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Supporting Online Material for

Comparison of Comet 81P/Wild 2 Dust with Interplanetary Dust from Comets

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This PDF file includes:

Materials and Methods
SOM Text
References

Correction: On pg. 2, text reading “48 GEMS in 5 CP IDPs and 50 “GEMS-like” objects in 4 Stardust tracks” was changed to “42 GEMS in 5 CP IDPs and 46 “GEMS-like” objects in 4 Stardust tracks.”

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Materials and Methods

Light Gas Gun Shot Preparation

The light gas gun shot of pyrrhotite into silica aerogel was prepared using a two-stage light gas gun at the University of Kent (UK) *(S1)*. A polydisperse sample of pyrrhotite grains (provided by the Natural History Museum, London) were used as projectiles. They were placed in a sabot which was discarded in flight. The range of the gun was evacuated to less than 1 mbar. Projectile speed was measured in flight by passage of the grains through two laser light curtains. Each curtain was focused onto its own photodiode. Interruption of the light curtains by passage of the projectiles provided two timing signals that, in combination with the known separation of the light curtains, provided the speed. The speed for the pyrrhotite shot was 5.91 km/s, with an uncertainty of order 1%. This speed was within a few percent of the Stardust comet dust impact speed of 6.1 km/s. The aerogel used as the target had a density of 25 mg/cc, in the middle of the range of the density gradient aerogel used to capture Wild 2 particles by the Stardust mission *(S2)*. The pyrrhotite impact track chosen for extraction, embedding and ultramicrotomy (see below) had a 10 micron diameter remnant pyrrhotite particle at its terminus.

Transmission Electron Microscope (TEM) Sample Preparation

In cleanroom conditions, Stardust and laboratory generated pyrrhotite impact tracks in aerogel were cut from surrounding aerogel *(S3,S4)* and gently compressed to flatten the track. CP IDPs, individual extracted Stardust particles and compressed Stardust and laboratory produced impact tracks were potted in a low-viscosity embedding medium (acrylic *(S5)* or Embed 812 with low cure temperature of 60°C). Ultramicrotomy *(S6)* was used to produce electron transparent thin sections mounted on carbon substrates on Cu TEM grids for TEM imaging and spectroscopy. Samples are stored in low humidity dry boxes in a cleanroom.

TEM Imaging and Compositional Analysis

Imaging was carried out using a monochromated 200 keV FEI Tecnai scanning transmission microscope equipped with a solid state EDAX x-ray energy-dispersive detector and a high-resolution Gatan Imaging Filter (HR-GIF). The compositions of 42 GEMS in 5 CP IDPs and 46 “GEMS-like” objects in 4 Stardust tracks were measured using 200 keV energy-dispersive x-ray spectroscopy. The IDPs are U219C11, U222B42, U220A19, U2012C-2I and U2073B-2I. The Stardust tracks are Arinna (C2,7,10), Febo

(C2009,2,57), Hopeful (FC5,0,5) and Lucia (C2115,33,123,0). The abundances of O, Mg, Al, Si, S, Ca, Mn, Cr, Fe and Ni were measured quantitatively using energy-dispersive x-ray spectroscopy in conjunction with a Cliff-Lorimer thin-film correction procedure. Analytical error was assessed by analyzing thin film standard NIST SRM2063 and thin-film mineral standards of enstatite, forsterite and FeNi-sulfides. Relative error of the individual measurements, determined chiefly by counting statistics and peak fitting algorithms, are estimated to be ±5% for O and Si, ±10% for Mg, S and Fe, and ±20% for Al and Ca, and ±50% Cr, Mn and Ni.

Supporting Notes

Results of Preliminary Examination of Comet 81P/Wild 2 dust

For details on the results of NASA's early examination of the Stardust samples carried out by international teams of researchers, the reader is referred to articles in the *Science* special issue of 15 December 2006 *(S7-S13)*.

Cometary origins of chondritic porous interplanetary dust particles

Observations of meteors have shown that a significant fraction of the dust entering the Earth's atmosphere is from comets. Studies of the atmospheric fragmentation of cometary meteors (clearly associated with a comet) show that they are composed predominantly of porous, extremely fragile objects *(S14)*. Chondritic porous interplanetary dust particles (CP IDPs) are the most porous and fragile meteoritic objects known. The high speeds at which some of them enter the atmosphere are consistent with capture from cometary rather than asteroidal orbits *(S15)*, and they have recently been collected from dust streams associated with specific comets (e.g. Grigg-Skjellerup) *(S16)*. Their anhydrous mineralogy and lack of evidence of post-accretional alteration are consistent with derivation from small, low-density bodies without liquid water like comets and some outer asteroids *(S17)*. The silicate mineralogy and mid-infrared spectral properties of CP IDPs are like those of comets Halley and Hale-Bopp and dissimilar to other classes of meteoritic materials *(S18-S20)*.

The cosmically primitive nature of chondritic porous interplanetary dust particles

CP IDPs contain at least 10 times more isotopically anomalous presolar constituents than other known meteoritic materials *(S16,S21)*. For example, about 10 presolar organic and inorganic grains have been identified in a single fragment of a single CP IDP (L2054 E1) and 8 in another single CP IDP (L2054 G4) recently collected during dust fall from the Comet 26P/Grigg-Skjellerup meteor stream *(S16, S22)*. CP IDPs are composed mostly of amorphous silicates (e.g. GEMS or glass embedded with metals and sulfides). Amorphous silicates are the dominant form of silicates in the outer disks of some young stars believed to be analogues of the solar nebula *(S23)*. Silicate grains are also abundant in the interstellar medium, >99% of them are amorphous *(S20)*, and the infrared ~10 µm silicate feature of some GEMS matches the interstellar ~10 µm silicate feature observed in astronomical spectra along most lines-of-sight *(S19)*. These considerations indicate GEMS in CP IDPs may represent surviving interstellar silicates that accreted into comets *(S24)*. Indeed, some GEMS have non-solar O isotopic compositions confirming their identity as presolar silicates *(S25)*. Other GEMS with normal (solar) O isotopic compositions are embedded in organic carbonaceous material with non-solar H and ^{15}N isotopic compositions *(S26)* strongly suggesting that they, too, are presolar silicates *(S27)*. Heating and irradiation experiments suggest GEMS were modified, primarily by exposure to ionizing radiation and sputtering, in cold (<1000K) astrophysical environments *(S24,S28-S29)* consistent with a long transit in the interstellar medium.

Sampling biases associated with Stardust comet dust capture and CP IDP collection in the stratosphere

Possible explanations for the non-detection of GEMS and [100]-elongated enstatite whiskers and platelets are that 81P/Wild 2 does not contain these silicate materials, that the Stardust capture conditions were too severe to allow their survival in recognizable form, that the CP IDPs collected in the stratosphere are an unrepresentative sampling of comets, or that CP IDPs are derived from a different class of comets than 81P/Wild 2. While it is possible that these silicates will be identified in the Stardust samples in the future, unambiguous identification of GEMS is unlikely due to the look-alike “GEMS-like” material generated by impact into silica aerogel. The identification of whisker-like enstatite elongated on the [001] crystallographic axis, unlike whiskers in CP IDPs, indicates that 81P/Wild 2 enstatite is like that in meteorites and terrestrial rocks.

The Stardust samples described in this work were captured in silica aerogel at 6.1 km/s. Shock and thermal effects on capture have been documented ranging from minimal to severe depending on mineral grain size and robustness even within a single impact track *(S7,S13)*. For example, sulfides display a range of alteration by capture including melting, quenching and reduction to metal. Even more robust silicate minerals show amorphous rims likely formed by intermixed molten aerogel and cometary debris. These include olivines and pyroxenes, including enstatite, found in relative abundance in the Stardust sample *(S13)*. Submicron grains are likely heavily modified while the interiors of some ~10 micron-sized grains have been found to be minimally damaged *(S7,S13)* indicating that the best preserved 81P/Wild 2 grains are likely the largest ones.

IDPs are collected by impact at 200 m/s onto silicone-oil coated flat-plate collectors (“flags”) mounted on wing pylons on ER2 or WB57 aircraft *(S30)*. Most IDPs recovered from the “flags” are 2-25 microns in diameter. Smaller IDPs are not recoverable due to background terrestrial sulfate aerosol on the “flags”. Larger IDPs are more rare although some as large as ~300 microns in diameter have been recovered *(S17)*. Chondritic porous (CP) IDPs are a biased sampling of extraterrestrial materials that are too fragile to survive atmospheric entry as larger (meteorite-sized) objects. Since cometary meteors are known to be composed of fragile materials, CP IDPs are probably a biased sampling of cometary materials. The preservation of implanted solar wind noble gases, solar flare tracks, and low-temperature minerals establish that many survive the gradual deceleration in the atmospheric with minimal thermal alteration *(S31-S32)*.

Search for GEMS and enstatite whiskers/platelets in Stardust foil samples

The studies described in this work focused on Stardust samples from the aerogel collector medium; however aluminum foils wrapped over the ribs of the collector frame provided additional collection surface area *(S2,S8)*. Analysis of craters formed by the hypervelocity impact of cometary debris into these foils show morphological and chemical evidence of impact by aggregates *(S2,S33)* such as might be expected from CP IDP-like material of relatively low density and high porosity, but well-preserved GEMS and enstatite whiskers or platelets have not been identified. Experimental shots of fine-grained meteorite powders, however, show that the more extensive shock and melting on impact into relatively dense metal erase most characteristic original textures and intermix residue compositions, and the foil substrates are unlikely to yield strong evidence regarding presence or absence of these silicates.

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