COSMIC SPHERULES AND GIANT MICROMETEORITES AS SAMPLES OF MAIN BELT ASTEROIDS

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New atmospheric entry calculations (1) indicate that the 0.1 to 1mm diameter spherules and unmelted micrometeorites that survive entry into the atmosphere are a highly selected fraction of meteoroids that collide with the Earth. While most particles smaller than 50μm enter without strong selection and alteration this is not the case for particles >100μm. The bulk of the total mass of extraterrestrial material that annually encounters the Earth is in 0.1 to 1mm size range but most of these particles experience extreme vaporization. Large dust particles (>100μm) survive atmospheric entry without excessive vaporization only if they enter at minimum velocity and within a range of incidence angles that becomes increasingly narrow with increasing size. If the entry is too steep the particles vaporize and too grazing they pass through the atmosphere (skip) and are not captured. The velocity filter is very effective and there is no real means of survival for large particles with initial velocities much larger than the escape velocity. This effect limits the origin of surviving dust particles >100μm to those with low inclination and low eccentricity orbits. Typical cometary particles, even after orbital evolution, have eccentricities and inclinations that yield high entry velocities (2) and severe vaporization. Low inclination SP comets with perihelia beyond 1AU can produce particles that encounter the Earth at low velocity but even these particles enter at higher velocity than those that spiral in from the asteroid belt under the influence of Poynting-Robertson (PR) drag. Neglecting gravitational perturbations associated with resonances, the asteroid particles will have typical entry velocities <12 km s^{-1} (2). The entry velocity differences between cometary and asteroidal particles produce a very stringent bias favoring survival of large asteroidal dust particles and we predict the melted and unmelted dust particles >100μm will be very strongly dominated by asteroidal particles.

Potential complications to asteroids being the dominant source of surviving large spherules and unmelted particles are: a) possible contributions by very active but now extinct comets with perihelia beyond 1 AU, b) resonance effects that could increase orbital eccentricity during Poynting-Robertson spiral from the asteroid belt (3), and c) catastrophic collisions that could destroy particles during transport from the asteroid belt. The most serious of these problems appears to be collisions. The predicted collisional lifetimes of 0.1 to 1mm dust spiraling in from the asteroid belt are less than estimated PR transport times (4). The model derived lifetimes may, however, underestimate the actual survival of particles against collisional destruction. The Al^{26} and Be^{10} data for spherules in the 0.1 to 1mm size range suggest that the particles are asteroidal and were exposed to irradiation as small bodies for the million year timescale consistent with PR spiral of large dust particles from the asteroid belt. The high levels of SCR produced Al^{26} require irradiation in the inner solar system and appear to rule out cometary origin for typical spherules (5). The near saturation levels of both of these nuclides requires million year exposures that are much longer than predicted collisional lifetimes. While successive fragmentation during evolution in the interplanetary medium may complicate the picture, it is clear that the collisional lifetime models should be re-examined.

The evidence is strong that the the 0.1 to 1 mm dust particles that survive atmospheric entry are predominantly and perhaps exclusively asteroidal in origin. Because the larger surviving particles all enter at essentially the same velocity, the collected samples should be representative samples of millimeter sized asteroidal debris that reach 1 AU. Unfortunately, dust liberation from the asteroids is not well understood and it is not known if the collected particles have many parent bodies or just a few. If dust generation by asteroids is nominally dependent on asteroid surface area then the particles would provide representative samples of a large number of asteroids. Because C type asteroids dominate the main belt, the most abundant collected particles would be samples of these objects. Near Earth objects have a small cumulative surface area and presumably are not significant contributors. If dust production by asteroids is dominated by the major families, say the ones that produce the IRAS dust bands, then the typical particles would be from these sources and could be dominated by only a few asteroids. Regardless of the source, the dust samples provide a different and likely more diverse sampling of the asteroid belt than is provided by conventional meteorites. The sampling bias is different because objects that produce conventional meteorites reach the Earth only by gravitational perturbation while the dust particles reach 1 AU due to continuous PR orbital decay, a quite democratic process that depends only on optical properties, size and density.

We have microprobed the unetched interiors of 500 stony cosmic spherules to provide a compositional characterization of the millimeter meteoroids reaching the Earth. Although some elements are depleted during atmospheric entry it is evident that the abundances of Mg, Al, Ca, Si, Ti and Mn are not. The distributions of these elements normalized to Si, all peak at values near chondritic proportions. The peaks of these distribuition show an excellent correlation with CM abundances but have distinct offsets from other chondrite groups. This data suggests that the major asteroidal debris reaching the Earth is compositionally related to CMs. The element distribution histograms imply that only a minor fraction of the spheres could be material with OC or CV composition at the mm size scale. Conspicuous offsets, particularly for Mn, indicate that CI composition material is not a major contributor. We have in addition examined a large number of unmelted particles larger than 100μm and many of these also indicate similarity to CM. The large unmelted particles should be samples of the same bodies that produce spherules and the only selection effect is that they entered at shallower angles than melted particles. Quantitative assessment of abundance relative to true CM material is difficult because of sample alteration and selection effects. The unmelted phases are biased towards high melting point minerals such as forsterite and enstatite. The "unmelted" particles are not perfectly preserved and have all been altered to various extent by strong heating, partial melting and weathering. They are more subject to weathering that the spherules because they are porous. The unmelted particles that appear to be CM-like often contain some, usually modified, fine grained matrix, large (>10μm) forsterite and enstatite grains and rare CAIs composed of diopside, spinel and perovskite. Many of the Fo grains contain micron sized FeNi spheres.

The link to CM composition material is significant because there is abundant evidence suggesting that CM-like material is much more abundant in space than suggested by its 2% representation in falls. CMs are the best spectral "match" to C asteroids and CM material is the most common xenolith found in other meteorites (6). The siderophile/Ir ratios of the meteoritic component of lunar soil suggest that CM-like material dominates the extra-lunar material currently accreted by the Moon(7). Finally the oxygen isotopic composition of stony spheres is consistent with CM material and inconsistent with a dominant component from OC or CI sources(8).

The spherule results show that CM composition material dominates the millimeter meteoroids that reach the Earth. If asteroid families do not dominate dust production in the main belt then the results also indicate that the C asteroids are compositionally related to CM meteorites. Original phase information for the spherules is lost during melting and it is modified even for the large "unmelted" particles. The small (<50μm) unmelted IDPs collected in the stratosphere are better preserved and provide important data on mineralogical composition on a size range that could be genetically related to the spherules. Recently a bona-fide CM particle was identified in the stratospheric collections on the basis of its tochilinite (PCP) content (9). The rarity of such particles shows, however, that material mineralogically identical to CMs is rare in interplanetary dust. While the elemental composition of the asteroid fraction may be CM, the particles do not normally have CM matrix mineralogy and hence are only CM-like. It is possible that the asteroids are dominated by CM-like material with mineralogical compositions that range from the serpentine/tochilinite assemblages of CM meteorites to the more common smectite dominated particles that are the most common hydrated IDPs. The mineralogical range could simply be due to varying degrees of parent body alteration.

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