INTERPLANETARY DUST ON THE EARTH'S SURFACE

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THE SEARCH—HOW AND WHY

It is now generally believed that the accretion of cosmic matter onto planetary surfaces has played an important role in the formation and evolution of the solar system. We know of at least three bodies (Earth, Moon, and Mars) with major signs of alteration by meteorite impacts. The number of these particles hitting the Earth's surface increases with decreasing size, so much that at microscopic sizes the amount of material falling may be a thousand times that falling as meteorites. This is one reason why considerable time, effort, and money has been spent in collecting cosmic dust. A second is that the dust may represent the only comet material we have the possibility of collecting for a good while. This is because we now believe that most meteors are cometary.

The first serious studies of cosmic dust were made in the mid-nineteenth century by Murray (scientific officer on the *Challenger's* voyage around the world) and Nordenskiold (a Swedish geologist). Murray introduced the phrase "Cosmic Spherules" for particles he found in ocean sediments[1]. Nordenskiold's "Cryoconite" ("Ice Dust") was found in Greenland ice, and described by him as being carbonaceous, containing iron, cobalt and phosphorus, and resembling Orgueil (a recently fallen carbonaceous meteorite) after the meteorite had been allowed to disintegrate in water[2]. Since then a variety of methods have been used to collect this dust. Perhaps the most common is to melt polar ice and filter it. Other methods that have been tried are: dissolving sedimentary rocks in acid and filtering the solution; flying collectors on aircraft, rockets and balloons; and even exposing greased meshes and dishes on remote islands and mountain tops[3].

Since the cosmic dust has been through a melting process, the search has tended to be limited to spherules. However, these too can be made by other means; for example, by industrial furnaces and by volcanoes. The main problem has always been to differentiate cosmic material from contaminants. It is the purpose of this paper to review the extent to which this has been achieved by examining the physical and chemical nature of the dust collected.

CONTAMINATION VERSUS COSMIC—THE EVIDENCE

(i) *Morphology and means of production.* One of the major features of cosmic dust collected from most sources is that a large number of the particles contain a core and a shell. Spherules are also found in which the shell is empty, as if the core has dissolved out. Such core/shell spherules are also found in the region of meteorite falls. (They were even collected in the region where the Siberian meteoroid fell, although nothing else was found.) The shell is usually magnetite (Fe_3O_4) and the core metallic, rich in iron, cobalt and nickel[4].

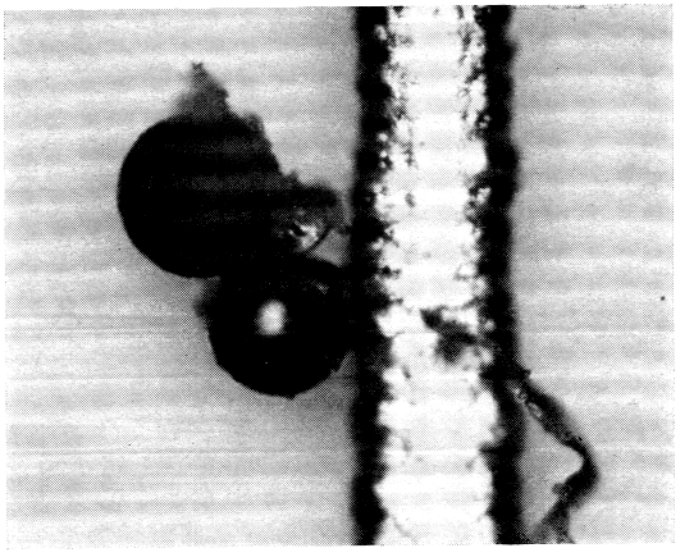

FIGURE 1. Photomicrograph of two spherules magnetically attached. The bar is a 25 micrometre wide copper grid.

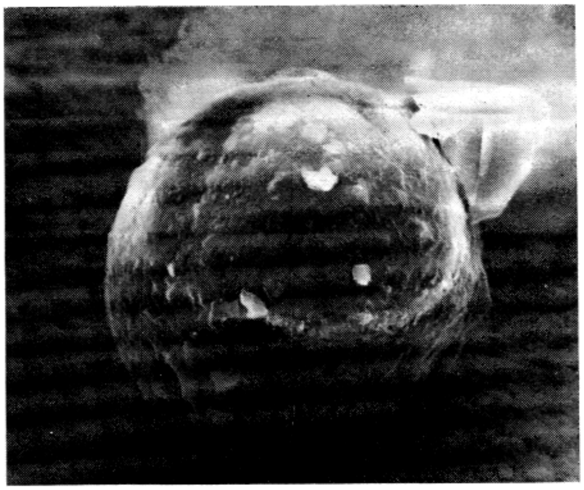

FIGURE 2. Scanning electron microscope photograph of a 30 micrometre spherule displaying a concentric 'core'.

The core and shell are produced because some elements burn more easily than others. Once oxidized, the element moves to the outside of the molten droplet to form its shell, leaving behind non-oxidized metal. Iron does this more readily than nickel and so nickel is found mainly in the core[5]. (A similar phenomenon occurs in nickel-steels when they are heated during working.) Unfortunately, this process will happen to molten droplets in furnaces and volcanoes as readily as on the surface of meteoroids, and such a structure could equally well appear in droplets produced by them.

We have succeeded in collecting a large number of black magnetic spherules (figures 1 and 2) from Antarctic ice. The ice was collected from three sites; two on Signy Island (South Orkneys) and one on South Georgia. All the spherules came from one of the Signy Island sites. It was the only site exposed to westerly winds which come from South America and we believe the spherules originated there. There are two possible sources; the Chilean volcanoes and ships using the busy trade route between Valparaiso and Montevideo.

One of the spherules, photographed in the electron microscope, clearly showed a core. The existence of a core, therefore, does not prove a cosmic origin for the dust. For additional clues we must look beyond morphology and consider composition in greater detail.

(ii) *Composition.* Comparison of the dust composition with that of meteorites as a means of proving a cosmic origin is very difficult. One of the most characteristic differences between meteorites and terrestrial rocks is that meteorites are very rich in nickel. Although some individual particles (especially those with large cores) are extremely rich in nickel, in the spherule analyses considered as a whole, the amount is notoriously low. It is possible that this is because the cores have been dissolved out. Alternatively, laboratory simulations indicate that some of the nickel may be left behind when the droplets come off the surface of the meteoroid. This is done by a mechanism similar to that for core formation. In short, the means whereby spherules were made from the meteoroid may have changed the elemental composition.

Although we do not know the precise composition of genuine cosmic dust, we can confidently argue that it should be the same wherever it is collected. The two sites for which we have most results with which to test this are the South Pole and Greenland[6]. The analyses may most easily be compared by plotting the results for one site against those for the other site (figure 3). A straight line indicates agreement, with all the elements that agree lying on the line. In figure 3 most elements agree reasonably well, the notable exceptions being iron and aluminium. Since they both lie above the line, their values in dust collected at the South Pole must be higher than in dust collected in Greenland. The cause for such disagreement is not clear, but an explanation must be found before the analyses can be meaningfully used.

It seems, therefore, that both physical and chemical findings throw doubt on a cosmic origin for most of the dust collected. This is consistent with some results recently produced by measurements of the annual fall rates.

(iii) *Annual fall.* The overall fall rate of material from space can be calculated by combining results of spacecraft, meteor and meteorite observations. The most recent results indicate about 10 000 tons per year is falling[7]. The figure for surface dust collecting is about 100 000 tons per year[3], so clearly most of the dust must be contamination.

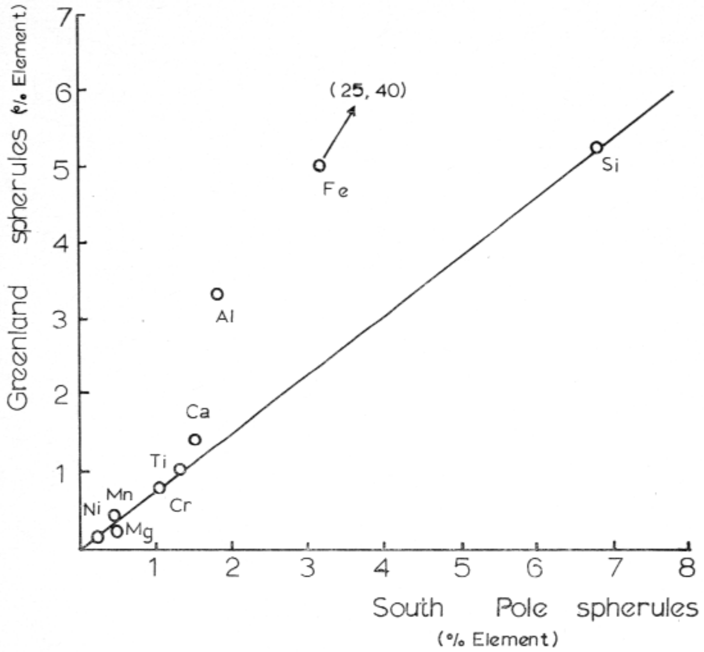

FIGURE 3. Plot to compare the analyses of spherules separated from ice collected at the South Pole and in Greenland. The determination for each element has an error of less than 10% of its percentage value.

In order to be able to claim with any confidence that we have in a given sample collected cosmic material we must be more selective in assessing the particles we have, and for this I would propose one additional criterion.

CARBONACEOUS MATERIAL

It has long been known that there is an association between meteor showers and comets; in recent years this has been extended to include faint sporadic meteors. From comet spectra many molecular bonds have been identified and one of the major constituents appears to be carbon.

With the operation of the American Prairie Network camera system it has been realized that the brighter asteroidal meteors are considerably more abundant than meteorites would infer. It also seems that they are very similar in density to the lowest density carbonaceous meteorites[8]. This suggests that the common—that is non-carbonaceous—meteorites are the exception rather than the rule, and that it is their great strength that makes them more likely to survive the atmosphere and reach our museums.

Therefore, whether cometary or asteroidal, a large majority of the meteors are carbonaceous and this should be reflected in at least the larger spherules collected on the surface of the Earth. Until quite recently it was difficult to detect carbon with the electron microprobe, the method of analysis usually used, and so carbon values do not appear in the literature. However, with the techniques now available for detecting carbonaceous material in meteorites and lunar samples, it may be feasible to use these in searching for carbonaceous cosmic spherules. Whatever the form of the carbon originally, the heating will probably have turned it into carbides. Industrial spherules will also contain carbides. It is, therefore, necessary to limit the search to sources in which industrial contamination is impossible, namely to sedimentary rocks and very old Antarctic ice.

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