Abstract

It's bigger actually? For more relevant comparisons with, and interpretations of, analyses of comet dust returned by NASA's Stardust mission to 81P/Wild 2, we explore the state of the alteration of the most primitive, fine-grained, extraterrestrial materials available. Our study compares the characteristics of small chondritic porous interplanetary dust particles (CP-IDPs) with large cluster IDPs collected in the stratosphere and also considers ultracarbonaceous micrometeorites (UCMMs) collected in snow and ice in the Antarctic. We show that some temperature-sensitive components in small (<2 μm) CP-IDPs can differ significantly from those of larger (>50 μm) cluster IDPs and UCMMs, and we describe new analytical approaches for investigating evidence of thermal modification below the solar flare track erasure temperature.

Comparing Wild 2 to Primitive Dust Samples

Linking Wild 2 to specific classes of CP-IDPs or micrometeorites has proven challenging. Comparisons with fine-grained materials, like CP-IDPs, are especially difficult because of severe loss and damage to the Wild 2 fine-grained fraction — although it has been argued that CP-IDP-like material must have been present (14, 15). GEMS and similar objects akin to ablation and plates with specific crystal habit are uniquely characteristic of CP-IDPs (10), and their discovery in ultracarbonaceous micrometeorites (UCMMs) from Antarctic snow and ice establishes UCMMs as part of the CP-IDP family (11, 12).

The Stardust hypervelocity capture greatly complicates positive identification of GEMS in Wild 2 dust.

• GEMS-like objects were produced via ablation interactions of comet dust, including its evolutions, with solar wind (13).

• A similar chondritic average composition probably are found in GEMS in Wild 2 (14), whereas report CP-IDPs/plates (13); but there are no robust identifications of GEMS or CP-IDPs outside of this study yet.

• A range of state comparisons are consistent with recent meteorite discoveries during capture, especially in fine-grained fracture (16).

What then is the state of preservation of CP-IDPs (and UCMMs) with which we compare Wild 2 CP IDPs are also biased by atmospheric entry heating and melting. Most IDPs are frictionally heated >500°C, and the larger the particle, the more likely it was strongly heated. Researchers have increasingly studied large cluster IDPs (typically >50 to 300 μm) because (a) they are easier to handle, (b) H and N isotopes are more sensitive to surviving molecular cloud material are larger and more common (21) (i), their interiors are presumed to be less heated than their outer surfaces during atmospheric entry, and (c) IDPMs provide a new resource of large cluster IDP-like material.

In some CP-IDPs, atmospheric entry effects are obvious: magnetite (Fe₃O₄) rims, vesicles in carbonaceous material, volatile loss and melted morphologies. In particles without these, the presence of surface (facing >50°C) of CP-IDPs, where the track erasure temperature (~160°C) (18).

However, for large cluster CP-IDPs IDPs and UCMMs, SF Tracks are not reliable thermal indicators because their interiors are sufficiently shielded that they appear unaltered. Even in small CP-IDPs with SF tracks, little is known about modifications at lower temperatures.

EELS Features as Heating Indicators

Electron energy loss spectroscopy (EELS) with a monochromated and aberration-corrected transmission electron microscope (STEM) enables:

• Low loss EELS detection of solar wind implanted H and He in situ in the surface of CP-IDPs indicating that these particles remain at or near the solar wind environment (20)

• Core loss EELS localized analyses of functional groups in carbonaceous material (like XANES AXANES 22), which can be used to assess the thermal history of organic chemistry changes associated with atmospheric entry and silicone oil removal.

GEMS and Sulphides as Heating Indicators

GEMS (glass embedded with metal and sulfides) and sulfides are potential indicators of thermal alteration below the solar flare (SF) track erasure temperature. Sulfide-decorated GEMS are more abundant in large cluster CP-IDPs and UCMMs likely to be strongly heated during atmospheric entry and less abundant in small CP-IDPs. Heating experiments in air of a small (20 μm diameter) track-rich CP-IDP to simulate atmospheric entry show that GEMS sulfides melt at 300-400°C and migrate to surfaces (20); contrasting interpretation of sulfide-decorated GEMS as evidence of netural condensation (21). GEMS in UCMMs may also suffer heating due to snow/ice exposure.

Conclusions

We demonstrate new approaches to investigate thermal modification of CP-IDPs below the solar flare track erasure temperature of ~650°C. These include chemical maps of GEMS and sulfide, sulfide crystal structure, EELS in the low loss region where H and He may be detected, and EELS in the core loss region where multiple-functional groups may be observed at the C K edge. Large cluster CP-IDPs suffer stronger heating than small CP-IDPs, on average. Even small CP-IDPs sized to be “pristine” by the absence of magnetite rims, vesicular, carbonized, melted morphologies and the presence of solar track structures in carbonaceous material can have variable alteration of these components most susceptible to alteration, i.e. the glassy GEMS and sulfides. Strophastropic CP-IDPs also retain some silicone oil, even with thorough hexane washing. These observations serve to inform comparisons to Wild 2 dust and other analyses on CP-IDPs such as isotope measurements.


