CARBONACEOUS METEOR ASH - A SIGNIFICANT CARRIER OF CARBON, ORGANIC MATERIAL AND NOBLE GAS TO THE SURFACES OF TERRESTRIAL PLANETS?

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With the exception of rare large impactors, the Earth's accretion of meteoritic matter is dominated by 10µg particles with diameters near 200µm [1]. Particles this size are observable from the ground as radar meteors [2] and they are at the peak of the meteoroid mass distribution. Over most of solar system history they have potentially been major carriers of carbon, organic matter and noble gas to the surfaces of terrestrial planets. It has generally been assumed however, that most particles >100µm would be "destroyed" during atmospheric entry in the sense that their noble gas contents would be lost and their carbon would be burned to CO and CO_2. Atmospheric entry calculations [3,4] indicate that the majority of 200µm particles are heated to temperatures above 1200 ˚C and they melt to form "cosmic spherules". Some particles >>100µm do survive atmospheric entry without melting but they are rare ones that escaped severe heating due to low entry velocity and chance low atmospheric entry angle.

We report new work that suggests that the large particles at the peak of the meteoroid mass distribution, the ones that are large enough to melt and form spheres, may indeed be significant and perhaps major carriers of noble gas and carbonaceous matter to planetary surfaces. The scenario is that large micrometeoroids that are strongly heated during atmospheric entry do melt to form silicate spherules but in the process they shed "carbonaceous meteor ash".

Common IDPs have very high carbon contents, generally above 10% [5] and sometimes above 50%. This material is partly carbonized during atmospheric entry but it is not destroyed and it is actually quite refractory. It undergoes thermal alteration and must lose some of its H, N and O but it survives. It is the only component of chondritic IDPs that does not melt during spherule formation. The carbonaceous ash is immiscible in silicate melt and is not wetted by it. We suspect that the carbon ash separates from the spherules and forms a previously undetected black rain of carbon soot falling from the mesosphere. It is likely that typical particles that melt yield flakes of surviving carbon soot. Remarkably some of these soot particles can carry very high concentrations of He and Ne. Although they have been strongly heated, it is likely that some organic materials also survive. The strongly heated carbon material should be a good analog to activated carbon with surface areas up to 1000 m^2g^{-1}. This material has fallen to Earth over all of its history and it is likely that it was the Earth's dominant source of soot long before the invention of airplanes, coal, and plants.

The first indication that carbonaceous ash could survive meteoroid melting was the observation of a rare type of IDP composed of a silicate sphere or spheres with attached or associated low Z material. The silicate spheres have FeNi spherules on their surfaces and have been called metal mound silicate spheres (also Mickey Mouse spheres because the first one observed looked like it had ears). The low Z material is dominantly an "amorphous" carbon but it also contains small amounts of FeNi and Si. The Si may be trace amounts of silicone oil that is so tightly bound to the carbon that its not completely removed by hexane washing.

The FeNi occurs as small metal beads dispersed in the carbon. TEM observations of microtome sections show that they are 10 nm to 1µm rounded grains typically surrounded by 3nm rims of graphite showing 0.34 nm fringes. The graphite rimming phenomenon is commonly seen in analogous industrial materials and is attributed to carbon exolved from the cooling metal beads. The mix of metal mound silicate spherules and irregular carbonaceous material with fine metal beads is striking. We cannot rule out the that these strange particles formed in space but we feel that it is most likely that they formed during atmospheric entry. They have been perfectly reproduced by pulse heating experiments on actual IDPs in the electron microprobe [6]. Some of the metal beads imbedded in the carbon appear to have been formed by reduction from silicates. We observed this phenomenon in pulse heating experiments of mixtures of powdered coal and olivine. The refractory carbon left after olivine melting contained fine grained metal beads coated with thin graphite rims, just like in the IDPs.

The survival of carbon residue in melted heated particles was a surprise because it seemed likely that carbon would burn during atmospheric entry. In pulse heating experiments of coal in air at the ram pressure of meteoroids at 90Km altitude, we clearly saw substantial survival of carbonized residue at temperatures of 1200 ˚C. Some carbon must be oxidized but the majority seems to survive the few seconds of high altitude pulse heating seen by small meteoroids.

Palma et al. [7] have analyzed a few of the soot particles and have found that some of them have retained high concentrations of He and Ne. This was unexpected because it seemed reasonable that the carbonaceous matter would outgas below the silicate melting temperature in the range of 1200-1300 ˚C. Two particles were analyzed that released most of their helium above 1500 ˚C.

To shed light on this remarkable finding, they also studied a normal (not strongly heated) particle that we demineralized in HF to remove its silicate components. This particle retained most of its Ne until heated above 1500 C. It is clear that the carbon in IDPs is a major noble gas carrier and that it contains sites that can retain He and Ne at high concentrations. It is possible that the carrier is carbon nanotubes and the gas enters the tubes during pulse heating. This work clearly shows that at least some fraction of the carbon in meteors survives atmospheric melting and that it can carry He and or Ne at concentrations >1 cc/g.

These results suggest that carbon ash should be seriously considered as a possible major carrier of ^{3}He to the surfaces of terrestrial planets. ^{3}He is an important tracer of the accretion of extraterrestrial material and it provides a means of determining sedimentation rates and intervals. Some of the He in IDP carbon is very tightly bound and would be quite robust in many subsurface environments including subduction zones. The detection of IDP ^{3}He in sedimentary rocks as old as 480 Ma [8] suggests that some of the terrestrially accreted ^{3}He is in a robust carrier. Because the carbon contains tiny metal grains it should be slightly magnetic. Future studies should consider the possibility that carbon might be a major carrier and take precautions that fine-grained meteor ash not be discarded or overlooked in sample collection or processing techniques. This might also be considered if ^{3}He is used as an accretion rate monitor for sediments on Mars.

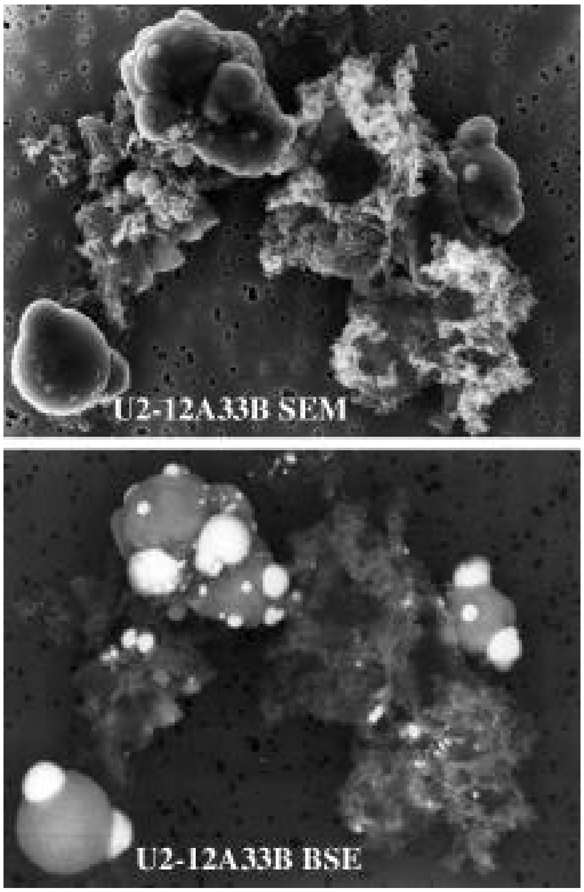

Fig 1 BSE and SEM of He rich IDP. Dark material is carbonaceous meteor ash.

The current rate of extraterrestrial material accreting to Earth is 40,000 tons per year, mostly in the form of 200µm particles that melt during atmospheric entry. It is possible that 4000 tons or more of this total mass is carbon that largely survives as a black rain of fine meteor soot. This soot has largely gone undetected but it is at least conceivable it may have had astrobiological implications for the early earth. During the first half billion years of earth history it is likely that the dust flux was many orders of magnitude higher than at present. The higher dust flux would be expected due to much higher populations in the asteroid belt and the Kuiper belt. Habing et al. [9] provide evidence that the majority of solar type stars are surrounded by intense dust disks for their first 400 million years. These disks would be cleared of dust on timescales of a million years or less, unless effective replenishment mechanisms are at work. Evaporation of comets and collisions between solid bodies are both plausible sources analogous to IDPs and zodiacal dust in our own Solar System. These disks could provide terrestrial planets with impressive quantities of carbonaceous meteor ash material that might provide interesting catalytic properties.

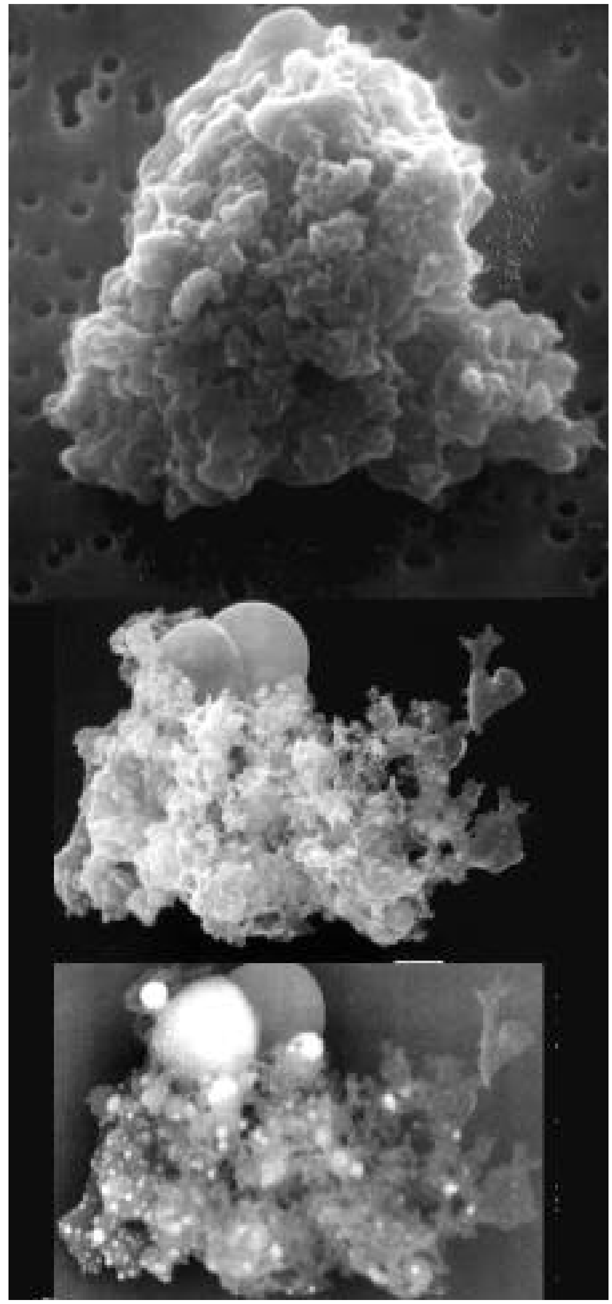

Fig 2 Lab heated IDP. Original- top, SEM center, BSE bottom.

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