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SAMPLING DUST FROM THE STRATOSPHERE

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Sampling Dust from the Stratosphere[1]

By Paul W. Hodge[2]

Of the numerous meteoric objects that enter the earth's atmosphere from interplanetary space, the smallest and most numerous are dust particles. Some of these particles result from ablation of larger bodies (Krinov, 1955), while others enter the atmosphere relatively unchanged (Whipple, 1950). They lose their cosmic velocities at heights between 100 km and 50 km above the earth's surface, slowly fall to the surface, and gradually mix with atmospheric dust of terrestrial origin.

For nearly 100 years scientists have been attempting to identify and study this extraterrestrial dust (Hoffleit, 1952). Investigations have been hampered, however, by the fact that the terrestrial dust in the atmosphere is so abundant and so varied that any meteoritic component is difficult to isolate. Many investigators have identified particles as being extraterrestrial from their appearance or from their magnetic or chemical properties. However, it has become increasingly apparent that many terrestrial particles have properties that resemble to a distressing degree those of meteoritic particles (Handy and Davidson, 1953). For this reason, we need to collect meteoritic dust from places where the possibility of terrestrial contamination is very slight. Artificial earth satellites can detect particles in the purest environment that we can explore, but they are not yet able to bring back samples for analysis. The best method at present is to use vehicles that reach somewhat lower altitudes, where the meteoritic dust has been slowed down and concentrated by the upper atmosphere.

We have concentrated on collecting dust by use of high-flying jet aircraft because (1) they are able to reach altitudes high enough above the troposphere to ensure a sample relatively free of terrestrial dust; (2) their speeds enable them to intersect a large volume of air in a relatively short time; (3) their flights are still below the altitudes where extraterrestrial dust has cosmic velocities; and (4) their flights are more frequent and more reliable than those of other upper-atmosphere vehicles, such as rockets or balloons.

The problems involved in obtaining and identifying high-altitude dust are numerous. The worst problem is contamination of the sample. The collection device—in our case usually a filter—may be contaminated when it is manufactured or packaged, when it is installed, when it is flown, or when it is dismounted; also, the sample may be contaminated during laboratory preparation or analysis. We have tried to minimize the amount of contamination by using only very clean filters; by constructing the collector mechanism out of aluminum, pieces of which are easily distinguished from the sample; by placing the collector on the aircraft in a position forward of possible sources of dust; and by using a dust-free laboratory in which to prepare and mount the samples.

Other problems, such as the breakage of filters by vibrations in the aircraft and the wearing of parts of the collector mechanism by extreme weather conditions, have been solved by numerous alterations to the design of the collector and by changes of the location of the collector on the vehicle.

Collections

Between January 1958 and December 1959, 45 filters were flown in collectors mounted on high-altitude jet aircraft. Of these filters, 26 were flown on a U–2 out of Edwards Air Force

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Base, Edwards, Calif., and 19 were flown on a B–52 out of Seattle, Wash. Because of necessary experiments conducted to discover the proper location of the collector on the aircraft, the proper type of filter, and the possible sources of contamination, many of the filters flown could not be used for analysis. The totals of usable filters were 21 from Edwards and 8 from Seattle.

Collecting devices

We made our first collecting device as simple as possible. A solenoid-operated shutter covers an air intake hole 6 mm in diameter at the front of the collector; the shutter can be opened by the pilot at a preselected altitude. Air passes through the opening into a chamber 2 cm in diameter. At the back of the chamber is a millipore filter in a removable housing. The filter is supported by a wire screen. This first collector (sketched in fig. 1) was used only on the U–2 out of Edwards Air Force Base.

We later built a more streamlined collector. While it has the same interior design, it has a more compact shutter mechanism and better characteristics of exterior air-flow. The filter housing, which is readily removable, allows fresh filters to be installed with a minimum of time, movement, and contamination. Each unit, consisting of a filter, a retaining ring, and a screen, is packaged in a sealed box ready for immediate installation. This collector (shown in pls. 1, 2) was used on the B–52 out of Seattle.

Examination of samples

All filters were first examined microscopically. We mounted the filter in glass, and examined an exposed area of 16 mm^2 under low power (200×). We counted the number of particles of all types on the filter, and recorded the size and description of each particle. We next examined the entire exposed area of the filter under 400× magnification. We noted the position of every opaque particle with a mean dimension greater than 3μ, and recorded the shape, dimensions, and surface characteristics of each of these particles. The particles could then be relocated immediately for further study or for removal from the filter for chemical analysis.

The results of these examinations are listed in tables 1 and 2. In each table the first column gives the number of the filter; the second column the number of particles of all types found in the first survey of 16 mm^2 of the filter area, normalized to an area of 160 mm^2; and the third column gives the number of opaque

Table 1.—*Particles on filters from first collector, on U–2 flights*

Filter series and number	Number of particles	
	All types, diameter $>6\mu$	Opaque, diameter $>3\mu$
A–1	820	74
A–2	400	60
A–3	2000	99
A–4	1120	91
A–5	660	40
A–7	900	33
A–8	840	—
B–1	730	89
B–2	330	—
B–3	250	35
B–5	870	30
C–1	620	67
C–2	1120	66
C–3	490	63
C–4	260	19
C–5	310	49
C–6	360	42
C–8	170	21
C–9	420	36

Table 2.—*Particles on filters from second collector, on B–52 flights*

Filter series and number	Number of particles	
	All types, diameter $>6\mu$	Opaque, diameter $>3\mu$
E–2	680	17
E–3	1100	83
E–5	1330	93
E–16	120	17
E–23	1090	128
E–25	190	29
E–26	160	29
E–28	50	32
E–28(2)	100	25
E–30	1010	40

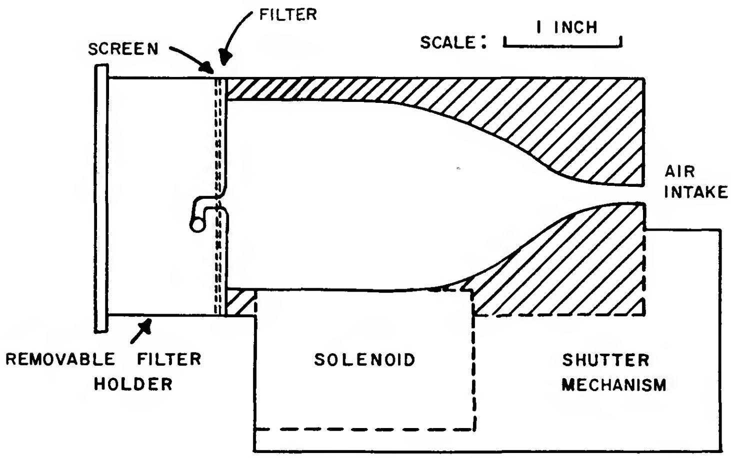


FIGURE 1.—Sketch of the first collector, which was carried by jet aircraft (U-2) out of Edwards Air Force Base, Calif.

particles found on the entire exposed area of the filter (160 mm^2). In all cases, particles that were obviously chips of aluminum derived from the collector itself were disregarded.

The particles found on the filters are of a wide variety of types and sizes. The nature and relative amounts of these various types are given in table 3, which is based on the data for all of the filters from the first collector. The filters from the second collector, on the B-52, gave similar results.

Table 3 also shows the results of the optical surveys with the microscope at 400×; included are all particles larger than the effective limit of recognition, i.e., 3μ in the mean dimension.

TABLE 3.—*Classification of particulate matter on the first collector*

Description	Origin	Percent of sample
Clear transparent	Filter and terrestrial	80
Semitransparent	Terrestrial	11
Aluminum	Walls of collector	1
Opaque		
Shiny, metallic-like	(?)	2
Dull, black irregular	(?)	5
Black spherules	(?)	1

The clear, transparent, blob-like particles were found to be as abundant on unexposed filters as on those with the longest exposures at high altitude; they were, in fact, found on millipore filters taken directly from stock. These particles, which are easily identified, were disregarded in the final scanning.

The semitransparent particles have the wide variety of shapes and colors characteristic of the types of terrestrial particles that are so common lower in the atmosphere. On the average, their abundance on the filter increased with collecting time, indicating that most were gathered during the flight of the vehicle.

The aluminum particles, which are readily identified by their appearance under the microscope, show no such relation; they are undoubtedly from the aluminum collecting apparatus. This conclusion has been verified chemically (Fireman and Kistner, in press).

The number of opaque particles generally increased with the length of the exposure of the filter at high altitude. Most of them are shiny, black chunks; some are smooth-surfaced fragments with rounded edges, while others are in the shape of cindery frameworks full of holes. They are often quite large, up to 50μ or more across, and commonly have a distinctly metallic appearance. A small percent are shiny, black spherules similar to those found in ground collections and which numerous investigators think to be meteoritic.

Space density of particles

The filters exposed by the first collector mounted on the U–2 aircraft provide a value of approximately 500 for the average number of particles greater than 6μ in diameter that were collected per hour. The general problem of the space density of particles cannot readily be studied in more detail from the data derived from these collections because we lack precise information concerning velocity altitude, weather, handling, and other conditions that characterized the flights. However, if we assume a velocity of 600 km/hr, we can obtain a rough value for the density of the particles at the assumed altitude of 60,000 feet. The area of the opening of the collector is 3×10^{-5} square meters; therefore, at a velocity of 600 km/hr the collector would sweep out 18 cubic meters of air per hour. From these data we derive a tentative value of 28 particles per cubic meter of air as the average space density. This value is uncertain, of course, because the relation between the number of particles collected and the exposure time cannot be exactly determined, and because the velocity had to be assumed.

Since we know the details of each B–52 flight, we can draw much more detailed conclusions from the particles on the second collector. For the five B–52 collections that can be strictly compared, table 4 lists the necessary data for determining space densities of the particles. The indicated air speed was converted into true air speed (column 3) by assuming standard atmospheric conditions and an average altitude of 45,000 feet. Column 4 gives the velocity in kilometers per hour, and column 6 gives the volume of air swept out during the exposure by the 6-mm diameter opening of the collector.

In order to derive from the data of tables 2 and 4 a value for the space densities of particles, we must first subtract from the number of particles on the filter the probable number of contamination particles. Although numerous transparent particles are found on a filter taken directly from the manufacturer's box, the number of opaque particles is negligible. We can expect, however, that some contamination occurs while the filter is being prepared and while it is being mounted on the aircraft. The most reliable values for the number of particles picked up at these times are therefore obtained from an examination of filters that have been flown but have not been exposed.

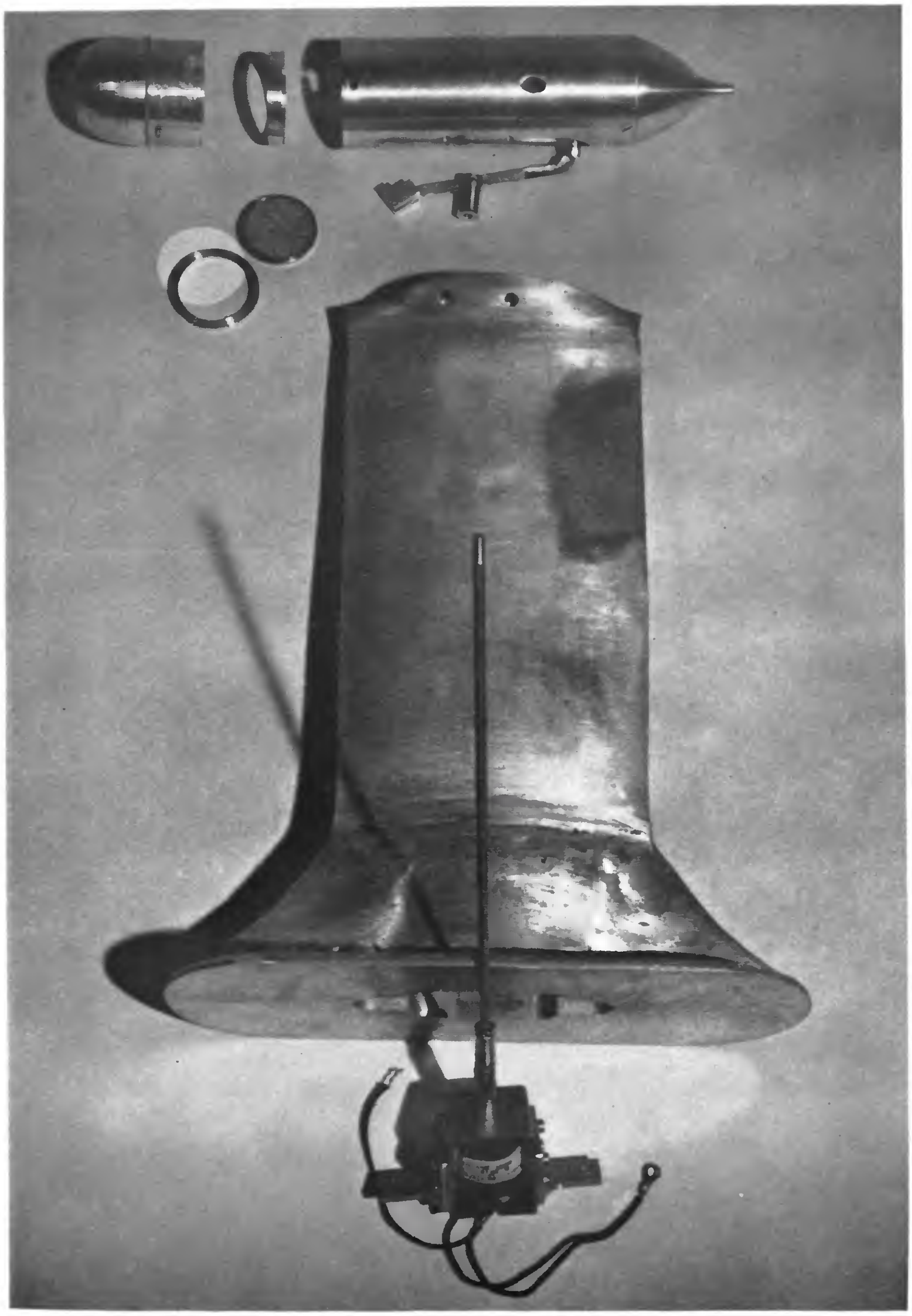
Two B–52 filters, E–25 and E–28, answer this description. The average number of contaminating particles derived from the values in table 2 for these two filters is 120 ± 70 particles of all types, and 30 ± 1 opaque particles. After we have subtracted these values from the counts for the other filters, we can obtain the probable true space densities (table 5).

The values for the probable space densities differ remarkably for the various filters. The wide variety of values for all particles can be partly explained by the great dispersion in the amount of contaminating particles, especially the transparent particles that are on the filters when they are received from the manufacturer. However, the number of opaque particles varies in the same way and in approximately the same amount as the transparent ones; it seems probable, therefore, that the amount of dust in the air at the sampled altitudes varies considerably. The mean space densities of the B–52 flights (table 6) agree remarkably well with the value determined from the U–2 filters. However, before we can draw further conclusions and in order to be confident that the

Table 4.—*Characteristics of B–52 flights, which carried the second collector*

Filter series and number	Indicated air speed (knots)	True air speed (knots)	Velocity (km/hr)	Exposure (hrs)	Volume (m^3)
E–16	240	456	844	0. 25	6
E–23	240	456	844	0. 33	8
E–26	230	446	826	0. 33	8
E–28(2)	240	456	844	0. 28	7
E–30	230	446	826	1. 0	25

Plates 1 and 2



Unassembled parts of the second collector, which was carried by jet aircraft (B–52) out of Seattle, Wash.

The second collector as assembled. The strut is 14 inches long.

TABLE 5.—*Space densities of the B–52 flights, which carried the second collector.*

Filter series and number	Altitude (in feet)	Weather	No. of particles per cubic meter	
			All particles diameter>6μ	Opaque particles diameter>3μ
E–16	40, 000	Clear	0	0
E–23	42, 000	Clear	121	12
E–26	48, 000	Clear	5	0
E–28(2)	44, 000	Clear	0	0
E–30	40, 000	Haze to 40, 000 ft.	36	0. 4

efficiency of our collector is what we have assumed, we need many more samples and we need independent measures.

The particle size distribution

For all types, the number of particles collected increases markedly as their sizes decrease. Table 7 gives the percentages in various size groups of (1) all particles found on the exposed filters of table 1; (2) only the opaque particles found on these filters, and (3) the opaque particles found on the exposed filters listed in table 2. The size distributions are in good agreement with each other, but they differ somewhat from the size distribution of all particles in general (fig. 2). The distribution of all particles is, of course, dominated by particles of terrestrial origin. The greater steepness of the distribution of the opaque particles is what we expect when we consider that their densities are probably greater.

Probable meteoritic particles

We can reasonably expect that among the particles collected at high altitudes there will be a larger percentage of dust of extraterrestrial origin than there will be among particles collected at ground level. We do not expect, however, that this difference will be very large, even at 40,000 or 50,000 feet. The evidence in the preceding sections suggests that probably most of the dust at these altitudes is made up of particles carried up from terrestrial sources by convection. However, the space density of particles at these heights is very much less than that at sea level, and therefore our chances of segregating the meteoritic component of the sample are greatly increased.

Except for particles collected from the vicinity of meteorite craters (Rinehart, 1958; Krinov, 1955), there are no known samples of meteoritic dust to guide one who wishes to search for such objects. Even chemical analysis will not suffice as a criterion. We expect part of the extraterrestrial component of atmospheric dust to be nickel-iron, like iron meteorites, but the composition or appearance of the rest is a matter of conjecture. What

TABLE 6.—*Mean space densities of the B–52 flights, which carried the second collector*

Particles	Number per cubic meter
All types, diameter>6μ	32±46 (rmse)
Opaque, diameter>3μ	2.5±4

TABLE 7.—*Size distribution of particles collected*

Diameter (μ)	First collector (on U–2)		Second collector (on B–52)
	Percent of all particles	Percent of opaque particles	Percent of opaque particles
3–6	54. 0	67. 6	69. 0
6–9	18. 9	17. 4	16. 9
9–12	9. 7	6. 7	8. 4
12–15	5. 4	5. 2	4. 0
15–18	4. 1	1. 5	1. 6
18–21	3. 2	1. 0	0. 1
21–24	2. 3	0. 5	0. 0
24–27	1. 6	0. 1	0. 0
27–30	0. 0	0. 0	0. 0

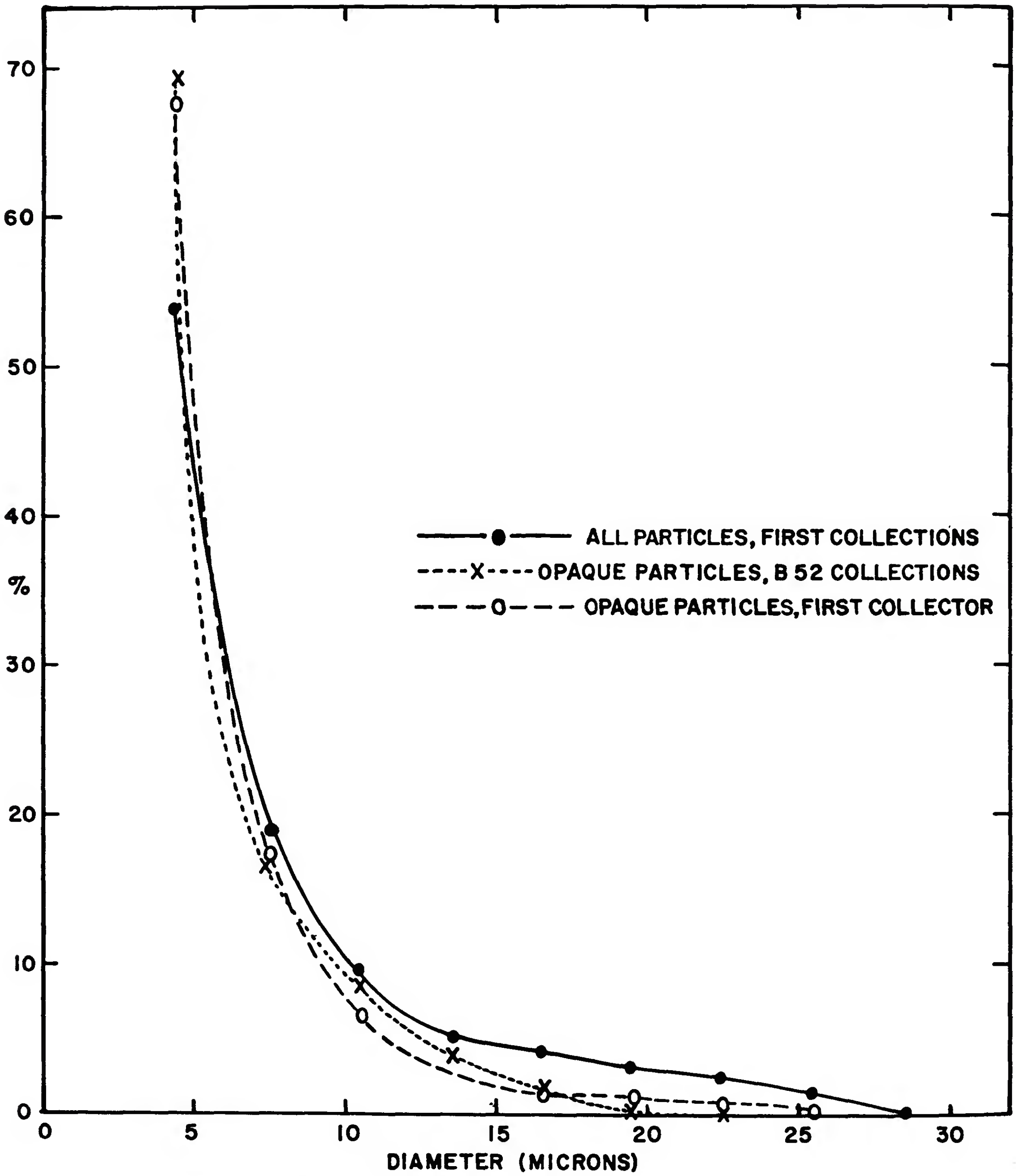


FIGURE 2.—Stratospheric particles distributed according to size.

would be the appearance of dust derived from large stony meteoritic bodies? Or from the disintegration of cometary meteors? Or from the zodiacal light particles? When we have obtained many data from a large number of collections at very high altitudes in the atmosphere and have analyzed chemically a large number of individual particles we will be better able to answer these important questions. At present, we have only fragmentary data on the chemical composition of stratospheric dust (Fireman and Kistner, in preparation; Junge, Chagnon, and Manson, 1960).

We can tentatively select those samples that appear likely to be extraterrestrial particles. Among these are a number of shiny spherules that are of great interest. They are identical in appearance to those particles found near recent meteorite falls—especially the Sikhote-Alin fall—that have been identified as droplets formed from the melting skin of the meteorite (Krinov, 1955).

Such spherules have been identified in both groups of samples; however, because we lack flight data for the flights of the first collector, we will discuss only spherules on the filters on the B–52. Of the 10 filters listed in table 2, five were found to contain a total of 10 spherules. These are described in table 8, where the sizes of individual particles are given in microns. That the spherules were actually collected during flight and were not contamination particles is supported by the fact that filters E–2 E–23, E–25, and E–28, which were flown but not exposed, contained no such particles. The space density for these spherules is calculated to be 0.2 per cubic meter at an average height of 45,000 feet. Stokes' law suggests that in a quiescent atmosphere these particles probably fall at a rate of approximately 1 cm per second from this altitude. Therefore, the computed rate of fall on the surface of the earth is 2×10^{-2} spherules/cm^2/day. This is 1/50th the value obtained by Hodge and Wildt (1958), who collected such spherules from Arctic regions and mountain tops. If our preliminary figures are correct, we must conclude that the ground samples are heavily contaminated by terrestrial spherules, and that even the high-altitude spherules are possibly of terrestrial origin. This latter statement is supported by the fact that we have evidence that for the space densities for all types of particles the ratio of the value for sea level to that for 45,000 feet is approximately 100 to 1, which is, considering the uncertainties involved, equivalent to the ratio for the spherules.

TABLE 8.—*Spherules on filters carried by B–52*

Filter	Number of spherules	Diameters (μ)
E–11	2	
E–23	4	3, 3, 6, 7
E–26	1	3
E–28(2)	1	4
E–30	2	7, 8

Conclusions

From a study of stratospheric dust collections we find that at 45,000 feet there are per cubic meter approximately 30 particles larger than 6μ in diameter. There is evidence that these particles are unevenly distributed in space at this altitude. Most of the particles are transparent or semitransparent and are probably of terrestrial origin. The space density of opaque particles at 45,000 feet is roughly two particles larger than 3μ in diameter per cubic meter. Some of these particles may be meteoritic, but there is no convincing evidence that any large percentage is not merely terrestrial dust carried to high altitudes by convective winds. We can conclude from this comparison of the number of spherules found at 45,000 feet with the number at sea level that many opaque, probably high-density particles are carried up into the stratosphere. The actual number of extraterrestrial particles collected must be very small.

Acknowledgments

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We are greatly indebted to the Boeing Airplane Company and to Project Jetstream, Geophysics Research Directorate, Air Force Cambridge Research Center, for making the collections.

Through cooperation with the Flight Research Center, National Aeronautics and Space Administration, we are continuing to make collections by means of aircraft flying to altitudes of 85,000 feet and higher.

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Abstract

Airborne particles have been obtained from stratospheric air by collectors mounted on high-flying jet aircraft. The estimated density of particles in the 10μ size range is found to vary widely, with an average value of about 30 particles larger than 6μ in diameter per cubic meter at 45,000 feet. Only a very small number of these particles are possibly meteoritic in origin.

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