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Melted Crumbs from Asteroid Vesta

--- Researchers studying some of the rarest of the smallest meteorites call them melted crumbs from asteroid Vesta.

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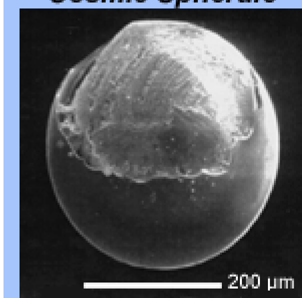
Cosmic Spherule



(From S. Taylor et al., 1997, *CRREL Report 97-1*, p. 21.)

Micrometeorite bombardment accounts for almost 30,000 tons of material entering Earth's atmosphere each year. Though most of the material evaporates during entry or is lost to sea or falls on the land unnoticed, thousands of micrometeorites have been collected successfully from deep-sea sediments and from the snow and ice of the polar caps. Susan Taylor (Cold Regions Research and Engineering Laboratory) and colleagues collected micrometeorites with an ingeniously designed robot from a decidedly out-of-the-way place: Amundsen-Scott South Pole Station water well. She and Greg Herzog and Jeremy Delaney (Rutgers University) selected 10 out of thousands of these extraterrestrial particles, 75 to 700 micrometers in size, because of their unusual shapes and mineralogy, and measured the Fe/Mn and Fe/Mg elemental ratios, which are known to help constrain the type and source of meteorites. The results show that nine of the cosmic spherules are broadly chondritic in composition as expected. However, one, along with six others reexamined from a previous study, are atypical with nonchondritic compositions. Taylor and coauthors propose an origin from an achondrite, Howardite-Eucrite-Diogenite (HED)-like parent body such as asteroid Vesta. HED-like objects account for about 6% of all meteorites, and only about 0.5% of all micrometeorites perhaps because of a natural mechanical toughness that would resist breakup and fragmentation.

Reference:

- Taylor, S., Herzog, G. F., and Delaney, J. S., 2007, Crumbs from the Crust of Vesta: Achondritic Cosmic Spherules from the South Pole Water Well, *Meteoritics and Planetary Science,* v. 42, p. 223-233.

PSRDpresents: Melted Micrometeorites --Short Slide Summary (with accompanying notes).

Concentrations of Cosmic Debris

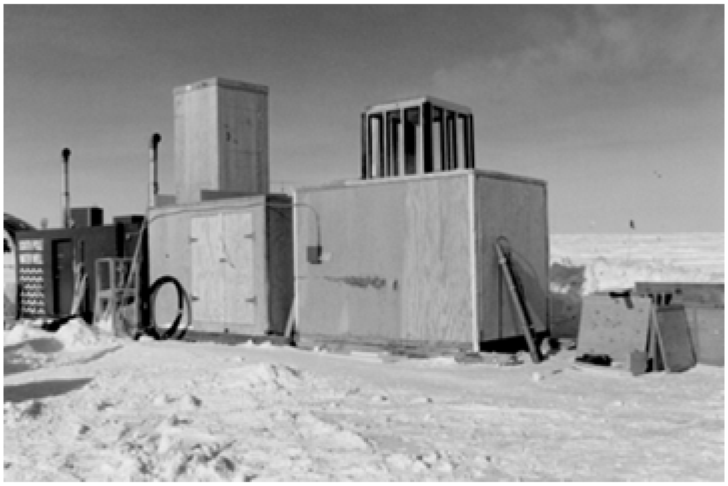
What better way to handle the summer heat than with a cool little story about ice ...Antarctic ice, that is, studded with the most minuscule grains from the cosmos. Researchers are studying extraterrestrial materials that are literally particles and spherules less than a millimeter in size but whose combined mass accounts for about 1,000 tons of new stuff added to Earth yearly. A micrometeorite is generally defined as a tiny meteorite larger than 50 micrometers but smaller than a millimeter. Micrometeorites that have melted, either partially or completely when plunging through Earth's atmosphere, are called cosmic spherules.

Just as the Antarctic blue ice serves as an ideal collector of meteorites (see **PSRD** articles: Meteorites on Ice and Searching Antarctic Ice for Meteorites) it also preserves micrometeorites and cosmic spherules that land on the surface and are subsequently incorporated into ice layers. In his book, *Meteorites, Ice, and Antarctica: A Personal Account*, William Cassidy (University of Pittsburgh, and founder of the U. S. Antarctic Search for Meteorites project, ANSMET) retells a detail from the thrilling story of Paul Siple, the Boy Scout on Admiral Richard Byrd's expeditions to Antarctica in 1928-1930 and 1933-1935. One day Siple collected a jar of grains from the bottom of an icy cavity where the crew had melted ice beneath the surface at one of the base camps for drinking water. Though no one knows where his jar is now, Siple's collection no doubt contained micrometeorites mixed with rock bits entrained in the glacier and volcanic debris from past eruptions of nearby volcanoes. Today's researchers are using modern systematic collections of micrometeorites and cosmic spherules from the Amundsen-Scott South Pole water well to make new discoveries in cosmochemistry and gain insights into the origin of the Solar System.

Collecting Cosmic Debris

The South Pole Water Well is a 4000-cubic-meter subsurface water pool, 100 meters below the surface. It has supplied the drinking water to the U. S. Amundsen-Scott South Pole Station in Antarctica since January 1995. This well is one of the largest sources of micrometeorites -- cosmic particles less than one millimeter -- exploited to date. The well itself acts to concentrate the micrometeorites because the large pool volume and low circulation rates allow the particles to form a lag deposit on the bottom of the well. There is a small well house on the surface that houses the drilling and operating equipment. An adjacent hole and shelter were constructed in 1997 next to the well house expressly for the collection of the micrometeorites. The remote-controlled robotic collector (designed and built at the Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire) is lowered down a 30-centimeter-diameter well neck to the icy bottom of the well pool where it maneuvers to suction, filter, and collect the micrometeorites and cosmic spherules without contaminating the well or water.

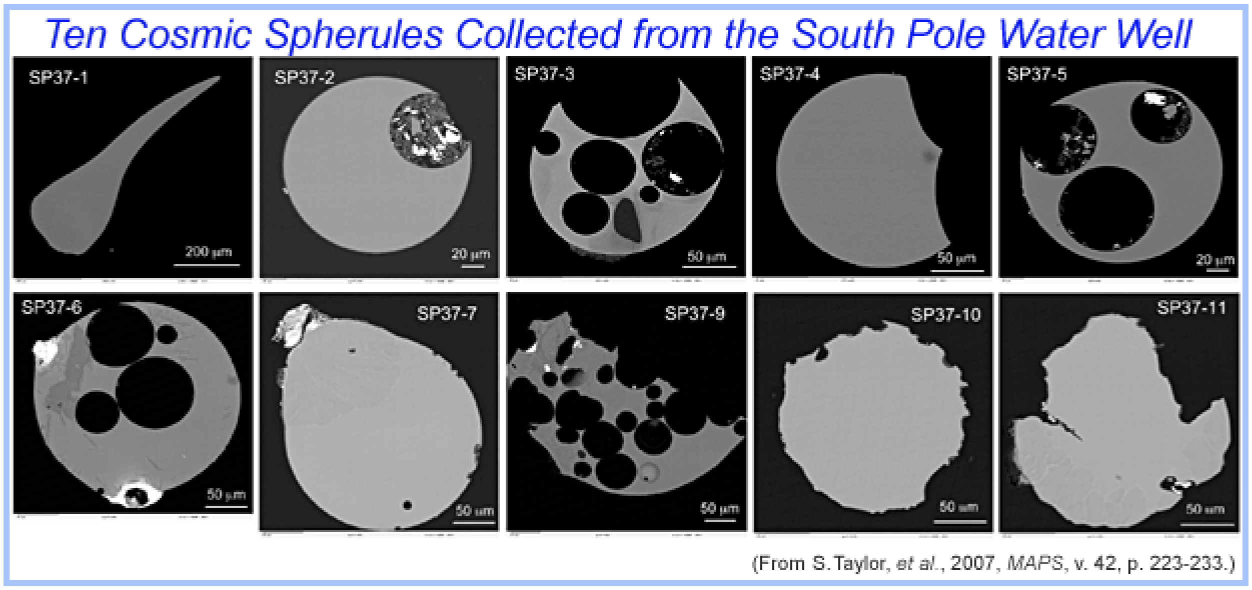
Surface Housings for Robotic Micrometeorite Collector at South Pole Water Well



(From S. Taylor *et al.*, 1997, *CRREL Report 97-1*, 34 p.)

These shelters (winch room and laboratory) at the South Pole Water Well house the tower assembly, winch and cable system, video equipment, and control equipment needed to support the remote-controlled collector.

After initial electron microprobe analyses of the micrometeorites and cosmic spherules collected from the well, the research team chose ten for further study because of their unusual shapes or mineralogy. Scanning electron microscope images of the ten cosmic spherules are shown below.

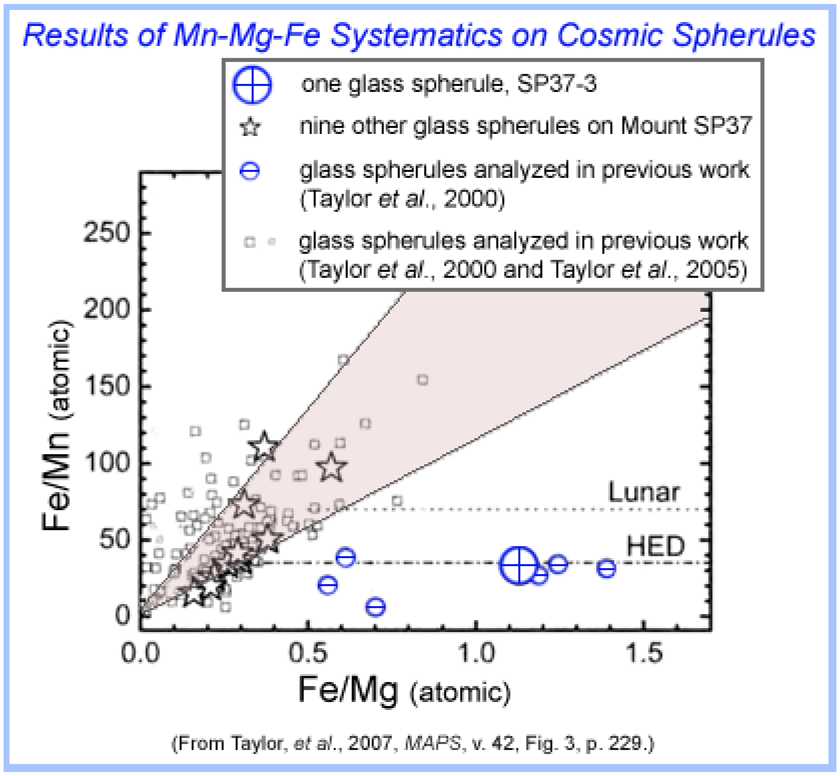


Scanning electron microscope images of cosmic spherules analyzed by Taylor, Herzog, and Delaney.

SP37-1 is a tiny glass particle with an elongated shape. SP37-2 and SP37-5 are glass spherules with vesicles that were filled with terrestrial oxide grains after landing on Earth. SP37-3 is another glass spherule with vesicles (black areas) with an unusual plagioclase feldspar (An90) grain, which appears as a non-circular dark grey shape in the lower part of the spherule. Anorthite has not previously been reported in cosmic spherules. SP37-4 is a glass spherule with no vesicles but a fractured edge. SP37-6 is a glass spherule with two (bright) metal regions and (darker grey) olivine grains. SP37-7 is a glass spherule with a (bright) bead of iron sulfide. SP37-9 is a vesicular fragment of a larger spherule. It contains some iron sulfide grains and regions that did not completely melt. SP37-10 and SP37-11 are glass spherules with parts dissolved away, leaving etched surfaces.

Analyses

Susan Taylor and colleagues, Greg Herzog and Jeremy Delaney, measured the concentrations of major and minor elements, including iron (Fe), manganese (Mn), and magnesium (Mg) of 10 cosmic spherules collected from the South Pole water well. Theirs is one of the first studies to use Fe/Mn and Fe/Mg ratios on micrometeorites. These particular ratios have been shown by previous researchers to be diagnostic tools for distinguishing achondrites from chondrites and have been used to help determine where the meteorites came from.

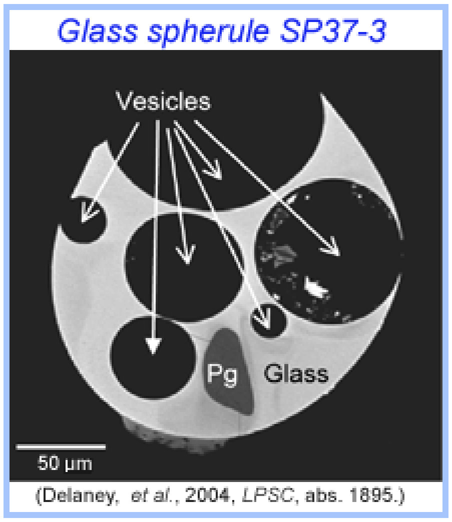


This plot of Fe/Mn and Fe/Mg ratios shows the results for the ten cosmic spherules analyzed by Taylor and coauthors and for numerous cosmic spherules from previous analyses. About two-thirds of all the data points plot in the range typical of chondrites (shaded, triangular region) as expected. Significantly, a group of seven cosmic spherules plot below the chondritic region (these data points are indicated in blue). The horizontal dashed line labeled "Lunar" represents ratios of lunar samples. The horizontal dahed line labeled "HED" represents ratios of HED (Howardite, Eucrite, Diogenite) achondrite meteorites.

Seven cosmic spherules, one from the current study (SP37-3) and six others reexamined from a previous study, have Fe/Mn and Fe/Mg ratios (plotted in blue) that lie well below the shaded chondritic region in the figure (shown above). These data points plot near the values typical of HED (basaltic) meteorites (see the dashed line) but clearly not of lunar samples (see the upper dashed line).

Taylor and colleagues also considered whether or not the cosmic spherules are like basaltic Martian meteorites. They found that the mineralogies did not match, yet were not so far off as to rule out a Martian origin. Given that HEDs outnumber Martian meteorites by about 10 to 1, the authors argue the seven noncondritic cosmic spherules are more likely to have come from a HED-like parent body. Trace element and oxygen isotope analyses of the seven cosmic spherules would give researchers even more information to better determine the sources of the spherules.

Another nod to an HED-like parent body is the plagioclase feldspar grain found in cosmic spherule SP37-3. Plagioclase feldspar ranges in composition from calcium aluminum silicate (anorthite) to sodium aluminum silicate (albite). Taylor and colleagues found the anorthite relic grain in SP37-3 is much more calcium-rich (An_{90}, which means 90% calcium in the sodium/calcium position in the crystal structure) than found in shergottite Martian meteorites, but is comparable to anorthite (An_{72-90}) commonly found in HED meteorites.



(Delaney, *et al.*, 2004, *LPSC*, abs. 1895.)

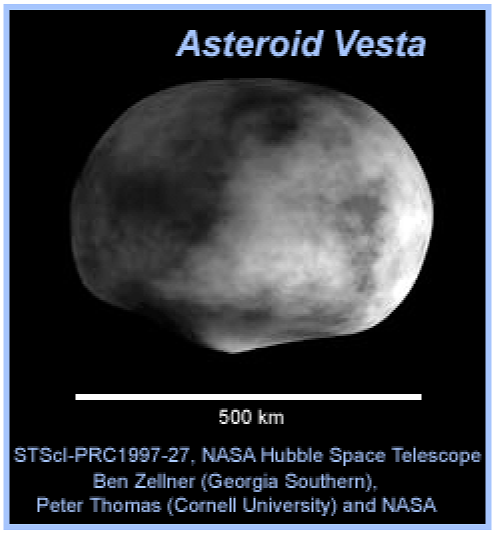
In the scanning electron microscope image shown here, the plagioclase feldspar grain is labeled "Pg".

Micrometeoroids are susceptible to mass loss and occasionally perhaps to mass gain when passing through Earth's atmosphere. How do we know that the measured concentrations of Fe, Mn, and Mg represent true concentrations unaltered by the heat during passage through Earth's atmosphere? Fortunately, as the authors point out, Mg is fairly refractory, which means it is not easily lost by evaporation. Also, the relatively constant ratios of Mn to other refractory elements (such as Ca and Al) measured by Taylor and coauthors imply Mn is not lost either. Iron, by contrast, is likely to be lost when cosmic spherules burn through Earth's atmosphere. Loss of iron could occur by evaporation or, more frequently, by physical separation of metal or sulfide. Loss of iron would shift the data points toward the orign, along rather than off the main trend (shaded region), and would not ruin the distinction we see between chondritic and achondritic spherules. So, the authors are confident that their Fe/Mg and Fe/Mn ratios represent the true mineralogy of the spherules.

Crumbs from the Crust of Vesta

Taylor and colleagues show the Fe/Mg and Fe/Mn ratios of the cosmic spherules are similar enough to HED meteorites that a HED-like parent body is likely. The HED meteorites are a class of achondrites that are igneous rocks formed from basaltic magmas. This class represents about 6% of meteorites that fall to Earth and only about 0.5% of all micrometeorites from the South Pole water well. There are far fewer of these HED-like micrometeorites and cosmic spherules than carbonaceous chondrites. The authors infer that a natural mechanical toughness of HED-like material would resist breakup and fragmentation, whereas the comparative mechanical weakness of carbonaceous material would tend to favor breakup and spherule formation.

The HEDs are the only class of meteorites whose spectral data have been matched (but not without some ongoing debate) with spectra from a potential parent body. That parent body is asteroid 4 Vesta. Hubble Space Telescope data show the asteroid has a basaltic surface and a giant impact crater near one pole. Isn't it remarkable that crumbs measured in micrometers can tell us stories about 500-kilometer-diameter asteroids?



STScI-PRC1997-27, NASA Hubble Space Telescope
Ben Zellner (Georgia Southern),
Peter Thomas (Cornell University) and NASA

NASA's Hubble Space Telescope took images of asteroid Vesta in 1996. This shows a computer model of Vesta created from Hubble topographic data. We'll know more about Vesta soon when NASA's Dawn Mission investigates Vesta and Ceres, two of the largest protoplanets in the main asteroid belt.

Additional Resources

LINKS OPEN IN A NEW WINDOW.

- **PSRDpresents:** Melted Micrometeorites --Short Slide Summary (with accompanying notes).

- Binzel, R. P. and Xu, S. (1993) Chips off of Asteroid 4 Vesta: Evidence for the parent body of basaltic achondrite meteorites. *Science*, v. 260, p. 186-191.
- Cassidy, W. A., 2003, Meteorites, Ice, and Antarctica: A Personal Account. Cambridge University Press, 349 p.
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- Love, S. G., and Brownlee, D. E., 1993, A Direct Measurement of the Terrestrial Mass Accretion Rate of Cosmic Dust, *Science*, v. 262, p. 550-553.
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- Maurette M., Olinger, C., Michel-Levy, M. C., Kurat, G., Pourchet, M., Brandstatter, F., and Bourot-Denise, M., 1991, A Collection of Diverse Micrometeorites Recovered from 100 Tonnes of Antarctic Blue Ice, *Nature*, v. 351, p. 44-47.
- Taylor, S., Lever, J. H., and Harvey, R. P., 1998, Accretion Rate of Cosmic Spherules Measured at the South Pole, *Nature*, v. 392, p.899-903.
- Taylor, S., Lever, J. H., and Harvey, R. P., 2000, Numbers, Types, and Composition of an Unbiased Collection of Cosmic Spherules, *Meteoritics and Planetary Science*, v. 35, p. 651-666.
- Taylor, S., Herzog, G. F., and Delaney, J. S., 2007, Crumbs from the Crust of Vesta: Achondritic Cosmic Spherules from the South Pole Water Well, *Meteoritics and Planetary Science*, v. 42, p. 223-233.

- Website Atlas of Micrometeorites, from Dartmouth College. Scanning Electron Microscope images of 234 micrometeorites collected from the bottom of the South Pole water well.
- Website Catalog of Micrometeorites, from the National Institute of Polar Research, Japan.

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