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The Muonionalusta iron meteorites

By Frans E. Wickman

Under the name Muonionalusta A. G. Högbom described in 1910 an iron meteorite, which had been found in the most northern part of Sweden. Since then two similar meteorites have been discovered in this area and still another had probably been found in the latter part of the last century but can no longer be traced. It appears desirable to place on record the known details of these finds, together with a description of their external appearance. Such a summary is especially called for, since the chance of discovering more pieces is good.

Muonionalusta I

The original find will be indicated by the Roman numeral one. There is not much to add to the description given by Högbom (1910). The discoverers, Viktor and Amalia (Carlsson) Mattila, are still alive, and when visiting the village Kitkiöjärvi (Kitkiojärvi in Högbom is a misprint) in 1956 the present writer had the good fortune to be guided to the place of discovery by Viktor Mattila himself. Their unanimous version of the discovery differs slightly from the one given by Högbom. They had been tending cattle in the forest and Viktor, then 10 years old, had amused himself by kicking at small stones. One was very much heavier than expected, and since it looked very different from the others they brought it home to the village. Fig. 1 shows Viktor Mattila standing on the place of discovery. Several outcrops occur in the immediate surroundings and the ground surface of the till contains lots of boulders. The coordinates of the place of discovery are $\varphi = 67°48'$ N and $\lambda = 23°6'$ E.

The structure of Muonionalusta I has been studied in detail by Malmqvist (1948).

Muonionalusta II

Some data regarding this sample have been presented in the Meteoritical Bulletin (Krinov, 1961), but no detailed description has yet been published.

It was found by Viktor Niemelä on August 15, 1946, while excavating gravel and sand for the foundations of a house (Fig. 2) in the village of Kitkiöjoki. The exact position of the find is about 10 m E of road No. 400 (running mainly along the Swedish-Finnish border) and about 200 m N of the crossroad to Tjäderbo. Its coordinates are $\varphi = 67°46'$ N and $\lambda = 23°15'$ E.

The unconsolidated sediments are a probably reworked till, the uppermost 30–50 cm consisting of loosely packed sand (see Fig. 2). Under this, there is a layer of gravel and boulders so solid that Niemelä had to use an iron lever to loosen the material.

Fig. 1. The discoverer of "Muonionalusta I", Viktor Mattila, at the place of discovery. Boulders and outcrops are frequent around the spot.

The meteorite was found at a depth of about 120–140 cm. It was surrounded by a rusty zone about 5 cm thick and he observed that the sediment was less densely packed on the eastern side of the meteorite and upwards at an angle of 45°. No depression or hole was observed on the surface of the ground.

Niemelä noticed the boulder on account of its weight when he threw it up to the ground surface with a shovel. Thinking it was an ore boulder he sent it to the Geological Survey of Sweden, where its meteoritic nature was recognized. The specimen has been purchased by the Swedish Museum of Natural History.

Muonionalusta II is approximately slab-formed, one side being shown in Fig. 3. Roughly this side can be described as consisting of three flat surfaces of different sizes forming a flat pyramid. The contour limiting the meteorite is also in reality rather sharp-edged in the plane of the picture. The side not shown in the picture is approximately flat. The maximum dimensions of the body are: length 26 cm, breadth 17 cm and depth (i.e. perpendicular to the plane of the figure) 10 cm; the total weight as received by the museum is about 15 kg.

The meteorite is covered with a thin layer of rust, about one millimetre thick. As already mentioned Niemelä observed that the meteorite *in situ* was surrounded by an approximately five centimetres thick brown zone. There are no traces of a fusion crust left.

The density of the specimen as determined by Dr R. Blix is 7.70 g/cm^3, a preliminary chemical analysis on a small amount of material gave Fe 91.2 per cent and Ni 8.3 per cent.

Fig. 2. "Muonionalusta II" was found in Kitkiöjoki during excavations for the foundation of the house in the background. In contrast to the ground surface shown in Fig. 1 no boulders are present.

Muonionalusta III

On June 7, 1963 Muonionalusta III was found by Mr. Carl Henriksson while participating in the building of a new private road for timber transportation between the road No. 400 and Bjurå on the Muonio River. The place of discovery was about 3.5 km ENE of the village of Kitkiöjoki, its geographic coordinates are $\varphi = 67°47'$ N and $\lambda = 23°21'$ E.

The workers were constructing a causeway, the material used coming from a sand pit opened in till, about 200 m distant. Henriksson was picking away boulders from the road surface in front of the road planer, when he noticed that one of the boulders was extraordinarily heavy and of a peculiar brown colour. Immediately he understood that he had found a meteorite, having been made aware of such a possibility from a pamphlet circulated to all households in the area by the author in 1956. The sample was sent to the Swedish Museum of Natural History, where we could confirm the identification and purchase the specimen.

In September 1963 the present writer had the chance of visiting the place of discovery in company with Mr. Henriksson. Unfortunately the sand pit had already been refilled, and only a small depression could be seen. However, its maximum depth had been about two metres. A mechanical excavator had been used in digging the pit, so no observations had been made at this place. The sediments at the place of

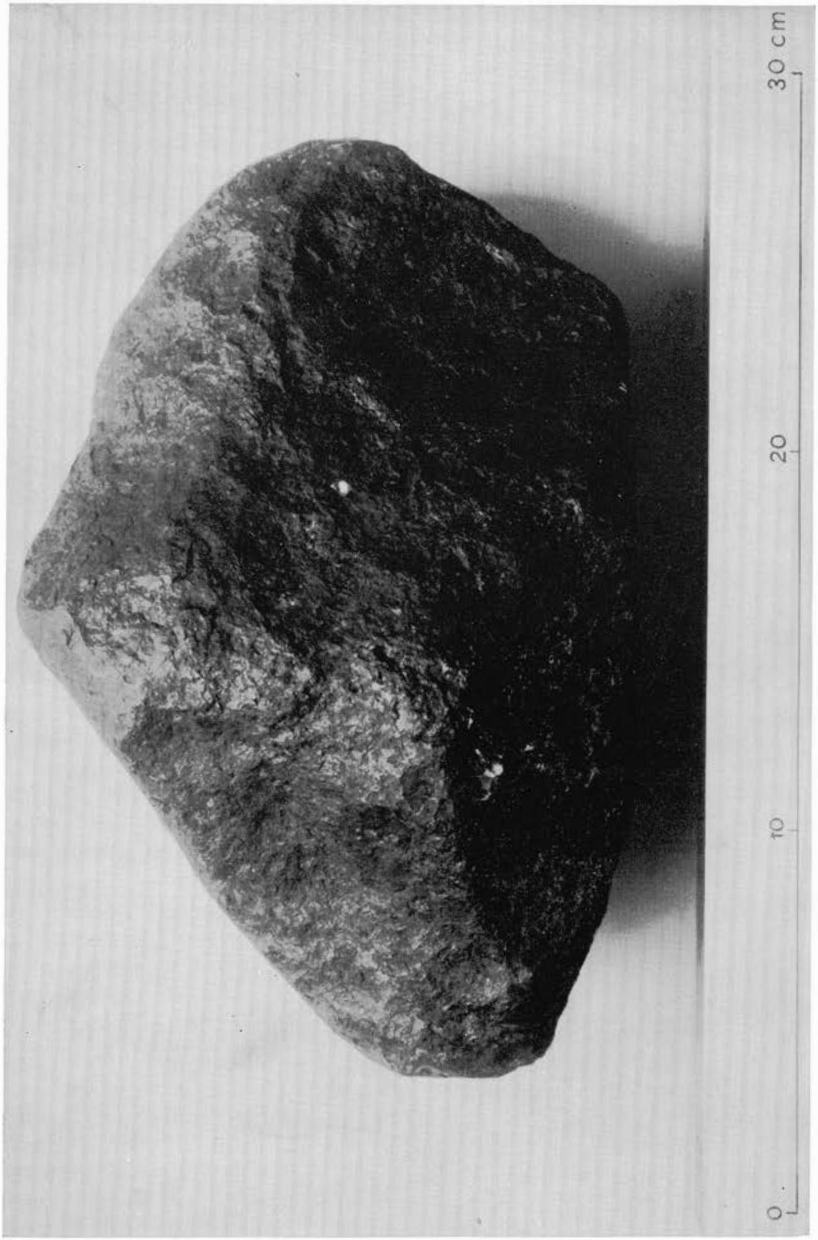

Fig. 3. The iron meteorite "Muonionalusta II".

discovery are best described as till reworked by glacifluvial processes. The general appearance of the place is shown in Fig. 4.

The meteorite itself is covered with a crust of rust which in most places is several millimetres thick. The crust is mainly of a blackish-brown colour, but several light-

Fig. 4. The place of discovery of "Muonionalusta III".

brown spots (see Figs. 5 and 6) occur, which have a diameter of about 2–3 cm and which seem to consist of an intimate mixture of rust, at least partly from the meteorite, and fine-sized particles from the till. Small crystals resembling pyrite also occur.

Muonionalusta III can be described as a slightly twisted slice, which seen from one side (Fig. 5) is almost triangular in shape and rather flat. The opposite side of the meteorite is more irregular in its form (Fig. 6) and may be described as a flat pyramid having four faces of unequal size. The maximum dimensions of the specimen are: length 22 cm, breadth 11 cm and depth 7 cm. The weight of it is 6.20 kg. The density of the specimen as determined by Mr. A. Parwel is 7.20 g/cm^3, and a preliminary chemical analysis on some small chips gave 8.0 per cent Ni.

Muonionalusta "0"

This specimen has not been preserved, but personally the present writer is convinced about the reliability of the data regarding its discovery.

In 1956, while visiting Kitkiöjärvi and Kitkiöjoki, the present writer found that an oral tradition existed regarding an iron meteorite found about 80–90 years ago within the village. In connection with the find of Muonionalusta I by the Mattila children, Mr. Karl (Olsson) Kuoppa told his children that he, probably in the 1870s, had been ploughing on the Waara farm in the village of Kitkiöjärvi and then found a small boulder similar to and of about the size of the one found in 1906. He had

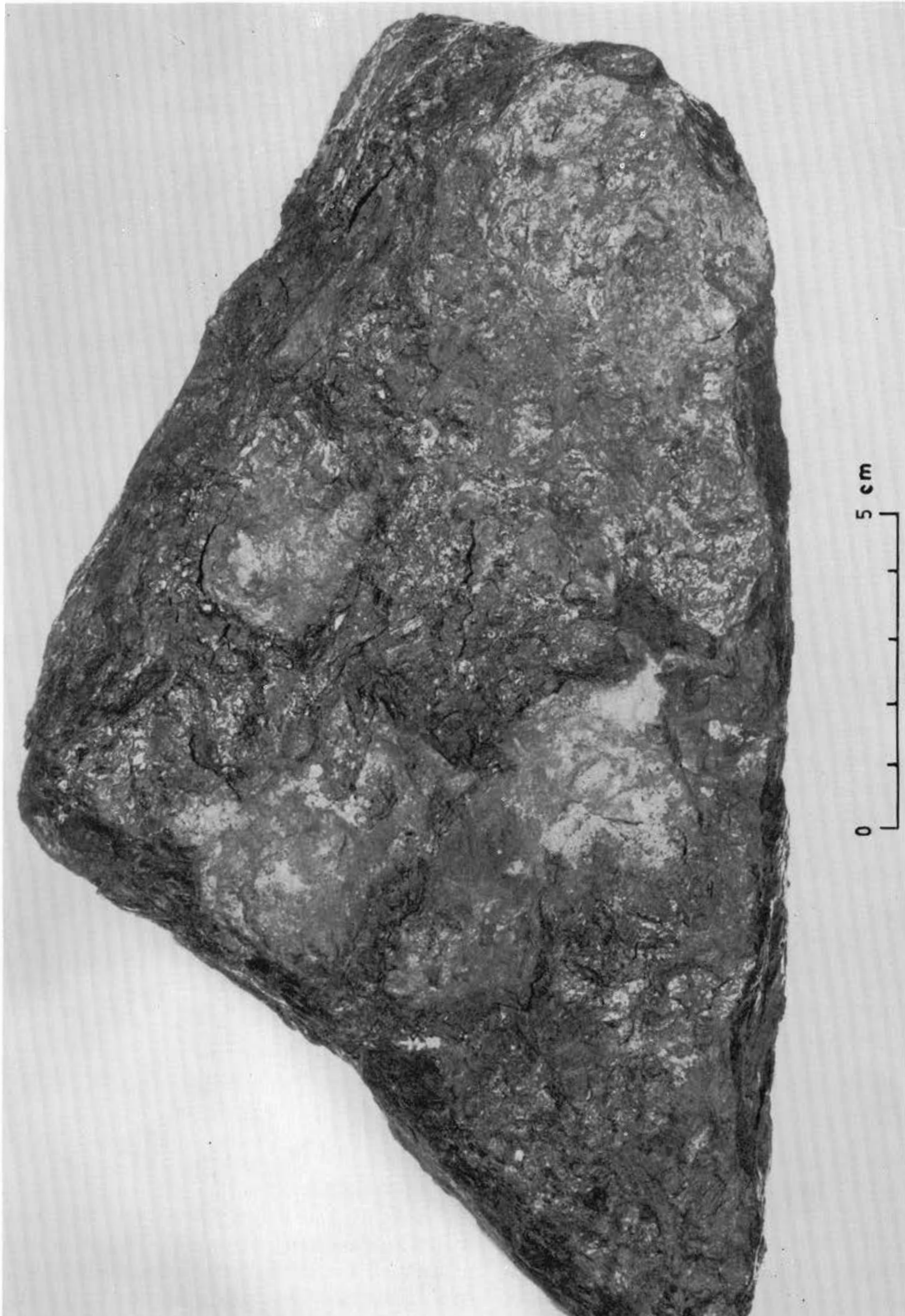

Fig. 5. The iron meteorite "Muonionalusta III" seen from one side.

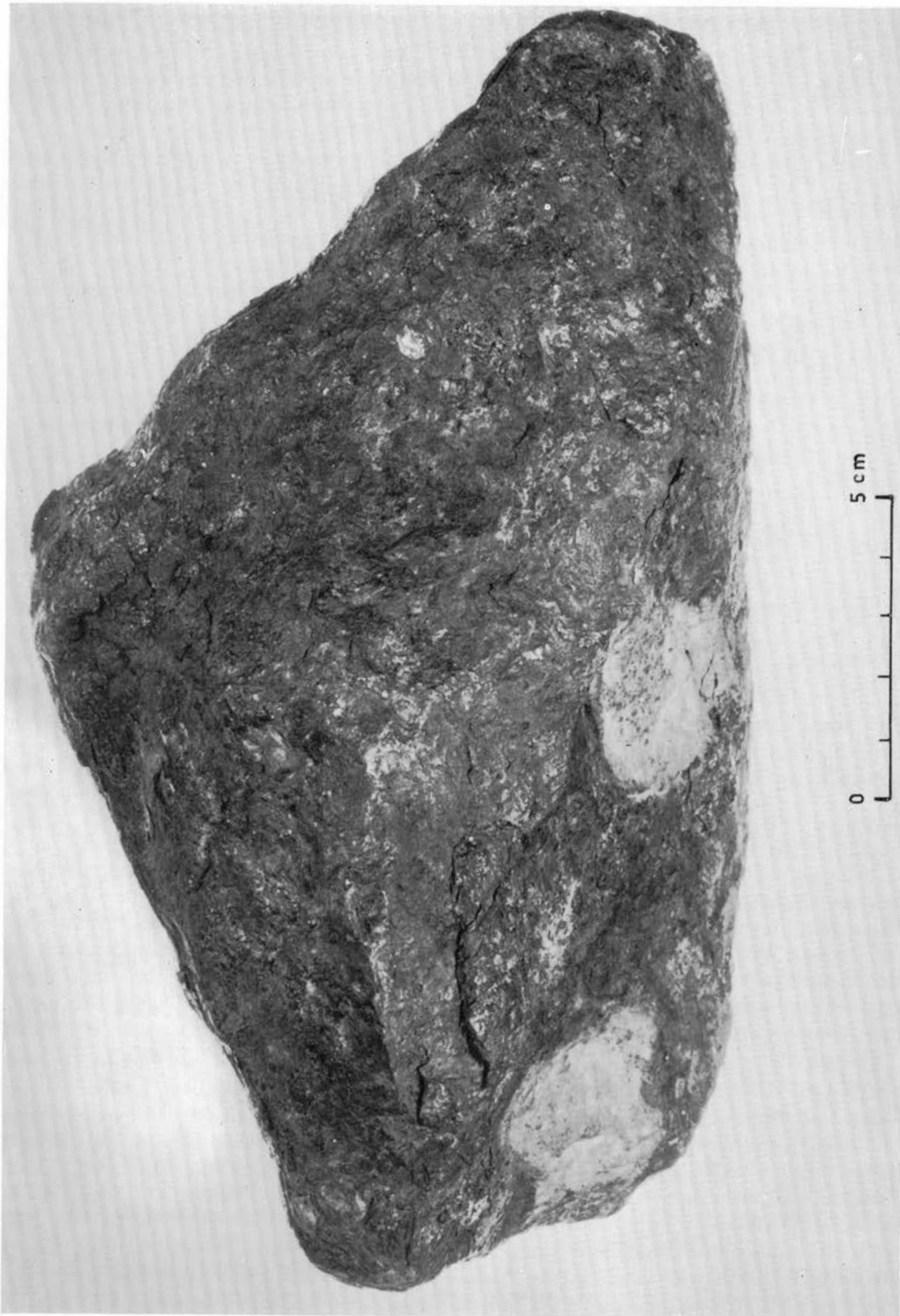

Fig. 6. The iron meteorite "Muonionalusta III" from the other side.

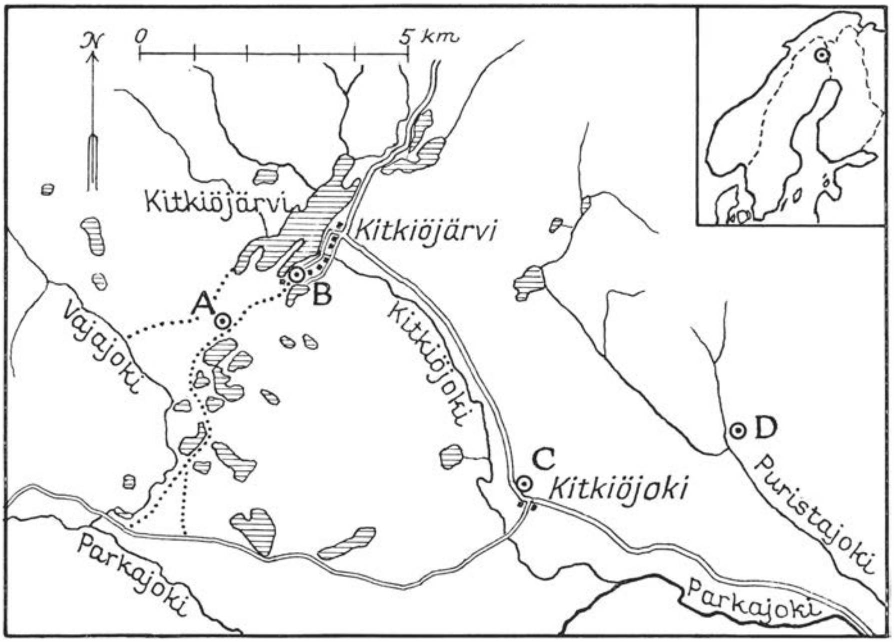

Fig. 7. Map showing the locations of the iron meteorites in the Kitkiöjärvi–Kitkiöjoki area. *A*: Muonionalusta I; *B*: Muonionalusta "0"; *C*: Muonionalusta II; *D*: Muonionalusta III.

been astonished by its weight and had shown it to other inhabitants of the village. They had also thought it a remarkable and interesting stone. Eventually it was thrown away and its present location is unknown.

Some problems concerning the fall

In the Kitkiöjärvi–Kitkiöjoki area we have thus three certain and one probable find of iron meteorites. The places of discovery have been plotted in Fig. 7 and on this map it is seen that the distance between I and III is almost exactly 10 km. The breadth of the zone as defined by the four points seems to be about three km. It is evident that a meteorite shower has fallen here. Interesting problems are then the total mass of the shower, its dispersion area and the time of the fall. We shall treat these questions separately.

The mass problem. The masses of the recovered meteorites are: 7.5; 15 and 6.2 kg. Assuming the mass of "0" to have been 6–7 kg, the total weight is about 35 kg. This value is not impressive to be from an iron shower, but in reality it is remarkable if all circumstances are taken into consideration. This region of Sweden is practically uninhabited, the small population being concentrated in a few small villages and some isolated farm houses. Roads are in the main rare, and those existing mostly follow the undulating surface of the ground. This means that both the number of excavations made per year and their size are small.

Outcrops of solid rock are also rare, the ground mainly consisting of glacifluvial sediments or of till which has been reworked by such processes. Bogs and mires also cover large areas. To some extent thin sheets of eolian sediments also occur on the ground surface. This means that an iron meteorite falling on the ground will generally penetrate the surface and be buried deep under the surface.

These circumstances taken together make finds of meteorites improbable in this area. The fact that four meteorites have been found in less than a century seems to make the assumption of a large number of buried meteorites necessary. We are hence forced to assume that the original mass must have been large.

There is also some evidence from quite another field, which points in the same direction. While meteorites are in space, they are bombarded by cosmic rays which through high-energy nuclear spallation reactions give rise to all isotopes up to a mass number a little higher than that of the heaviest nuclide present in the meteorite. The intensity of the primary flux will decrease with depth inside the meteorite and therefore a depth effect is to be expected and has actually also been studied during the last decade. A consequence of this is that the content of the elements produced by cosmic rays will show a correlation with the size of the meteorite. Very illuminating in this respect is the following table from Wänke (1960, p. 959):

Meteorite	Mass in kg	He in 10^{-6} cm³/g	Sc in 10^{-9} g/g
Cape York	66 000	0.0002	0.21
Gibeon (Harvard)	15 000	0.36	0.18
Gibeon (Amalia)	15 000	3.51	0.43
Odessa	large	1.51	0.33
Carbo (surface)	450	20.9	1.9
Carbo (interior)	450	19.8	1.6
Tamarugal	320	23.1	2.3
Treysa	63	24.1	2.0
Thunda	62	27.1	2.6
Mt Ayliff	13.5	36.2	3.6
Clark County	11.3	47.8	4.6

When studying this table it must be remembered that the existence of ablation during passage through the atmosphere and perhaps also previously in space makes a direct comparison difficult. Nevertheless it is quite clear that the smallest values belong to very large meteorites.

Fortunately measurements of this kind exist for the Muonionalusta meteorites. In 1953 Chackett *et al.* among other iron meteorites also studied the helium content of both Muonionalusta I and II. Regarding No. I they state (p. 264):

"The presence of an appreciable amount of neon is an indication of a leak at some stage of the experiment, or of incomplete pumping initially. The relatively few experiments in which this occurred have been discarded as untrustworthy, except in the case of one meteorite (Muonionalusta I). In this isolated case the helium value was so small that about 5 or 7 g of material had to be used instead of the usual 0.1 or 0.2 g, and even then the amount of helium found was only about 10^{-8} cc N.T.P.; so it was hardly surprising that we did not find it possible to exclude neon from air to a considerably lower limit than this. Even so the correction for the contamination by atmospheric helium amounts to only 10 or 15 %, so that there can be no error in the figure quoted in Table II, as this is given to one significant figure only."

The values found were

	He content in 10^{-6} cm^3/g
Muonionalusta I	< 0.002
Muonionalusta II	0.013

Wänke (1960) determined the content of scandium and titanium as follows

$$\begin{array}{ll} \mathrm{Sc} & 0.19 \times 10^{-9}\ \mathrm{g/g} \\ \mathrm{Ti} & 0.6 \pm 0.2 \times 10^{-6}\ \mathrm{g/g} \end{array}$$

A comparison with the table shows that these helium and scandium values are only consistent with a very large meteorite.

The time of fall. Nothing can be said about the terrestrial age of Muonionalusta I, since it was found on the ground surface. The observation at the discovery of Muonionalusta II during the excavation work that the sediments were less packed on its eastern side shows that the meteorite must have fallen after the retreat of the ice. Furthermore, as Prof. Geijer has pointed out to me, even if it is not possible to estimate its terrestrial age, the fact that it has penetrated into the ground about 1.3 m having a mass of 15 kg means that it must have fallen in the summer because such a penetration would have been most unlikely when the ground was frozen.

No direct evidence can be expected from Muonionalusta III since it was found in a secondary position. However, the fact that it was covered with a thick crust of rust and the observation that Muonionalusta II *in situ* was surrounded by a 5 cm thick zone of rust is a strong indication that they had been buried a long time. How long is difficult to discuss in a realistic way because many factors will influence the corrosion of the meteorite and the possible precipitation of iron in the ground water. Such factors are the pH of the ground water, and its oxygen content, the annual temperature distribution, the possible occurrence of troilite on the very surface of the meteorite when it was buried.

Another line of approach is to explore the existence of any literary sources or oral traditions about the fall. When it occurred, it must have been a spectacular phenomenon which most likely would not have been easily forgotten. In this area the first permanent settlements are from the end of the 17th and the beginning of the 18th century. As far as I was able to find out during my stay there in 1956, no oral traditions existed. Prof. P. Geijer has kindly looked for any literary sources and he states that during the period 1749–1801 both in Finland and Sweden and during the period 1821–1859 in Sweden an ordinance was in force instructing the clergy of the country to include with their yearly population statistics also reports on any happenings out of the ordinary that had been noted in their territorial parishes during the year. With regard to various natural phenomena these reports have been compiled, condensed and published by Sidenbladh (1908). Since light and sound phenomena should have been observed not only locally but also over a large area, the more densely populated area at the northern end of the Gulf of Bothnia is of special interest. The most northern observation of a meteor reported in Sidenbladh's work is in 1760 from Degerselet, about 200 km almost due south of Kitkiöjärvi. This meteor was observed in a southsoutheastern direction, however, and is thus excluded. Since the middle of the 19th century several meteors have been observed in northern Sweden, but they can not be connected with the Muonionalusta shower.

The dispersion area. As already stated the number of meteorites from this fall must be large. It is then natural to ask about the size and form of its dispersion area. As far as is known at present, the dimensions are about 10×3 km. From the observation by Niemelä on Muonionalusta II we know that the travel direction of the meteorites was roughly east–west. The largest masses usually travel farthest and are found at the far end of the dispersion area relative to the direction of travel. The masses found show no such distribution, being about the same size, the largest lying in the middle of the observed area.

If the total mass is large, the sizes of the four fragments seem small when compared with other showers of iron meteorites. It is hence more probable that so far we have only discovered the central or eastern part of the dispersion area. If this is the case the most interesting parts are west of Kitkiöjärvi. This region, however, is a complete wilderness for more than 50 km consisting largely of bogs and mires. It is therefore very difficult to make a systematic search. If, however, we have found the western part of the dispersion area the most promising future "hunting-ground" is on the Finnish side of the border.

The fact that both Muonionalusta I and II contain very little helium can be explained in different ways, and cannot be taken to support any specific interpretation. Nevertheless, it is interesting to note the difference in the helium contents of the two pieces. Muonionalusta II may represent a fragment somewhat closer to the surface of the meteorite than No. I. However, the study of the rare-gas content in fragments of the Sikhote-Alin fall by Vinogradov *et al.* (1957) shows that such a simple interpretation is often incorrect.

In conclusion it must be stated that the dispersion area so far recorded is probably not complete, and, on account of the inherent difficulties, we have only to wait for new finds to solve the problem of its dimensions and orientation.

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I wish to express my gratitude to Hjalmar Lundbohms Minnesfond for a travel grant in 1956 to visit Kitkiöjärvi and Kitkiöjoki and to Statens Naturvetenskapliga Forskningsråd for a grant making it possible to visit the place of discovery of Muonionalusta III. Dr P. Padget has kindly corrected the English.

Note added in proof: Dr. H. Wänke has kindly informed me in a letter that the determination of Sc (Wänke 1960) was made on Muonionalusta II. A determination of argon and chlorine in Muonionalusta I has given the following results (Vilcsek & Wänke, p. 381 in *Radioactive dating*, International Atomic Energy Agency, Vienna 1963)

$$Ar^{36} \leqslant 0.01 \times 10^{-8}\ cm^3/g;\ Cl^{36}\ 0.87 \pm 0.79\ \text{dis. min}^{-1}\ kg^{-1}$$

Also these figures indicate that the meteorite was probably very large.

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