Micrometeorite Pre-Solar Diamonds from Greenland Cryoconite?

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Introduction.
An acid-resistant residue prepared from Greenland cryoconite has been investigated to
determine whether the micrometeorite component within the cryoconite contains pre-solar
material analogous to that found in primitive chondritic meteorites. The residue has been
analysed for carbon content and stable isotopic composition \[1\], by electron probe micro-
analysis (EPMA) for major element chemistry and then by a combination of X-ray diffraction
(XRD) and transmission electron microscopy (TEM) to elucidate the structure of any
constituent mineral phases. The cryoconite sample, which was collected ca. 25 km inland of
the ice margin at the latitude of Søndre Strømfjord on the west coast of Greenland, was
processed by Dr. J.W. Arden at the University of Oxford following procedures used on bulk
meteorite samples for the isolation of pre-solar dust components (see \[2\] for details of the
experimental methods).

Results.
1) Stable carbon isotopes.
The results of the stable carbon isotope analysis have been previously reported \[1\], but
suggested that the residue contained meteoritic pre-solar diamond and silicon carbide (SiC).
Furthermore, the abundance of these components within the micrometeorite fraction of the
cryoconite was estimated to be in excess of the maximum values obtained for the most
primitive meteorites \[3\].
2) Electron probe micro-analysis.
The major element chemistry of the residue revealed it to be largely constituted of a mixture
of micron-sized metallic alloy grains. These grains were composed of aluminium, titanium
or a chromium-titanium-iron composite, and were often found embedded in larger (up to
c.400 \(\mu\)m diameter) grains that were rich in silicon (Si) and zirconium (Zr).
3) X-ray diffraction.
The residue yielded a complex pattern of diffraction lines, but from which only the mineral
zircon (\(ZrSiO_4\)) could be positively identified. The presence of zircon explained the Si and
Zr from the EPMA results, but it was somewhat surprising, considering their abundance
within the residue, that no lines characteristic of the metallic alloys were identified.
4) Transmission electron microscopy.
The TEM results confirmed the presence of zircon, but also revealed rutile (\(TiO_2\)) and, more
importantly, diamond. The diamonds were present within the residue as an aggregate of
crystals with a mean grain size of ca. 5 nm; this is comparable to that of pre-solar diamonds
isolated from primitive meteorites \[4\]. This being said, individual diamonds were observed
within the aggregate approaching 30 nm in diameter which is greater than any reported from
the primitive meteorites. The aggregation of the diamonds allowed a good electron
diffraction pattern to be obtained; three rings at 2.06 Å, 1.26 Å and 1.08 Å were seen, which
corresponds to diamond \((111)\), \((220)\) and \((311)\) respectively. These results show an excellent
correlation with the values obtained for diamonds from an acid-resistant residue of Allende,
where spacings of of 2.06 Å, 1.26 Å and 1.07 Å were observed \[4\].
Unfortunately no SiC grains were identified. However, pre-solar SiC is present within the
primitive meteorites at a reduced concentration with respect to pre-solar diamond \((i.e.\ a
maximum of 941 ppm for diamond and 14 ppm for SiC \[3\]). Correspondingly, if the
micrometeorites mirror their larger counterparts in the relative concentrations of pre-solar
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material, then intuitively SiC would be more difficult to isolate. It is also apparent that this problem would be exacerbated if, unlike the diamonds, the SiC did not aggregate together during the preparation protocols.

Conclusions.
The bulk of the cryoconite residue was found to be composed of metallic alloys. It is well established that aerospace activities have produced a debris belt about the Earth composed largely of metals, refractory oxides and silicate grains [5]. Orbital decay of such debris particles allows them to enter the Earth's atmosphere, where they are subject to the same collection mechanisms as extraterrestrial dust. It is therefore perhaps not surprising that similar material has become concentrated along with the micrometeorites in the cryoconite samples. Given this possible source it is perhaps feasible to explain why the alloys in the residues could not be identified by XRD, as intuitively the ablation processes that formed them are not replicated in the formation of terrestrial alloys from which the XRD standards are derived.

The stable carbon isotopic analysis of the residue had suggested the presence of pre-solar diamond and SiC components analogous to those isolated from the primitive meteorites. Examination of the residue by TEM has confirmed these tentative conclusions for the diamond, although no SiC was isolated. The carbon isotope analysis also implied that the concentration of the pre-solar material within the micrometeorite fraction of the cryoconite was greater than even the most primitive meteorites. Although the TEM results can not verify these conclusions, it is still considered possible that they could be valid, i.e. some micrometeorites may be composed of almost pure fine grained matrix. Notwithstanding that the mean grainsize of the cryoconite diamonds was similar to that from the primitive meteorites, a few larger grains were observed. It is therefore possible to speculate that the respective sources of the diamonds for the micrometeorites and their larger counterparts may be different.

Further work.
Two new residues have been prepared using larger aliquots of cryoconite in an attempt to verify the results reported here. These residues are currently undergoing TEM and stable carbon isotope analysis. Pre-solar SiC and diamonds are known to be the hosts of isotopically light nitrogen, possessing mean $\delta^{15}N$ values of $-625\%$ [6] and $-343\%$ [7] respectively, and consequently the residues are also scheduled for stable nitrogen isotopic analysis.

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References.