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A CHEMICAL AND TEXTURAL COMPARISON BETWEEN CARBONACEOUS CHONDRITES AND INTERPLANETARY DUST

D. E. BROWNLEE, R. S. RAJAN,
and D. A. TOMANDL

Interplanetary dust probably has a cometary origin. Collectible samples of this material are likely to be more representative of the meteoroid complex than are meteorites. Since 1974, NASA U-2 spacecraft has been able to collect over 200 interplanetary particles in the stratosphere. Roughly 10% have spheroidal shapes indicating previous melting. The rest seems to come from the gentle fragmentation of a single type of parent-body material: a black aggregate of grains mainly 1000 A in size, whose properties are closely similar to Cl and C2 chondritic material.

A considerable amount of evidence indicates that the dominant source of interplanetary dust is the gradual disintegration of short period comets (Whipple 1967, Millman 1973). Fragmentation of asteroids and capture of interstellar grains are additional sources of interplanetary dust, but they appear to be only of minor importance. Once micron-sized particles are injected into the interplanetary medium their orbital parameters undergo relatively rapid evolution largely due to the effects of radiation pressure from solar photons. Interplanetary dust should be more uniformly mixed within the inner solar system than the earth-crossing meteoroids which are currently producing meteorites.

In 1951, F. L. Whipple developed a theory predicting the existence of micrometeorites, interplanetary dust particles which enter the earth's atmosphere without significant heating (Whipple 1951). Recently it has finally become possible to collect large quantities of micrometeorites by using air sampling collectors in the stratosphere flown on NASA U-2 aircraft (Brownlee *et al.* 1976a,b). In stratospheric collections made with the U-2s since 1974, over 200 interplanetary particles were collected from a cumulative air sample of over 2 x 10^5 m^3. Of the collected extraterrestrial particles, roughly 10% have spheroidal shapes indicating previous heating to their melting points, probably during entry into the atmosphere. The spheres have three basic compositions: 1) a Ni bearing mixture of troilite (FeS) and magnetite (Fe_3O_4); 2) a mixture of Fe, Ni metal (Fe/Ni = 10 to 20), magnetitie and the metastable iron oxide wüstite ($Fe_{1-x}O$); 3) mixture of olivine (Mg, $Fe)_2$ SiO_4) and magnetite with approximate chondritic abundances of Fe, Mg, Si, Ca and Ni (no S).

The majority of the collected extraterrestrial U-2 particles were not heated

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to their melting points and are true micrometeorites as defined by Whipple (1951). Proof that these particles are extraterrestrial and not strongly heated during atmospheric entry, was the recent detection of solar wind implanted ^{4}He in 6 of the 10 particles analyzed for He (Rajan *et al.* 1977). Solar wind He ions are implanted to a depth of ~10^{-5} cm in surfaces exposed to space. The measured concentrations of ^{4}He ranged from 2 x 10^{-3} to 2.5 x 10^{-1} cm^3 (STP) g^{-1}. These concentrations are higher than found in most gas-rich meteorites but are comparable to levels found in lunar soils. The large quantities of He found in the stratospheric micrometeorites confirms their extraterrestrial origin and implies that they were neither strongly heated nor physically altered during atmospheric entry.

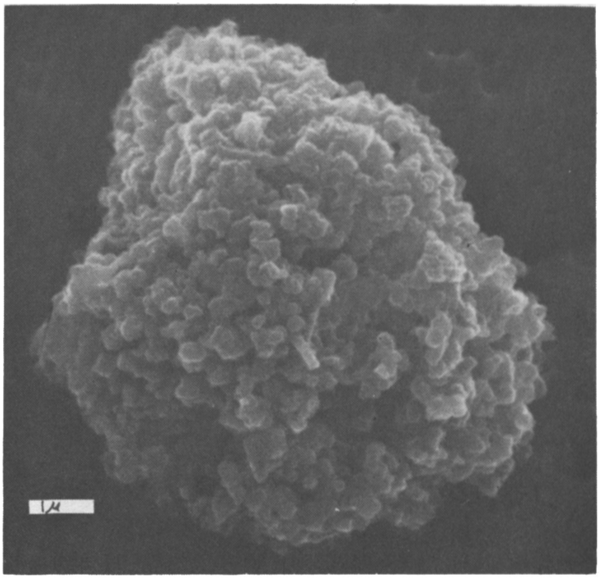

Figure 1. Extraterrestrial particle U2-10A(13). A typical porous aggregate with an element composition very close to carbonaceous chondrites. Scale bar is 1 μm.

With only a few exceptions the non-spherical extraterrestrial particles collected by the U-2s appear to have been produced by gentle fragmentation (probably in space) of a single type of parent body material. This parent material is a black aggregate of grains ranging in size from 10 Å to >10μm with the majority of the grains being ~1000 Å in size (Figures 1 and 2). The relative elemental abundances of most of the 4 μm - 25 μm micrometeorites match C1 meteorites within a factor of 2. Table I gives the results of electron microprobe analysis of four chondritic micrometeorites ranging in size from 3 μm to 12 μm. Microprobe measurements indicate that the average carbon content of the particles is ≥4 wt. %. Imbedded in the black fine-grained particles are occasional micronsized grains of iron sulfides containing 1-5 wt. % Ni, enstatite and olivine which ranges in Mg content from pure forsterite to Fe = Mg.

The micrometeorites have the following properties which indicate close similarity to C1 and C2 chondrites, but distinction from other meteorite types:

1) consist of fine grains (~1000 Å)
2) contain ~5 wt. % carbon
3) contain iron sulfides with Ni > 1 wt. %
4) contain enstatite and Mg rich olivine
5) contain magnetite

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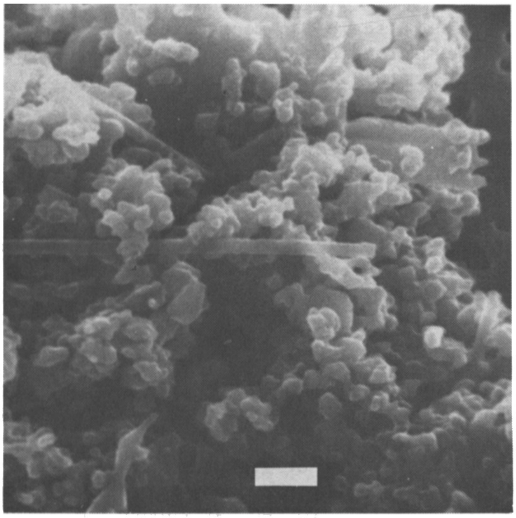

Figure 2. Part of a chondritic interplanetary dust particle with a very complex high porosity structure. Scale bar is 1 μm.

TABLE I

ELEMENTAL ABUNDANCE RATIOS (WEIGHT PERCENT) OF FOUR INTERPLANETARY DUST PARTICLES COMPARED WITH THE MURCHISON C2 METEORITE

Element Ratio	Murchison	11 B(2)	10 B(9)	5 B(24)	6 E(33)
Fe/Si	1.60	1.52	1.75	1.20	1.38
Mg/Si	0.897	0.696	0.988	0.648	1.05
S/Si	0.255	0.600	0.566	0.373	0.590
Ca/Si	0.0984	0.067	0.129	0.069	0.073
Al/Si	0.0853	0.061	0.058	0.065	0.050
Ni/Si	0.107	0.071	0.107	0.065	0.072
Cr/Si	0.0216	0.029	0.026	0.024	0.038
Mn/Si	0.0134	0.031	0.048	0.021	0.036
Ti/Si	0.00467	0.0039	0.0039	0.0040	0.0048

Murchison values are from Fuchs et al. 1973. The particle abundances were measured with an electron microprobe and reduced with the particle ZAF program of Armstrong and Buseck (1975).

In general the micrometeorites are very similar to the fine-grained material in C1 and the matrix of C2 carbonaceous chondrites, although in several ways they appear to be distinctly different. Of the four micrometeorites which have been crushed and analyzed by transmission electron microscopy, none contained fine-scale structure similar to C1 and C2 meteorites examined with the same techniques. The fibrous, platy textures of the hydrated silicate phases commonly seen in C1 and C2 meteorites were not observed in the examined micrometeorites. The dif-

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ference could be due to thermal alteration, but this is probably not the case because on a 10 Å to 10,000 Å scale the micrometeorites appear to be finer grained than the meteorites. The micrometeorites are complex aggregates of large numbers of rather equidimensional grains with widely diverse physical properties. Additional apparent differences between micrometeorites and carbonaceous chondrites are that the dust particles are often considerably more porous and contain grains that have not been observed in meteorites. Among some of the unusual findings in micrometeorites are micron-sized stacks of FeS platelets, a high Si mineral that may be SiN or SiC, and whisker-like rods.

The sources of interplanetary dust probably are comets while the sources of conventional meteorites are probably asteroids (Chapman 1976, Anders 1975), although a cometary origin for at least some meteorites is still a strong possibility (Wetherill 1974). Unfortunately the origins of interplanetary dust and meteorites are not known with certainty and data from analysis of these materials cannot be used in any straightforward way to compare asteroids and comets. It is clear however that both primitive meteorites and interplanetary dust are aggregates of very small grains, some of which appear to have condensed from the gas phase. If meteorites are asteroidal, then they probably represent a collection of grains which accumulated between Mars and Jupiter. If interplanetary dust particles are cometary, then they probably consist of grains which accreted further out, possibly tens to thousands of AU from the sun. The most exciting aspect of cometary dust grains is the possibility that they formed far enough out in the solar nebula that they are cumulates not of solar nebula condensates but of pre-solar interstellar grains.

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DISCUSSION

WHIPPLE: How long before you can collect enough material to measure the $^{18}O/^{16}O$ and $^{17}O/^{16}O$ ratios?

RAJAN: A 1 mg sample is the absolute minimum amount that can be used for oxygen isotopic studies. That would imply ~5 x 10^5 particles. In a good U-2 flight

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lasting about 5 hours, we generally collect ~10^2 particles with our present collector set-up.

GROSSMAN: Aside from the gas contents, could you summarize the major points in favor of an extraterrestrial origin?

RAJAN: Yes. There are basically five other observations. 1. The aggregates are made up of fine grained material varying in grain size of ~50 to 100 Å. 2. The relative chemical abundances of cosmically abundant elements such as Fe, Mg, Ca, Si, Ni, S are in agreement with carbonaceous chondrites to better than a factor of two; several other elements, that are terrestrially abundant, such as Cu, Cl, Zn, etc. were not detected. 3. The silicates analyzed so far, have compositions toward the enstatite and forsterite end members. 4. The presence of Fe, Ni bearing sulphides, often of the form $Fe_{i-x}S$ and the presence inside the aggregates of a Ca, Al and Ti bearing phase (high temperature condensates?). 5. Finally, our recent measurements of carbon contents in six particles, using microprobe give mean carbon contents of over 5%.

LIPSCHUTZ: Given the diameter of a particle like SP-14, its mean temperature and the diffusion coefficient of ^4He in olivine, etc., what is the residence time of ^4He in such a particle?

RAJAN: From comparison with rare gas studies in lunar soil, our He^4 observations are consistent with a lifetime of ~10^3 years for SP-14 particle.