Meetings

Cosmic Dust

In 1923 Oliver C. Farrington commented that ". . . [meteorites] are our only *tangible* source of knowledge of the universe beyond the earth." There is strong evidence, however, that dust, in addition to meteorites, is falling on the earth and that this dust is a possible second tangible source of knowledge about "the universe beyond the earth." It is hoped that among the dust particles reaching the earth there will be some that were left over from the formation of the solar system. Other possible sources of dust are comets, sporadic meteors, ablation products from the passage of meteorites through the atmosphere, debris from collisions in space between meteorites or larger bodies, and regions outside the solar system. Because the study of extraterrestrial dust is not simple and does not have clearcut conclusions, and because of its interest to increasing numbers of scientists, it was felt that the conference on cosmic dust, which was held in New York City on 21 and 22 November 1963, would be of great mutual value to active workers in this field.

The conference was divided into three sections: (i) Cosmic dust—its origins, distribution in space, and capture by the moon and planets; (ii) terrestrial increment of cosmic dust—present day and in the past; and (iii) chemical composition of cosmic dust and analytical techniques.

Bertram Donn (Goddard Space Flight Center) and William A. Cassidy (Lamont Geological Observatory) discussed condensation of dust from primordial vapor. Donn considered a sublimation process that produced initial condensation nuclei in a supersaturated vapor. Crystal growth continued on nuclei by perpetuation of defect structures and whiskers of sublimate were produced. He suggested that these primary grains would be preserved today only in comets, which must be the main source of supply of interplanetary dust grains. The grains making up the zodiacal cloud have usually been presumed to be spheres, but could well be irregular in shape such as the ones he describes. Satellite data indicate that both "dust-ball" and compact particles exist. The former would be more likely to be derived from comets and thus be representative of primary particles. Cassidy reported experimental data on the high-temperature chemistry of the system Fe-FeO-MgO-SiO_2 and extrapolated the data to vaporous temperatures. Considering a process of condensation from vapor to a mist of liquid droplets, he pointed out that condensing primordial vapor could be fractionated by various mechanisms. Assuming that the element abundances of the solar atmosphere were representative of primordial abundances, condensation histories can be suggested that will produce major-element assemblages typical of the carbonaceous chondrites and of the high-iron and low-iron stony meteorites at different stages during condensation of solar matter.

On the assumption that carbonaceous chondrites represent the groups of meteorites altered least from the original aggregations of cosmic dust particles forming all meteorites, John F. Kerridge (Birkbeck College, London) reported a study of the low-temperature minerals from the fine-grained matrices of 15 carbonaceous chondrites. He thought it probable that in a parent body formed by aggregation of chondrules and dust particles along the lines suggested by Wood, a zone of low-temperature hydrothermal metamorphism existed in which the low-temperature minerals of carbonaceous chondrites formed.

Richard B. Southworth (Smithsonian Astrophysical Observatory), Martin Harwit (Cornell University), and Alan W. Peterson (General Dynamics) discussed various aspects of the zodiacal cloud. Since the dust particles that make up the cloud must have been supplied recently because the lifetime of a particle in this region of space is relatively short, Southworth and Harwit considered sources of particles in the cloud. Southworth pointed out that inferred orbital eccentricities and inclinations of particles in the cloud indicate a cometary rather than an asteroidal origin for the dust. One would expect that a major source of the dust should be short-period comets. Data obtained by study of comet Arend-Rowland (1957 III), however, suggest the main source of dust should be long-period comets. Analysis of the role of Jupiter as a perturbing influence may resolve the apparent conflict.

Harwit suggested a new source of dust from a reservoir of loose dust that never aggregated into comets but has existed in comet-like orbits. This dust could have been brought into close proximity to the sun over the past few billion years by the Poynting-Robertson effect. Those grains that successfully passed the orbit of Jupiter would become part of the zodiacal cloud. Taking into account the dust-free zone surrounding the sun, Peterson discussed infrared emission from the zodiacal cloud and implications regarding particle concentration in the cloud. He proposed infrared studies as a means of determining the space-distribution law and albedo of dust in the cloud and also for estimating the radius of the dust-free zone around the sun. If this radius were known from such observations, the temperature at the distance of this radius could be estimated and an idea of the chemical composition of the dust could be obtained from its deduced evaporation characteristics. Estimates of dust concentration in the zodiacal cloud would also be dependent on these data.

Satellite and rocketborne experiments were described and discussed by Charles T. D'Aiutolo (National Aeronautics and Space Administration), R. A. Skrivanek and Robert K. Soberman (Air Force Cambridge Research Laboratories), C. Hemenway (Dudley Observatory), I. Linscott (Union College), Maurice Dubin (National Aeronautics and Space Administration), and L. Secretan (Goddard Space Flight Center). D'Aiutolo reported that measurements of the meteor hazard to space vehicles, accomplished with the Explorer XVI satellite, indicate that the shielding requirement for space vehicles is quite low because only a small fraction of the total flux has penetrating power. The 96-foot Micrometeorite Measurement satellite now being designed for launch will measure the incidence of penetration events in materials whose thicknesses reach 0.016 inch and will record the direction of each impacting particle. Skrivanek and Soberman reported the rocket-borne collection of particles from noctilucent clouds between altitudes of 75 and 95 km. The collection made in noctilucent clouds contained 100 to 1000 times more particles than a collection made when no such clouds were visible. Both sets of particles contained nickel and iron and many of the particles collected from the clouds apparently were coated with ice; the circular impression made by the particle often was larger than the particle itself. Hemenway, Linscott, Dubin, and Secretan reported high-velocity impacts on the outer surfaces of the periscope lenses of the Project Mercury vehicle. The largest such suspected impact site has a diameter of 1 mm.

C. E. Melton (Douglas Aircraft Company) reported particle collections made in the atmosphere between 10,360 and 12,500 meters prior to and during some major meteor showers. Collection rates did not vary significantly for shiny, black spherules noted in the collectors but irregular, porous, opaque particles appeared to increase in numbers during meteor showers. Glassy particles were observed in the collections but were also found in sealed control collectors and are thought to be contaminants.

Tovy Grjebine (Centre National de la Recherche Scientifique, France) reported on an extensive program for collecting atmospheric dust that has been conducted by the French Atomic Energy Commission since 1958. Allowing for industrial contamination, he estimates the rate of infall of cosmic dust as 2.4×10^9 tons per year for the earth. Tovy Grjebine, Claude Lalou, J. Ros (Centre National de la Recherche Scientifique, France) and M. Capitant (Bureau de Recherches Geologiques et Minieres, France) described spherules recovered from cores taken in the Mediterranean basin. Magnetic fractions contained spherules classified as shiny black, metallic brown, stony brown, transparent, and white. Electron-microprobe analyses indicate the spherules are poor to lacking in nickel, high in manganese, and in some cases high in sulfur. No conclusions were reached on the origin of the described spherules.

Thomas A. Mutch (Brown University) reported finding microscopic spherules among allogenic and authigenic minerals in filtrates of halite solutions. The halites are of Paleozoic, Mesozoic, and Cenozoic ages. Particles of suspected cosmic origin are hollow spherules, solid spherules, and some irregular grains. The solid spherules seemed to consist of magnetite and the irregular grains contained magnetite and a possible sulfide. Electron-microprobe analyses gave four typical composition groupings. These are sulfur-rich, iron-rich, iron-rich with traces of manganese, and a group containing iron, calcium, silicon, and aluminum as major elements with a number of minor elements. His estimated accumulation rate of cosmic dust in halite is 1.4×10^8 to 1×10^9 metric tons per year for the earth.

Particle collections from Antarctic ice were reviewed by Richard A. Schmidt (University of Wisconsin) and from Greenland ice by Chester C. Langway, Jr. (U.S. Army Cold Regions Research and Engineering Laboratory), and Ursula B. Marvin (Smithsonian Astrophysical Observatory). Schmidt reported that meltwater from Antarctic snow cores yielded black, metallic spherules and yellowish, glassy spherules. The latter were very rich in silicon dioxide and could be similar to tektites in composition. The spherule accumulation rate based on estimates for Antarctic snows is 1×10^5 metric tons per year for the earth, but higher rates may occur at lower geomagnetic latitude. Langway and Marvin compared black spherules from the Greenland ice with artificial weld-spatter. Electron-microprobe analyses provide no criteria to use in differentiating them. They noted, however, that the industrial spherules tended to have a somewhat greater density than natural ones.

Although E. L. Krinov and O. A. Kirova (Committee on Meteorites, Academy of Sciences, U.S.S.R.) were unable to attend the conference, they did submit papers that will be included in the symposium volume. Krinov described and classified microscopic particles produced by the Sikhote-Alin iron meteorite fall in 1947 and Kirova reported collecting procedures and descriptions of particles produced by the Podkammenaya-Tunguska occurrence in 1908. The body that caused the 1908 occurrence may have been a comet. It is, therefore, interesting to note that among the spherules collected around the epicenter of the aerial explosion of this body there were not only magnetic spherules similar to those reported for the Sikhote-Alin fall but also impressive numbers of transparent siliceous spherules.

Hugo Fechtig (Max Planck-Institut für Kernphysik) and Karl Utech (Technische Hochschule, Braunschweig) reported experiments on diffusion of nickel in melts of nickel-iron alloy, and pointed out that if cosmic spherules are ablation products of nickel-iron meteorites they should not contain much nickel.

Frederick R. Park and Arch. M. Reid (Mellon Institute) discussed studies on natural and artificial spherules from many sources by electron-probe microanalysis, x-ray diffraction, and optical-metallographic methods. They found the presence of nickel to be the most valid single criterion of an extraterrestrial origin for small magnetic particles, but pointed out that it is not an infallible one and absence of nickel does not preclude such an origin.

Reports on electron-microprobe analyses of possible cosmic particles were made by Richard K. Larson, E. J. Dwornik, and I. Adler (U.S. Geological Survey) and by Frances W. Wright and Paul W. Hodge (Smithsonian Astrophysical Observatory). Larson, Dwornik, and Adler discussed methods of preparing tiny particles for electron-probe analysis. Their analytical data for spherules collected from the atmosphere, found in impactite and tektite glass, and in Antarctic ice showed no common feature that indicated extraterrestrial origin. They doubted the cosmic origin of some of the spherules analyzed and emphasized the lack of criteria for such a determination. Wright and Hodge agreed more with Park and Reid in pointing out the presence of nickel in most of the particles whose extraterrestrial origin was considered most probable on the basis of other evidence. The artificial spherules examined by them had compositions high in sulfur and also differed from the probable extraterrestrial particles in other ways. Most, but not all, spherules from volcanic deposits were found to be quite different from the probable extraterrestrial particles examined.

Norman N. Greenman (Douglas Aircraft Company) presented a preliminary report on low-temperature annealing of Venus Flytrap particles. Results suggest that low-temperature annealing of these particles does occur, and might represent annealing of radiation damage incurred in space.

William A. Cassidy (Lamont Geological Observatory) described a program for the nondestructive radioactivation analysis of individual spherules with diameters greater than 100 microns. Groups of spherules of undoubted natural origin from ancient sub-bottom ocean sediments, of possible natural origin from modern ocean-sediment and ocean-surface collections, and of artificial origin from welding operations and soot were irradiated individually in a reactor and then counted with a multichannel analyzer. Resulting spectra showed marked similarities within groups of similar origin but not enough consistent differences to distinguish between some of the groups with different origins. Spectra from one transparent green spherule of undoubted natural origin were compared to spectra of samples of known composition. In this one case the spherule appeared to be very high in silicon dioxide and to compare remarkably well with the decay spectrum of a sample of average tektite composition.

In one of a series of three papers dealing with the possibility that an unknown but measurable fraction of ocean sediments is cosmic in origin, William Sackett (Lamont Geological Observatory) pointed out that the contribution of cosmic dust should not be greater than about 10^6 tons per day (or 3.65×10^8 tons per year) for the earth because this corresponds to the measured accumulation rate for some of the least active depositional environments in the oceans. If higher rates are postulated for the accumulation of cosmic dust it must be assumed that an appropriate fraction of the greater influx never reaches the bottom of the ocean in these areas. The two other papers in the series [Oliver A. Schaeffer, S. O. Thompson, and G. Magrue (Brookhaven National Laboratories) and Craig M. Merrihue (University of California, Berkeley)] dealt with a search for cosmogenic nuclides in ocean sediments. Schaeffer, Thompson, and Magrue reported that they were unable to find He^3, Ne^{21}, and A^{38} in the magnetic fraction of a modern Pacific red clay sample and in a core from the Pacific and one from the Atlantic.

Merrihue, on the other hand, reported about 6×10^{-9} cc of He^3 per gram of magnetic fraction from the same modern red clay as run by the Brookhaven group. He felt that this indicated an extraterrestrial origin for about 1 percent of the magnetic fraction. This conclusion is supported by degassing experiments on the magnetic fraction in which the isotopic ratio of evolved argon changed with the degassing temperature, and became less radiogenic than atmospheric argon at higher temperatures. He feels that the cosmic gases are more similar in abundance and isotopic composition to primordial gases than to cosmogenic gases. Further work will be necessary to resolve these apparently conflicting reports.

Summary and Comments

Even though the first section of the conference was speculative in nature no one cared to speculate on dust outside the solar system. Therefore the conference had a relatively local subject, astronomically speaking. Two of the methods for condensation of dust which were discussed involved solid-vapor and liquid-vapor equilibria. It is probable that each process occurred to some extent during formation of primordial dust. Three modes of existence (or stages in the existence) of primordial dust in the solar system were discussed. These were as discrete particles falling toward the sun as evidenced by the zodiacal cloud, as aggregates of dust grains embedded in icy heads of comets, and as dust grains forming the imperceptible matrix of carbonaceous chondrites. Implicit in these discussions was the realization that contamination by secondary or altered dust was possible in all these assemblages. The question of ratios between primordial and later dusts is important in satellite and rocket-borne collections. For collections made at or near the earth's surface, this question is further complicated by the problem of terrestrial-dust contamination. Terrestrial dust, of course, can be either natural or artificial. To date, the advantage of collecting dust from certain terrestrial environments has been that large amounts of material can be processed. In certain of the terrestrial sources industrial contamination can be ruled out by collection from ancient sediments such as geological strata, ancient ice or salt, and ancient ocean sediments, followed by careful handling after collection. Ancient deposits have the possible drawback, however, that a certain fraction of infalling cosmic dust may be lost relatively quickly in a terrestrial depositional environment, leaving only a nonrepresentative fraction consisting of the more chemically and physically resistant individuals. No information is available on this. These same sediments, however, have the partially offsetting advantages that either they are easily processed for their insoluble residues, as in the cases of ice and salt, or a small sample represents a great length of time for accumulation of the cosmic increment. In the latter case the proportion of cosmic material relative to terrestrial matter should be high and the rare, larger cosmic dust particles will be found. These particles lend themselves more readily to compositional analysis. Of the methods of analysis that were discussed, all will ultimately be found of value in getting compositional data on cosmic dust and certain of them could be used in sequence on the same particle.

Of special interest is the question of how great a fraction of certain ocean sediments is cosmic in origin. The question remains controversial, but a beginning was made in answering it at this conference. It is notable that siliceous spherules were described in a number of collections containing possible or probable cosmic dust grains, and further work may indicate that these represent a previously unrecognized component of the cosmic increment. It is notable also that no criteria were reported that would serve beyond doubt to identify extraterrestrial dust.

It is felt that the conference served a useful purpose in acquainting workers from a wide variety of research backgrounds with current work on cosmic dust in fields other than their own. The participants also gained a better perspective on the limitations and capabilities of theory and practice as applied to questions about cosmic dust. As one result, a more concerted approach may be made to some of the discussed problems.

Many of the papers presented at the symposium will appear as a monograph entitled *Cosmic Dust* which will be published in June 1964 in the *Annals of the New York Academy of Sciences*.

The New York Academy of Sciences is to be commended for its sponsorship of this conference, its financial support for various foreign participants, its handling of many detailed arrangements, and its undertaking to publish the presented papers.

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