha impact crater, North-West Greenland

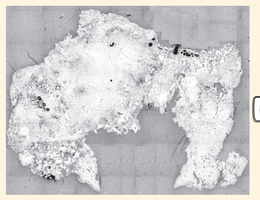
Adam A. Garde[1], Svend Funder[2], Carsten Guvad[1], Kurt H. Kjær[2], Nicolaj Krog Larsen[3], Jette Dahl-Møller[4], Gernot Nehrke[5], Hamed Sanei[3], Anne Sofie Søndergaard[3] and Christian Weikusat[5].

[1]Geological Survey of Denmark and Greenland (GEUS), Denmark, aag@geus.dk, [2]Centre for GeoGenetics, Natural History Museum, University of Copenhagen, Denmark, [3]Department of Geosience, Aarhus University, Denmark, [4]Geobiology and Minerals Section, Natural History Museum, University of Copenhagen, Denmark, [5]Alfred Wegener Institute, Bremerhaven, Germany.

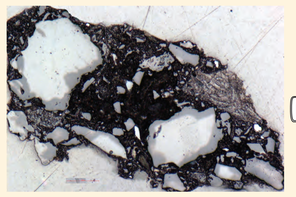
Subfossil, un-charred, ~2.5 Ma old tree trunks up to 2 m long, washed out from under the ice sheet in adjacent Washington Land



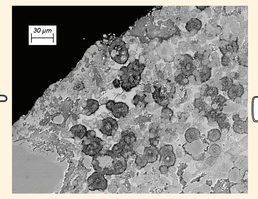
Gymnosperm subfossil wood



Heated carbonaceous particle from impacted subglacial source



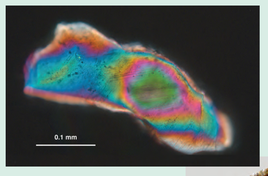
Microbreccia with carbon in matrix



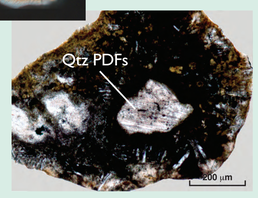
Impact glass showing expulsion of carbon around micro-orbicules

Sampling glaciofluvial sand recently washed out from the Hiawatha crater

Glaciofluvial impactite grains

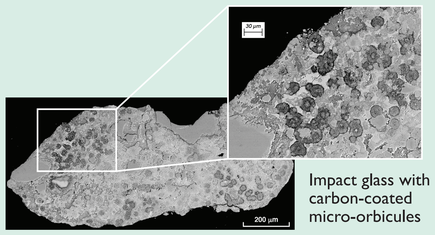


Shocked quartz fragment with planar deformation features (PDFs)

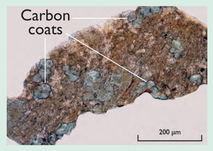


Shocked quartz with PDFs and partially melted feldspar.

Glassy matrix: feldspar microcrysts and organic carbon

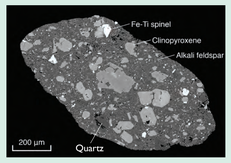


Impact glass with carbon-coated micro-orbicules

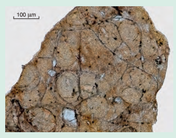


Impact glass with carbon-coated, immiscible globules

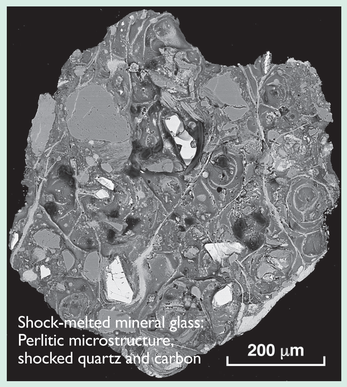
Impact glass with shrinkage crack and beginning radial crystallisation. Garnet-like composition. Plume melt droplet?



Microporphyritic feldspar- and cpx-rich melt grain with unmelted quartz fragments



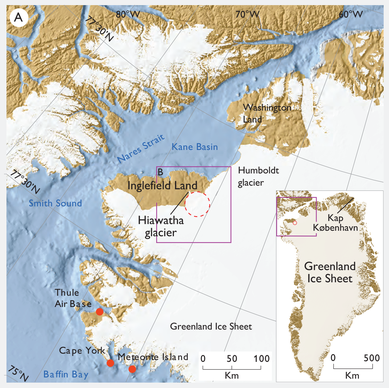
Shock-melted mineral glass: perlitic microstructure



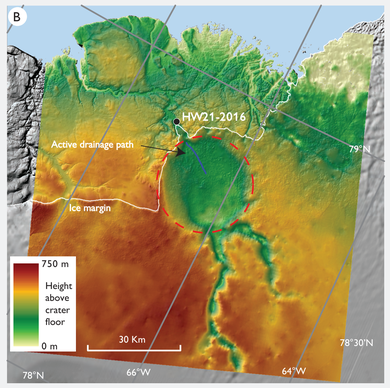
References

Gilmour, I. et al. 2003: Geochemistry of carbonaceous impactites from the Gardnos impact structure, Norway. Geochimica Cosmochimica Acta 67, 3889–3903.
Howard, K.T. et al. 2013: Biomass preservation in impact melt ejecta. Nature Geoscience 6, 1018–1022.
Kjær, K. H. et al. 2018: A large impact crater beneath Hiawatha Glacier in northwest Greenland. Science Advances 4, eaar8173, 11 pp.
Lindgren, P. et al. 2007: Preservation of Organic Carbon in Impact Melt Breccia, Haughton Impact Structure. LPS XXXVIII, 1142.
Schultz, P. H. et al. 2014: Preserved flora and organics in impact melt breccias. Geology 42, 515–518.

The Hiawatha impact crater



Location in Greenland



Subglacial topography and sediment sample site

- Discovered in 2015, first publication by Kurt H. Kjær and others in 2018 (Science Advances).
- Hidden under the Greenland Ice Sheet, d = 31 km, one of the 25 largest terrestrial impact structures
- Possibly the youngest large impact structure on Earth, with the fall watched by humans?

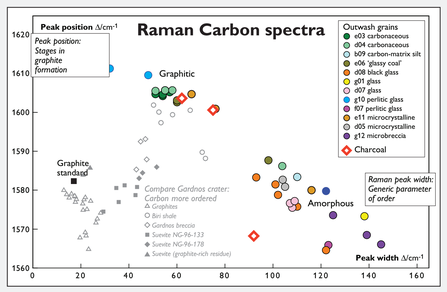
Detection and characterisation of carbon using Raman spectrography

Raman peak widths and peak positions document a wide range of carbon ordering and degree of graphitic platyness at Hiawatha.

The ordering is lowest in the shock melt mineral glasses.

Carbon in mantles around microliths is more ordered.

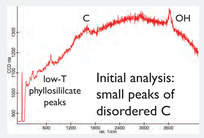
In general, the Hiawatha carbon is much less ordered than the metamorphosed carbonaceous material in Gardnos crater breccia (Gilmour *et al.* 2003).

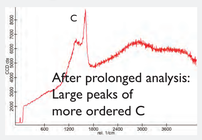


Evidence of low carbon ordering in shock melt glasses

The carbon in melt glasses is dispersed.

Laser-induced, in-analysis crystallisation of carbon is observed.

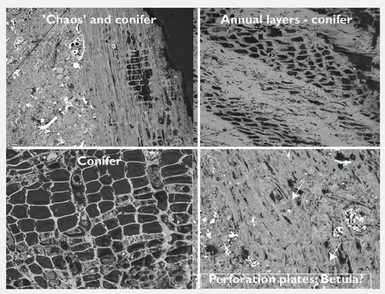




A likely source of the organic carbon

- Lumps of charcoal in the Hiawatha glacier, glaciofluvial grains of homogenised carbon, as well as carbon in microbreccias and impact glasses record widely different degrees of impact heating.
- The charcoal found in the Hiawatha glacier stems from conifers such as *Pinus* and *Picea*, which are now extinct in North Greenland. Unpublished ^{14}C analysis shows that the Hiawatha wood is older than ~50 ka.
- Trunks of fresh, light brown wood occur in glacial outwash rivers in adjacent Washington Land. Remnants of land plants and trees are common in the 2.5 ma, estuarine Kap København Fm, eastern North Greenland, deposited during a warm period. See maps in box above.
- Such wood from unconsolidated surficial deposits under the Greenland Ice Sheet constitutes the only plausible source of all the carbon found in Hiawatha impactite grains.

Subfossil charcoal collected from the tip of the Hiawatha glacier. It is black, light, and very fragile, and thus qualifies as charcoal as opposed to lignite, in spite of its low reflectivity (R_0).



Objectives and conclusions

- The newly discovered Hiawatha crater has a highly unusual organic carbon content in shock melt glasses, microbreccias, and around shocked quartz grains. Only few other impact structures contain appreciable organic carbon (e.g. Gardnos, Haughton, Darwin, Popigai, see references).
- Dispersed organic carbon was incorporated in microbreccias and shock melts.
- Solid organic carbon was heated, depleated and homogenised to form particles with high reflectance (R_0 = 1.0–3.5).

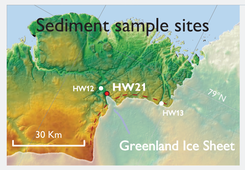
WHAT IS THE SOURCE OF THIS CARBON AND WHAT CAN IT TELL US?

- The obvious carbon source is subfossil wood, known from adjacent Washington Land and the 2.5 Ma Kap København Fm in eastern North Greenland. The carbon content is therefore compatible with a very young age of the impact.
- In an impacting scenario through ice, the Greenland Ice Sheet would have protected the unconsolidated plant debris from being removed by the airblast.

Impact-induced depletion of organic carbon: Results of C pyrolysis of glaciofluvial sediment

A dramatic loss of labile proto-hydrocarbons ('S2') is observed in the sedimentary organic matter towards the impact site, independently of grain size.

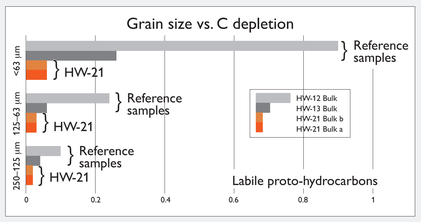
This is associated with increased depletion of total organic carbon (wt.%) and an increased fraction of inert ('dead') carbon towards the impact site.



HW21: Glaciofluvial sediment draining the crater.

HW12 and HW13: Reference samples with similar bulk composition.

Outwash plain in front of the Hiawatha glacier, looking NW from helicopter



The relationship between sample locality, sediment grain size and labile proto-hydrocarbons for sample HW21 and the two reference samples HW12 and HW13.

The clear 'bull's-eye' spatial distribution of organic carbon can be attributed to an intense external heat source.

A sudden loss of labile proto-hydrocarbons associated with the proximity to the impact area is difficult to explain by any diagenetic or geological process, except intense external heating which is well constrained by other evidence of this catastrophic impact

Carbon reflectance (R_0)

- **Charred wood**: low, bimodal R_0.
- **Carbonaceous grains** and carbon in microbreccias: variable, generally higher R_0, documenting heating and C-H-O depletion.