STUDY ON THE EXTRATERRESTRIAL MATERIALS IN ANTARCTICA (VIII) ON THE DISTRIBUTION OF THE YAMATO METEORITES

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Abstract: No definite explanation has been given yet to the distribution of about 1000 meteorite fragments found in the vicinity of the Yamato Mountains, Antarctica. A discussion was given based on the assumption that meteorite showers fell in the vicinity, but it was found difficult to explain the observed distribution even if we assume the fall of as many as five different meteorite showers in the field. It seems that ice sheet movement has also contributed to the present distribution.

1. Introduction

We have been studying the extraterrestrial materials found in Antarctica since 1965. We have reported the study of microtektite (SHIMA, 1966), cosmic dust (SHIMA and YABUKI, 1968), and the Yamato meteorites (SHIMA *et al.*, 1973; YABUKI *et al.*, 1976). The Yamato meteorites consisted of 9 specimens collected in 1969 (YOSHIDA *et al.*, 1971; KUSUNOKI, 1975), 12 in 1973 (NARUSE, 1975; SHIRAISHI *et al.*, 1976), 663 in 1974 (YANAI, 1976) and 307 in 1975 (MATSUMOTO, 1976) by the Japanese Antarctic Research Expedition team. These meteorites comprise iron meteorites, enstatite chondrites, carbonaceous chondrites, achondrites and ordinary chondrites (MATSUMOTO, 1976). It has not yet been reported from any other regions of the world that different kinds of meteorites are distributed in a small area. Two explanations have been given to such a distribution: One is the fall of as many as five meteorite showers and the other is the transportation of meteorites by ice sheet. In this paper, we compared the Yamato meteorites with other meteorite showers and discussed their distribution pattern, based on the assumption that different meteorite showers fell in a small area.

2. Distribution Pattern of the Yamato Meteorites

Fig. 1 shows schematically the various falling patterns of meteorite on the earth (SHIMA, 1967). Most ordinary case is that a large meteorite breaks in the atmosphere and some pieces of fragments reached the surface of the earth (the left side case in Fig. 1). Sometimes, a meteorite hits the earth and a topographic depression as a crater is formed by the impact, and simultaneously the meteorite is broken up to be scattered in the vicinity. Such a fall is called "the fall of crater-forming meteorite", and twenty examples have been reported so far.

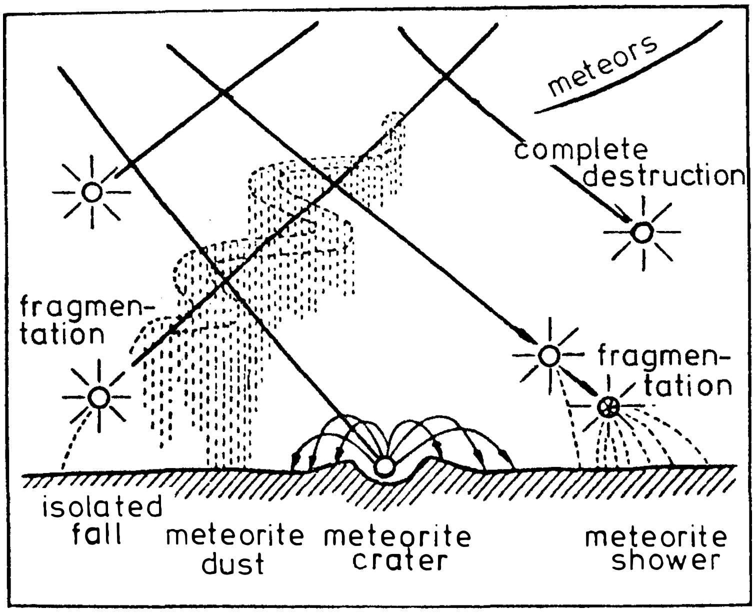

Fig. 1. Schematic diagram of meteorite falls (after SHIMA, 1967).

Sometimes, meteorite breaks up in the atmosphere and many fragments fall in an area just like a rainfall (the right side case in Fig. 1). This case is called the meteorite shower.

Table 1 is the record of meteorite showers which have been hitherto reported, and they are arranged according to the number of specimens. Table 1 also shows the distribution area, weight of the largest fragment and the date of the fall of each meteorite shower. The showers with only the year (without day and month) in Table 1 are the ones whose falls were not observed by anybody, and the year means when the fragments were found. The symbols 'a', 'c', 'p' and 'i' in the column of name in Table 1 indicate that the kind of meteorite is achondrite, carbonaceous chondrite, stony-iron meteorite (pallasite) and iron meteorite, respectively. Those without symbol are ordinary chondrites. The Yamato meteorite shower is conveniently classified as ordinary chondrite in Table 1, because this kind predominates over other kinds.

Fig. 2 shows the points at which the Japanese Antarctic Research Expedition team found the Yamato meteorites (YANAI, 1976; MATSUMOTO, 1976). One dot does not always mean only one meteorite and sometimes it means several fragments. As shown in Fig. 2, the distribution area of the Yamato meteorites is about 50×40 km^2 in the southern part of the Yamato Mountains. The number of meteorites collected in this area has amounted to about 1000, and the number is expected to increase by the further search. However, it decreases sometimes when the fresh broken surfaces of two fragments can be joined together suggesting that they might have been one specimen before. A few such cases are included in Table 1. Thus, the number of specimens in Table 1 is somewhat

Table 1. The record of meteorite showers.

Name of shower	Number of specimens	Weight of the largest specimen (kg)	Distribution area (km²)	Date	Locality
Holbrook	>14000	218	4.8×1.0	1912. 7.19.	Arizona
Pultusk	>10000	200	8.0×1.6	1868. 1.30.	Poland
Mocs	>10000	56	14.5×3.0	1882. 2. 3.	Rumania
Brenham(a)	~ 8000	450		1882 ; 1948	Kansas
L'Aigle	3000	9	12.0×4.0	1803. 4.26.	France
Knyahnya	> 1000	293	14.5×4.8	1866. 6. 9.	U.S.S.R.
Yamato	~ 1000	11.2	40×50	1969 ; 1975	Antarctica
Panter	1000	0.1		1938. 6.16.	Philippine
Pleinview	900	9	27×5	1917 ; 1950	Texas
Allende(c)	hundreds	110	50×6	1969. 2. 8.	Mexico
Esterville(p)	hundreds	200	12.9×1.9	1879. 5.10.	Iowa
Forest City	500	35	3×1.5	1890. 5. 2.	Iowa
Sikhote-Aline(i)	400	1745	3×1	1947. 2.12.	U.S.S.R.
Kirin	> 100	1700	50×10	1976. 3. 8.	China
Norton County (a)	> 100	1000		1948. 2.18.	Kansas
Stannern	200—300	10	12.9×4.8	1808. 5.22.	Czech
Pasamonte (a)	200— 75	0.3	46.7×1.5	1933. 3.24.	New Mexico
Hessle	> 100	10	14.5×4.8	1869. 1. 1.	Sweden
Mino	~ 100	4	12×5	1909. 7.24.	Japan
Temham	~ 100	15	19.3×4.8	1897	Australia
Bruderheim	~ 100	10	5×4	1960. 3. 4.	Canada
Johnstown	100	23	16.1×3.0	1924. 7. 6.	Colorado
Homestead	100	34	11.2×6.4	1875. 2.12.	Iowa
Pervomaiskii	97		6.0×4.0	1933.12.26.	U.S.S.R.
Richardton	71	8.5	14.5×8.0	1918. 6.30.	N. Dakota
Krymka	70	5	10.0×6.0	1946. 1.21.	U.S.S.R.
Kunashak	several tens	5	35.0×7.0	1949. 6.11.	Siberia
Lowicz(p)	58			1935. 5.12.	Poland

ambiguous. In the Sikhote-Aline meteorite shower (KRINOV, 1966) consisting of iron meteorite, the number of collected fragments was 8282, but it decreased to 400 as shown in Table 1, because this shower had many fragments whose broken surfaces could be joined together. In the Norton County meteorites, the number of specimens is over 100 as shown in Table 1, but according to another report the number exceeds 1000. We do not know whether the whole fragments that reached the earth surface were collected. In general, smaller fragments can be hardly found, especially on the ground. The minimum weight of collected fragments was 0.3 gram in the Holbrook meteorite and 1 gram in the Allende meteorite (CLARKE *et al.*, 1970), while it was 0.1 gram in the Yamato meteorites because the collection was made in an ice field. Apart from the ambiguity mentioned above, the Yamato meteorites are represented by a large number of

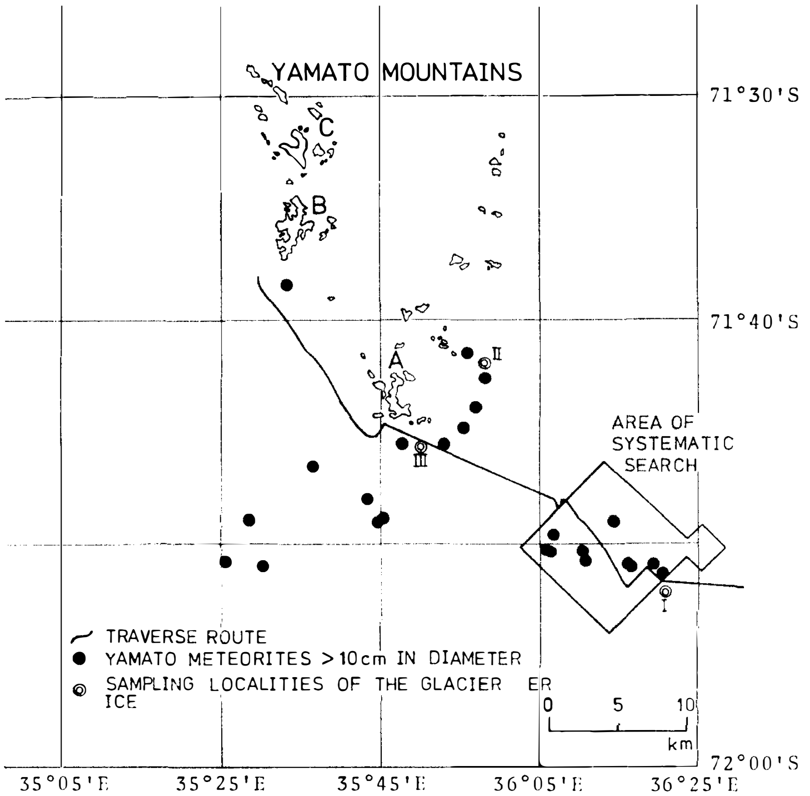

Fig. 2. Sampling localities of the Yamato meteorites (after YANAI, 1976).

specimens, the number ranks within the tenth in the world if the specimens are ascribed to a meteorite shower.

The fragments of a meteorite shower are generally strewn along the flying cource. The major axis of their distribution is commonly 10–20 km, or longer in some cases; it was about 45 km in the Pasamonte meteorite shower (NININGER, 1952) and about 50 km in the Kirin meteorite shower. The distribution area of the Yamato meteorites, about 50×40 km^2, is the widest of all showers reported till now. However, it is very difficult to know exactly the distribution area for one meteorite shower, because five kinds of meteorite showers are mixed with each other in a small area.

The area of systematic search for the Yamato meteorites is shown in Fig. 2 (YANAI, 1976). This area is 10 km square, divided into sections, each side of which being 500 m (Fig. 3). Meteorites were searched in every section. The solid dots in Fig. 3 indicate the points at which meteorites were collected. The meteorites in this area consisted of two kinds, ordinary chondrite and achondrite.

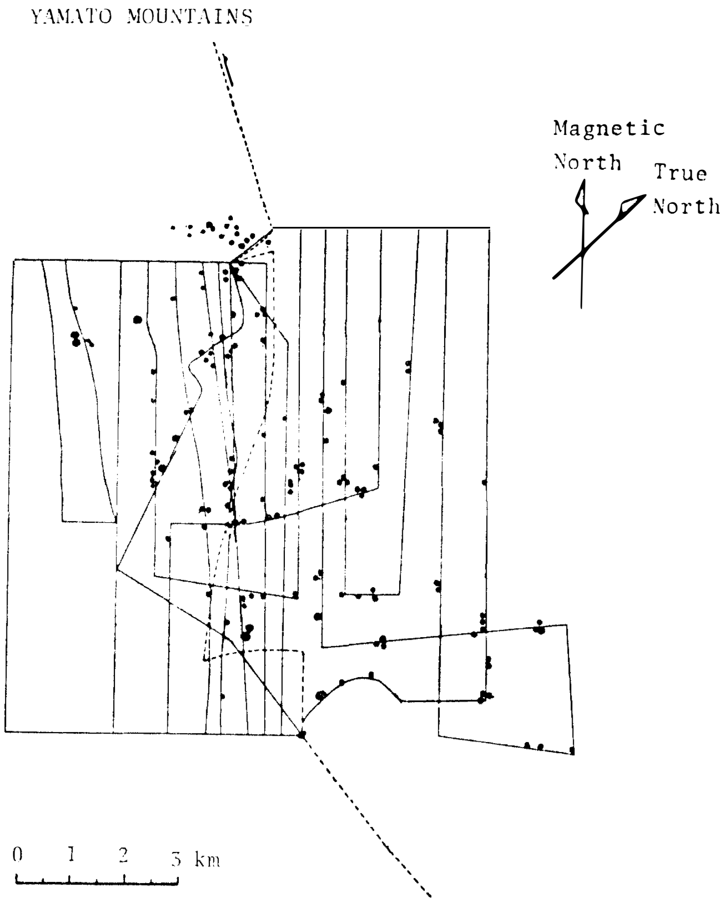

Fig. 3. Area of the systematic search for the Yamato meteorites (after YANAI, 1976).

3. Discussion

In most meteorite showers their falls were observed, but in a few cases, for example the Plainview and Brenham meteorites, the fall was not witnessed. The Yamato meteorites are of the latter case.

The number of specimens of a meteorite shower involves a few problems, besides the ambiguity mentioned above. One of the problems is the minimum size specimen recognized as an individual constituent of the meteorite shower. In the Sikhote-Aline meteorite shower, which is iron meteorite, small particles down to 10 μm in size were collected by mean of a magnet. These particles are similar to the metallic microparticles called cosmic dust. The number of specimens is one shower depends on whether these microparticles are counted or not. In a meteorite shower, only the fragment covered entirely with the fusion crust may have to be counted as an individual specimen. There are three cases in which collected fragments have the fresh broken surface without cover of the fusion crust. (1) When the meteorite breaks in the lower sky, its fragments may not be covered entirely with the fusion crust because of the short flying time and may have a fresh broken surface. (2) The fresh broken surface is also found when the meteorite is broken up by the shock of the fall on the ground. (3) The meteorite may be broken by the change of temperature after the fall. In the first case, the fragments must be counted as the constituents of the meteorite shower, although they may not have the fusion crust on the broken surface. Therefore, it is inadequate to count up only the fragments covered entirely by the fusion crust. Some of the Yamato meteorites have a much thinner fusion crust on the broken surface than the ordinary crust. The presence of such a thin fusion crust suggests that the meteorite was broken up in the sky but its flying time was very short.

The distribution area of the Yamato meteorites is slightly wider than those of other meteorite showers. It may be ascribed to the fall of two meteorite showers (showers of ordinary chondrites and achondrites) in the same area. However, such an example has not yet been reported in meteorite showers. The Plainview meteorite shower was once regarded as such a case; it was reported first as consisting of ordinary chondrite and later achondrites also were found in the same area. Further investigations, however, clarified that this meteorite shower consisted only of ordinary chondrite with brecciated achondrite. Therefore, it may be difficult to regard the wider distribution area of the Yamato meteorites as the result of duplicate falls of different meteorite showers in the same area.

Fig. 4 shows the distribution patterns of the fragments and the flying course of four meteorite showers reported so far. The flying course was determined on the basis of the reports of eyewitnesses. It is natural that the fragments were spread along the flying course. The weight of falling fragment generally increases from the early stage to the later stage of the flight, and the largest fragment falls last. This is clearly shown in the Plainview meteorite shower, in which the flying course changed slightly on the way (Fig. 4). In the Bruderheim meteorite shower, this feature may not be apparent and many of heavier fragments seem to have fallen rather at the later stage. The Pasamonte meteorite shower presents another case, in which the fragments nearly equal in weight were distributed along the flying course. However, there is also a quite opposite case, although it is very rare; in the Johnstown meteorite shower, larger fragments were scattered at the early stage of the flight (Fig. 4).

The flying course of the Yamato meteorites seems to be similar to that of the Plainview meteorites as shown in Fig. 2; that is, at the early stage the course may have been toward the south along the east side of the Yamato Mountains and then changed southeastward over Massif B. However, the degree of change in the course seems to be slightly larger than that of the Plainview meteorites. Therefore, it may be reasonable to interpret that the observed distribution pattern is a result of the overlap of some meteorite showers having different flying courses. Judging from the distribution pattern of ordinary chondrites in Fig. 3, the flying course may be nearly east-west as shown in the Bruderheim meteorite shower (Fig. 4).

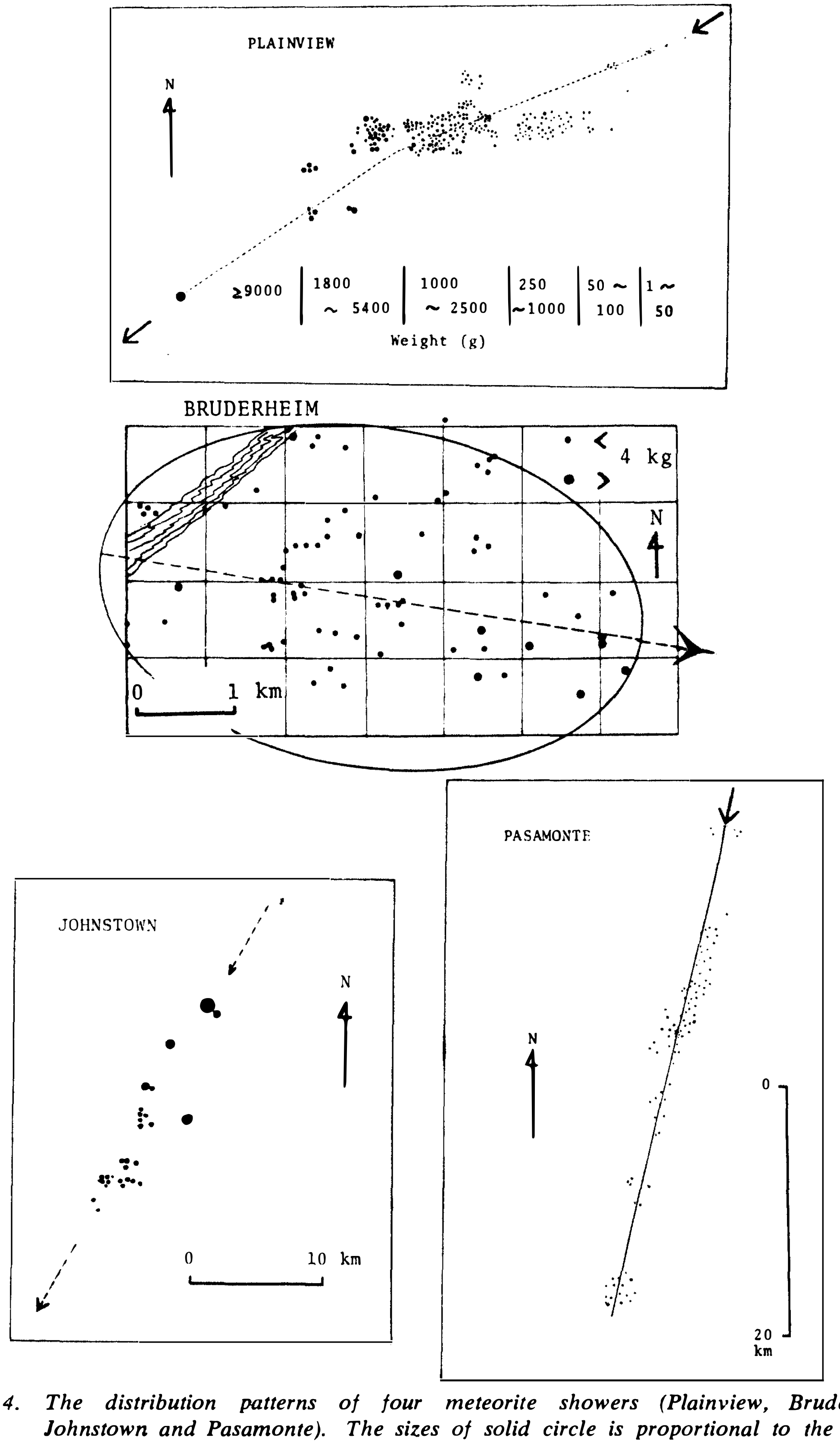

Fig. 4. The distribution patterns of four meteorite showers (Plainview, Bruderheim, Johnstown and Pasamonte). The sizes of solid circle is proportional to the weight of fragments. The flying course of each meteorite shower is also indicated on the maps.

About 80% fragments of the Yamato meteorites are below 30 gram in weight. Although the number of the fragments weighing 1–0.1 gram decreases remarkably, the Yamato meteorites undoubtedly contain much finer fragments compared with other meteorite showers. If the Yamato meteorites fell as a meteorite shower in the observed area, it is expected that the grains below 0.1 gram may be scattered over the ice field. YABUKI *et al.* (1976) examined cosmic-dust-like materials in the ice which was sampled at points I, II and III in Fig. 2. They reported that in the size and the annual fall rate these materials were similar to the so-called cosmic dust found in many glaciers, especially the glaciers near Syowa Station, Antarctica, and that there was no material that appears to have been derived from the Yamato meteorites. The number of fine materials is too small to consider that the Yamato meteorites fell as a meteorite shower in this area. This fact seems to suggest that the meteorites of several meteorite showers which fell in different areas were transported by the movement of ice sheet and were accumulated in the present area.

The Yamato meteorites consist of enstatite chondrites, achondrites, carbonaceous chondrites, ordinary chondrites and iron meteorites, mixed with each other and spread over an area of nearly 10 km square. The following two ideas are proposed for the mechanism which brought about such a distribution pattern of meteorites (SHIMA *et al.*, 1973). (1) Meteorites fell in a small limited area as different showers and/or as individual meteorites. (2) Meteorites fell in different districts as showers and/or individual meteorites and then they were accumulated in the present area by the ice sheet movement. In this paper, we discussed the number, the distribution area, the size distribution along the flying course and the number/weight relation of the meteorites, by comparing the Yamato meteorites with other meteorite showers. In consequence, it seems to be difficult to accept the idea that different kinds of meteorite showers and/or individual meteorites fell at different times in the present area.

There still remain many problems about the distribution of the Yamato meteorites. Further studies of the Yamato meteorites, the analysis of the ice sheet movement, and search for cosmogenic material in other areas in Antarctica and the Arctic region are wanted to throw more light on these problems.

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