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N:o 67

TRACING OF GLACIAL BOULDERS AND ITS APPLICATION IN PROSPECTING

BY
MATTI SAURAMO

WITH 12 FIGURES IN THE TEXT

HELSINKI ~ HELSINGFORS

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Contents.

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MARCH 1924
IMPRIMERIE DE L'ÉTAT

INTRODUCTION.

All new discoveries of ore deposits made in Finland during the last few decades have got their first impulse from the finding of glacial boulders derived from those deposits. This is due to the peculiar geological structure of the country, and certain other conditions. There is at present little chance of finding ore in actually exposed rock, mainly because earlier prospectors who only paid regard to exposed occurrences have searched the country very thoroughly. The greatest part of the bedrock, including its mineral resources, is hidden beneath several kinds of younger deposits, as drift, sand, clay, peat-bogs, and also lakes. Thus the loose drifts and boulders, in many vast areas, are the only witnesses that give any hint of the existence of mineral wealth that lies deep hidden under the soil. In searching for the sources of loose boulders, prospectors lacking geological training will in most cases fail completely, while men employing scientific methods may be able to solve such problems easily, as is confirmed by experience. Special methods of tracing the boulders to their sources have been developed. For this purpose geological maps must be consulted, and use must be made of the data available concerning the directions of the movement of the Quaternary land ice that has carried the boulders.

Utilization of boulders in the search for ores has old traditions in Finland. As early as 1740 Daniel Tilas published an article[1] in which the principles of this method, based on actual observations, were clearly outlined. During his travels in southwestern Finland in 1737 and 1738, Tilas had noticed the distribution of the peculiar rapakivi granite as boulders in a tract between the towns of Turku (Åbo) and Uusikaupunki (Nystad), where this rock does not occur in place. He recognized that the frequence of rapakivi boulders increases toward the northwest. Finally he met with the source of these boulders in the region now known as the Uusikaupunki (Nystad) rapakivi area. North of this area he found no boulders of rapakivi. Having later

[1] Daniel Tilas, Tankar om Malmletande i anledning af löse gråstenar. Kongl. Svenska Vetensk. Akad. Handlingar för år 1740, pag. 190—193.

recognized the same relation between loose boulders and their source in other tracts also, he inferred that the source of loose boulders in Finland is to be found in a direction between northwest and northeast. The prospectors, he remarks, may take advantage of this rule to locate an ore deposit when they find ore in boulders. He adds, referring to a paper of Rössler, that the distance of the source may, in some degree, be concluded from the nature and frequency of the boulders.

The idea of Tilas was probably known to the later prospectors in Sweden and Finland. There exists, however, as far as is known to me, no direct information whether this method was ever employed in earlier times. There is nothing about it in the writings of C. O. Bremer (1824) or H. J. Holmberg (1858). In 1858 Axel Gadolin, the illustrious mineralogist, reports a boulder-tracing[1] worthy of note in this connection. He had found, in the parish of Kurkijoki (Kronoborg) in Karelia a large boulder of gneiss containing pyrite, pyrrhotite, chalcopyrite, and cordierite, and traversed by a dike of granite. The paragenesis of minerals being very characteristic, he expected to find the source of the boulder. After unsuccesfully tracing along a brook near the boulder, Gadolin went in a direction pointed out by the local striation. Instantly he met with another boulder of exactly the same kind and then, at a distance of half a verst (0.6 km) came to a rocky hillock which proved to be the source of both boulders. Thus, this tracing was based upon observations of the same nature as the method employed and developed later by O. Trüstedt by his classical discovery of the Outokumpu copper ore.

In the literature known to the writer, there are not many records of the use of the boulder method in prospecting from other countries which were glaciated during the Quaternary period. In North America the diamond field of the Great Lakes presents a very interesting problem of this kind, early attacked by the American geologists.[2] Diamonds have been found in the glacial drifts within a wide area south of the lakes. Their source has not so far been disclosed, and in view of the great extent of the areas in Canada where it may possibly be situated, and our incomplete knowledge of their geology, it is certainly a hard task to find it.

In Sweden several discoveries of ore-deposits in the provinces of Västerbotten and Norrland have resulted in recent years, during

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[1] Axel Gadolin, Geognostische Skizze der Umgebungen von Kronoborg and Tervus am Ladoga-See. Verhandl. d. K. Mineral. Gesellschaft zu St. Petersburg 1858.

[2] W. H. Hobbs, The Diamond Field of the Great Lakes. The Journal of Geology, Vol. VII, 1899, pp. 375—388.

and after the world war, from finds of ore boulders. After detailed geological field surveys of the special ore fields the ore deposits in place were located by means of magnetometric and electrometric exploration and eventually disclosed by diamond drillings. Most important of these new ore fields is that of Skellefteå in Västerbotten.[1]

Little as appears to be done in the practical application of the boulder method, the geological problem of transport and distribution of glacial boulders has been dealt with in many countries, especially in Great Britain.

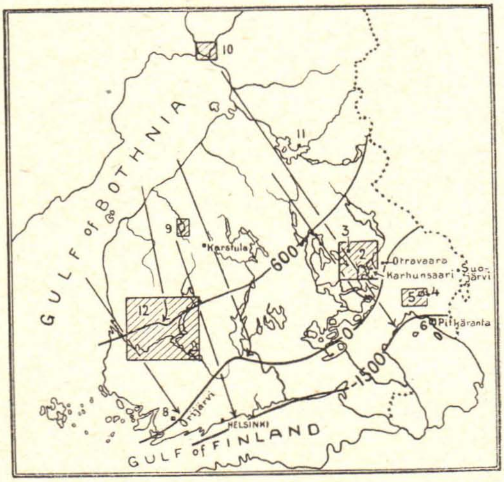

Fig. 1. Map of the southern part of Finland showing the location of the special map areas designated by the same numbers as the figures in the text, and three ice border lines of recession, years —1,500, 0, and 600 (Year 0 is the year when the ice border started to retreat from the Second Salpausselkä).

To illustrate the methods of scientific prospecting employed in Finland, and also to contribute to their further development from a glaciologist's point of view, the writer has collected the scattered materials and observations, mostly hitherto unpublished, concerning the distribution of glacial boulders of known provenance in the central area of latest glaciation in northwestern Europe, especially in southern Finland. The mode of movement of the ice sheet, and the transport of materials by it, will then be treated on the basis of these data and also of studies on the striae and the varve sediments. Thereafter

[1] Axel A. Gavelin, De nya sulfidmalmfyndigheterna i Västerbottens län. Teknisk Tidskrift, häft. 10, 1923.

attention will be directed to the same phenomena from the opposite point of view, namely, the problem of tracing a glacial boulder back to its source.

Most of the examples of the distribution of known rocks as boulders presented in the following pages have been studied during the prospecting work carried out by geologists during the last few years, while others are connected with theoretical investigations in glacial geology. The investigators whose works will be referred to are P. Eskola, V. Hackman, A. Laitakari, A. A. Th. Metzger, M. Sauramo, M. Saxén, O. Trüstedt and H. Väyrynen. The outline map of southern Finland (fig. 1) shows the location of each special area studied.

EXAMPLES OF DISTRIBUTION AND TRACING OF BOULDERS.

THE OUTOKUMPU ORE FIELD.

The discovery of the large deposit of copper ore at Outokumpu[1] by O. Trüstedt in 1910 is a classical example of very successful prospecting by means of glacial boulders. In view of the size and richness of this deposit,[2] the discovery marks the beginning of a new period in the mining industry of Finland. And the hunt for the source of boulders was in that case for the first time developed into a practical method of prospecting, which has later been employed, more or less successfully, in a number of other cases.

Several favourable circumstances co-operated in bringing the Outokumpu prospecting to a fortunate result. Above all, it may be emphasized that success would not have been probable, had the general geology of the region not been so thoroughly known as it was. Altogether, the discovery of Outokumpu may justly be spoken of as one the greatest triumphs of applied geology.

The boulder which suggested the prospecting in question was found in the parish of Rääkkylä, Karelia, (see map fig. 2) in March 1908 during excavations at the Kivisalmi canal. It was a heavy, rusty block about five cubic metres in size, embedded in drift three metres below the surface. The foreman took it for a meteorite and sent samples of it to the Geological Commission. There it was proved to be a rich quartzite-sulphide ore containing 3.75 per cent copper. From the characters of the ore could immediately be concluded that it was probably derived from some deposit of considerable dimensions, and Mr. O. Trüstedt was commissioned to undertake the

[1] The discovery of the Outokumpu ore field has been described or mentioned earlier by: J. H. L. Vogt, Hvorledes Outokumpu, Finlands nye kobbermalmfeld, blev fundet, Teknisk Ukeblad, 1911, and Zeitschrift f. prakt. Geologie, 1919, h. 2; J. J. Sederholm, Mineral Resources and Mining Possibilities of Finland, Engineering and Mining Journal, Januar 28, 1922.

[2] The amount of ore so far known to exist at Outokumpu as a sheet of a thickness varying between 2 and 16 metres is about 7 million tons, with a very constant copper content of 4.5 per cent.

search for its source. In the same winter he surveyed magnetometrically the vicinity of Kivisalmi, but with a negative result. Then, in the following summer, his attention was directed to the quartzites occurring north of Kivisalmi, as it seemed probable that the Quaternary land ice had carried the boulder from that direction. The source, however, was not found in those quartzites. Mr. Trüstedt therefore returned to Kivisalmi in order to study the

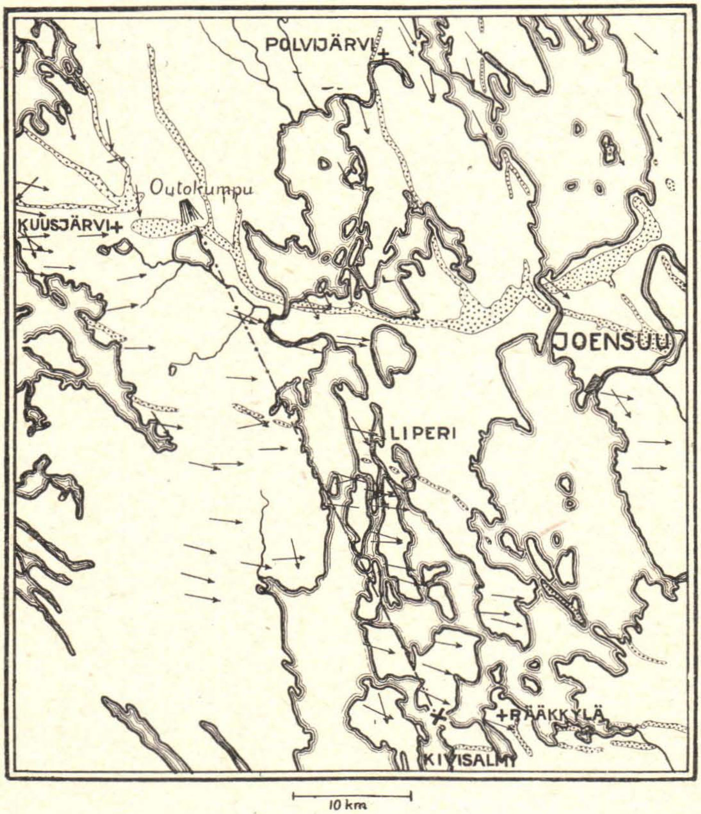

Fig. 2. Map of a part of Eastern Finland showing the fan of ore boulders close to the Outokumpu field, and the place (×) at Kivisalmi where the first ore boulder was found. Dotted areas represent eskers and sand plains, and arrows, the striae.

drift material near the ore boulder. It was found to consist almost entirely of micaschists which form the bedrock in the surrounding area. But among them were also found a few boulders of olivine rock which does not occur at all in place near Kivisalmi. These suggested the working hypothesis that the ore might lie in quartzite near an olivine rock. From earlier geological mapping[1] such a combination was known to occur at Outokumpu in the parish of Kuusjärvi, appr. 50 kilometres N. N. W. of Kivisalmi. Here the ore prospector, in fact, found other boulders of the same ore, together with olivine rock, as at Kivisalmi, spread over a limited area. Their source could be

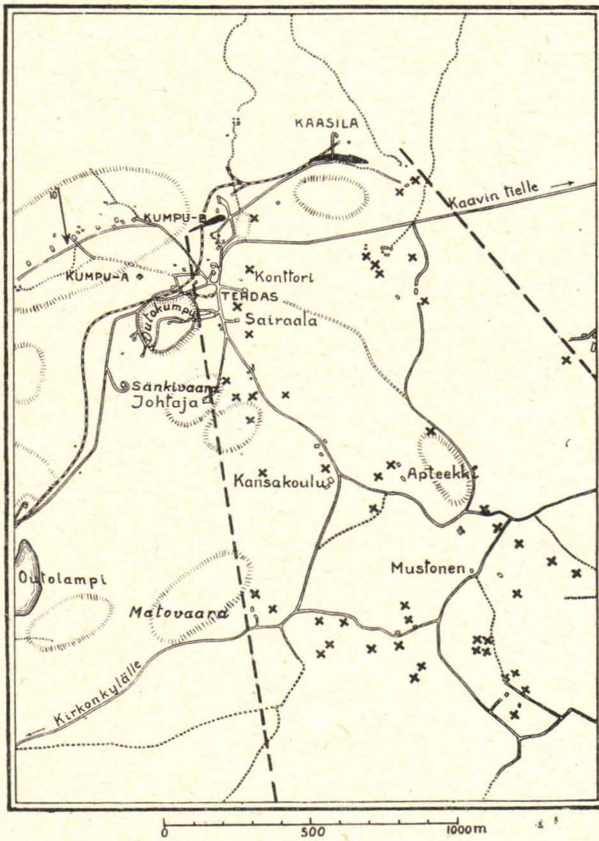

Fig. 3. Map of the Outokumpu copper ore field. The black, narrow areas represent the outcrops of ore (Kaasila and Kumpu B). The crosses indicate the places of ore boulders found, and the dotted lines, the borders of the boulder train.

located in the neighbourhood of the north-western boundary of this area, but the bedrock was here covered with drift and peat-bogs.

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[1] by W. W. Wilkman; the geology of the Eastern Finland has been described by B. Frosterus, Bergbyggnaden i sydöstra Finland. Bull. de la Comm.Géol. de Finlande N:o 13, 1902.

All that was done in the summers of 1908 and 1909. In the following year diamond drill borings were started. A hole was drilled against the schistosity in micaschist, but no ore was met with. Then another hole was drilled, again with a negative result. Diamond drill borings cost money. People began to talk of thoughtless spending of public means. A third hole, however, was drilled, and an ore sheet of a thickness of 9 metres containing 6 per cent of copper was bored through. Thus the ore of Outokumpu was discovered after two years' pertinacious work, in March 1910.

The map in fig. 3 shows the situation of the boulders relative to the outcrops of ore, and some topographic features of the surrounding area. Originally the outcrops of ore were entirely covered with glacial drift and peat-bogs. There are two of them, one, at the Kaasila mine, having a length of appr. 200 metres from northwest to southeast, and another, at the Kumpu B mine, still shorter, the breadth being in both cases from 5 to 20 metres. From these outcrops the ore sheet has been found to extend 1.8 kilometres southwest, gently pitching in that direction and not reaching the rock surface anywhere west of the Kumpu B mine.

As may be seen from the map, 49 boulders in all of ore have been found in a well defined area extending 2 kilometres from the outcrops toward the southeast. Close to the outcrops the boulders group themselves into two separate bunches, but a little farther off they grow together and form a single fan extending in the direction indicated by the striae observed in the neighbourhood. Going southward, no further ore boulders were found in the sand plains or gravel ridges of the Jaamankangas esker which are encountered in that direction. South of this esker the fan has not been traced, except for the search near Kivisalmi.

THE PYRITIC ORE OF KARHUNSAARI.

The pyrite of Karhunsaari, an island in Lake Orivesi, parish of Liperi, may be mentioned here as a further example of ore deposits discovered in consequence of the find of glacial boulders. Such occur here in great abundance on the shore, and were first noted by a farmer. The location of this deposit has so far been only partly made out. It lies in a hill close by the boulder locality, and its case is not therefore of very much interest from the point of view of the present treatise. It is noteworthy that the boulders of pyrite are here exceedingly well preserved and unweathered.

THE PYRITIC ORE OF OTRAVAARA.

Some samples of a boulder containing pyrite ore were sent in 1918 from the village of Kuusjärvi, in the parish of Eno in Karelia, to Suomen Malmintutkimus O. Y. (Finnish Ore Exploration Company). Dr. A. Laitakari, at that time the managing director of this company, examined the locality and disclosed, quite near the boulder find, a remarkable pyrite ore deposit, now known as the Otravaara mine. Several other bodies of pyrite were later revealed in the neighbouring tract.

According to the report of Saxén,[1] six ore boulders in all have been found in the whole region. Two of them lay quite near the chief ore of Otravaara, two others not far from an ore pit named Räsvaaranlaita, and the last two close to an inconsiderable pyrite ore lens near Kuikas farm. The four first boulders had a size of appr. one cubic metre, while the others were much smaller. In addition, numerous boulders of gossan occur here in the drift, having probably been derived from a layer of gossan that existed as such in glacial time. A thick layer of gossan also lies upon the fresh ore in places. The mineral borgströmite, a basic ferric sulphate, is found in the boulders as well as in the outcrops.

THE PYRITIC ORE OF JALONVAARA.

The discovery of the pyrite ore of Jalonvaara in the parish of Suistamo, Karelia, by Eskola in 1919 also represents a case in which the rock in place was found by means of studying the glacial boulders.[2] The ore field has been surveyed magnetometrically and electrometrically, and explored by diamond drill borings.[3] Subsequently some development work was carried out. (See map fig. 4.) The length of the ore body from north-west to southeast, is appr. 600 metres, and its breadth from 3 to 10 metres. The area of its outcrops is not exactly known, the ore being covered by drift. Apparently it is far shorter than the real extension stated above.

The ore field lies on the southeastern slope of the great and high hill of Jalonvaara, the summit of which is 1.5 kilometres to the north-

[1] Martti Saxén, Über die Petrologie des Otravaaragebietes im östlichen Finland, Bull. de la Comm. Géol. de Finlande N:o 65, 1923, pag. 49.

[2] Notes of P. Eskola at the Geological Commission.

[3] Suomen Geologinen Komissioni, vuosikertomus — Geologiska Komissionen i Finland, årsberättelse, 1920, pp. 15—16, and 1921, pp. 13—17.

west. The area of distribution of boulders east of the ore field is gently undulating land with morainic ridges, rocky knolls and basins filled with peat-bogs or small lakes. In the south there rises abruptly

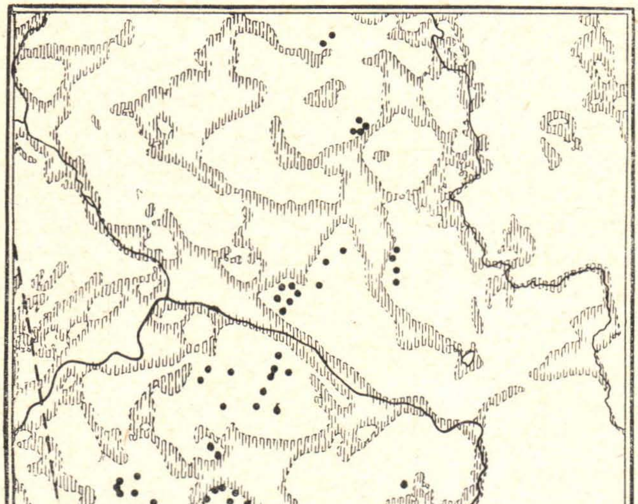

Fig. 4. Map of the Jalonvaara ore field. 1 = peat-bogs; 2 = dry land (drift and rocks); 3 = the ore in place; 4 = ore boulder. The dotted line indicates the northern border of the boulder train.

the high diabase hill of Riuttavaara, and still farther, beyond the Veljakanjoki river, the prominent Jalonvaara esker.

The study of the distribution of boulders has been carried out in great detail by Eskola and Hackman. The results are shown on maps 4 and 5. The boulders, 166 in all, are most frequent close to the ore field. Farther avay they become more sparse. Their distribution is in some degree discontinuous because they were not looked for in the peat-bogs. Remembering this, it may be said that the boulders are distributed very evenly over a fan-shaped area. This is parallel to the youngest striae and roches moutonnées formed by land ice, when moved from the west (N80—85W). There are also some striae

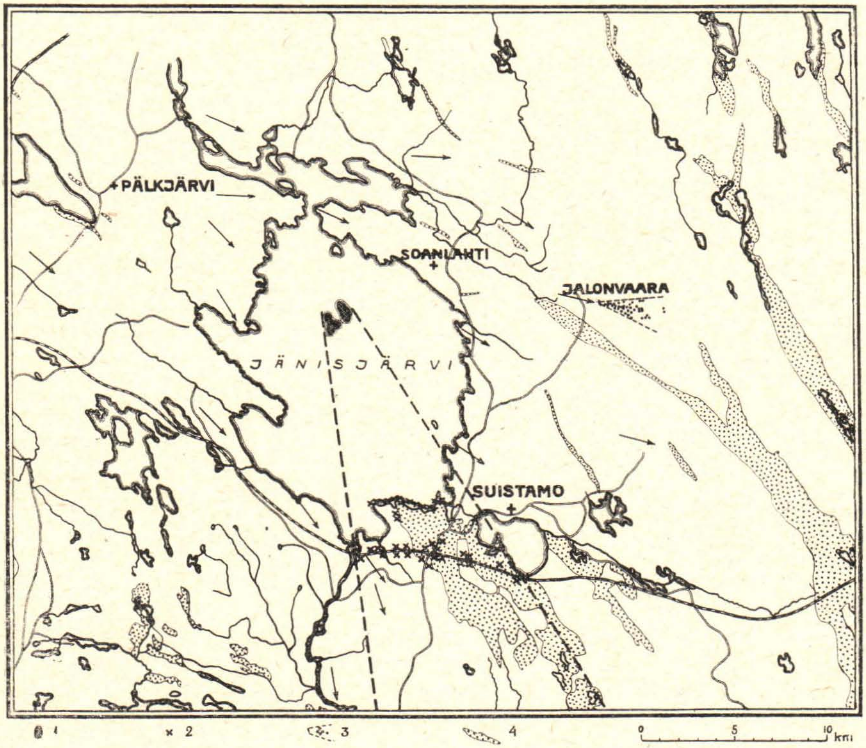

Fig. 5. Map of the surroundings of Lake Jänisjärvi, Karelia, with two boulder fans. 1 = The dacite of Jänisjärvi in place; 2 = boulder of dacite; 3 = The Jalonvaara ore field, with its boulder train; 4 = esker. The dotted lines represent the border of the boulder train.

from the north-west, apparently indicating the direction of a somewhat earlier ice movement. The boulders have, as at Karhunsaari, escaped decomposition surprisingly well.

THE DACITE OF JÄNISJÄRVI.

In the same autumn as the ore of Jalonvaara was detected, Dr. Eskola found, in a region southeast of Lake Jänisjärvi, several glacial boulders of an aphanitic volcanic rock, very rare in Finland. On the shore of Lake Jänisjärvi the boulders, in places, form more than a half the pebbles, but toward the northeast and west this rock becomes rarer and, beyond a certain limit, as seen on the map, fig. 5, no such boulders were observed at all.

Farther southeast boulders of the same rock were found in sections recently made on a new railroad from Matkaselkä to Suojärvi. Here also, as is seen from the map, they occur within a certain reach only. As no such boulders have been noted in the region north and west of Lake Jänisjärvi, it was evident that they must have been derived from some occurrence within the basin of this lake. In fact, Eskola found the volcanic rock actually exposed on two islands named Selkäsaari in the middle of the lake.[1]

The map shows clearly that the boulders are distributed throughout a very narrow area with its longer axis trending almost exactly northwest and southeast. The striae observed here are nearly parallel to this fan. It is worthy of note that the fan of Jalonvaara and that of the dacite of Jänisjärvi have not the same direction.

THE COAL (SHUNGITE) OF SUOJÄRVI.

Metzger[2] has described the distribution of a peculiar variety of coal called shungite which occurs as boulders in the Jatulian area of Suojärvi. They are derived from a slate bed which trends southwest and northeast between the dolomite and gabbro, but is nowhere exposed. Apparently a narrow belt in the slate formation, revealed by electrical indications which are not due to any magnetic ore bodies, represents the source of the boulders. Considering that the uneven distribution of boulders may be attributed to the large areas of peat covering the drift deposits, it appears that the boulders have been transported from their source in a broad stream toward the southeast, parallel to the local striation.

THE PITKÄRANTA ORE FIELD.

The distribution of boulders in the Pitkäranta area was studied in 1923 by Dr. P. Eskola who has given the following account.

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[1] Pentti Eskola, On the Volcanic Necks in Lake Jänisjärvi in Eastern Finland. Bull. de la Comm. Géol. de Finlande N:o 55, 1921.

[2] Adolf A. Th. Metzger, Die jatulischen Bildungen von Suojärvi in Ostfinnland. Bull. de la Comm. Géol. de Finlande N:o 64, 1924.

The oxide and sulphide ores of the well-known ore field of Pitkäranta[1] are replacements in tilted up beds of limestone and skarn with a total length of more than five kilometres. For the most part their outcrops are covered by drift and have been detected by magnetometric surveying. The region of their distribution is situated along the boundary between a flat area of micaschist and somewhat more elevated and rugged areas of granite gneiss. Very regular bands of hornblende schist and, on both sides of these, ore-bearing limestone-skarn layers run along the boundary between granite gneiss and micaschist. The northeast portion of the field is part of the wide area of rapakivi which cuts through all the other rocks.

Unassorted glacial drift covers all parts of the area where the rocks are not exposed, except for a broad belt running over the Herberz mine toward the south. Here the quaternary deposits consist largely of esker material and sand.

At the time when the ore field of Pitkäranta was first detected, great numbers of boulders of ore and skarn were found near the western or »Old mining field». Fuhrmann,[2] in 1810, after his first unsuccessful trial of mining, suggests that most of the ores may have been eroded away from the rock in place, as large quantities of ore and gangue occurred as boulders south of the vein. »Not only a single vein, but whole mountains may be reconstructed from those boulders», he states. It is known, in fact, that considerable amounts of ore were worked from the boulders during the early period of mining at Pitkäranta.

At present but few boulders of skarn may be seen at the locality in question, south of the Meyer and Omeljanoff mines. Most of them have apparently been buried under the vast dumps, or removed out of the way of houses, roads and gardens, as a densely inhabited village now occupies the spot.

The map in fig. 6 shows the distribution of ore and skarn boulders now found on the surface which, between the Meyer—Ristaus zone and the lake shore, is covered with very stony gravel. It may be seen that skarn and ore boulders are still nowadays comparatively numerous immediately south of the ore zone, but going southward their number decreases rapidly, until, at Kaseniemi and south of Peltoniemi on the island of Pusunsaari, they are even more frequent than near the outcrop. This remarkable circumstance first seemed difficult of understanding and rather suggestive of the existence of an unknown

[1] O. Trüstedt, Die Erzlagerstätten von Pitkäranta. Bull. de la Comm. Géol. de la Finlande N:o 19, 1907.

[2] Quoted by Trüstedt, op. cit. pag. 15.

occurrence at Peltoniemi, but the magnetometric surveys made in great detail by Mr. Trüstedt give no indication of such a possibility. A satisfactory explanation was found by studying the composition of the drift and especially a section recently made at a new road from the cellulosa factory at Peltoniemi to the village of Pitkäranta. This is the locality where two skarn boulders northeast of Peltoniemi are indicated on the map.

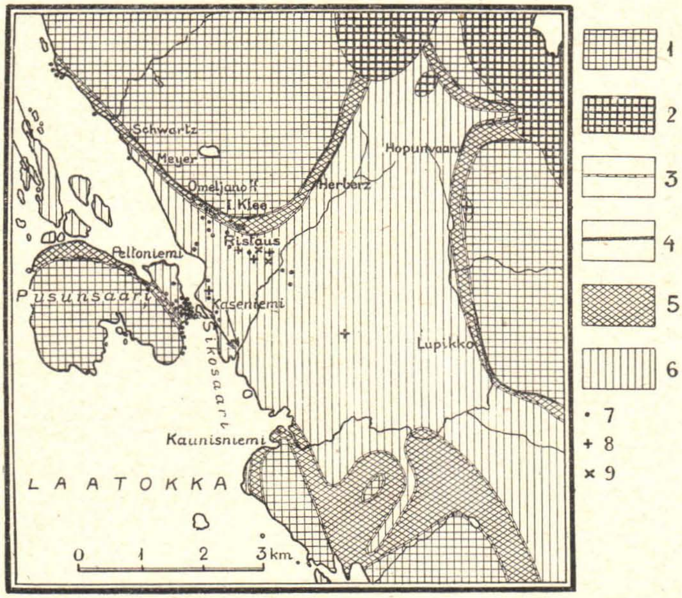

Fig. 6. Geological map of the Pitkäranta region showing the distribution of ores and rocks of the ore formation as boulders. 1 = granite gneiss; 2 = rapakivi granite; 3 = limestone and skarn; 4 = hornblende schist; 6 = mica-schist; 7 = boulder of skarn; 8 = boulder of magnetite; 9 = boulder of sulphide ore. Arrows represent the striae.

This section (fig. 7) shows two well defined layers of drift, entirely different in composition, though this is not clearly visible from the picture. The lower layer, whose upper boundary is at the level where the hammer is placed, is from 1.5 to 1.8 metres thick and consists almost entirely of angular boulders of micaschist. This rock also occurs in place below the drift. The upper layer, again, is about 0.5 m thick and consists chiefly of more rounded boulders of granite gneiss. Two boulders of diopside skarn were found in this section exactly at the boundary between the upper and lower layer.

The boulders lying on the surface are likewise chiefly of granite gneiss in the whole area from the ore belt to the lake shore and still on the northern part of Peltoniemi and Kaseniemi, but farther south the micaschist becomes the dominant material of the drift. Now, the ore and skarn boulders found south of Peltoniemi and on Kaseniemi were situated exactly at the boundary line between the northern area of granite gneiss drift and the southern area where micaschist forms the surficial drift.

These observations are no doubt of great interest for the problem of transport of drift materials. They prove that the drift next upon the substratum has its source in the nearest vicinity, and is overlain

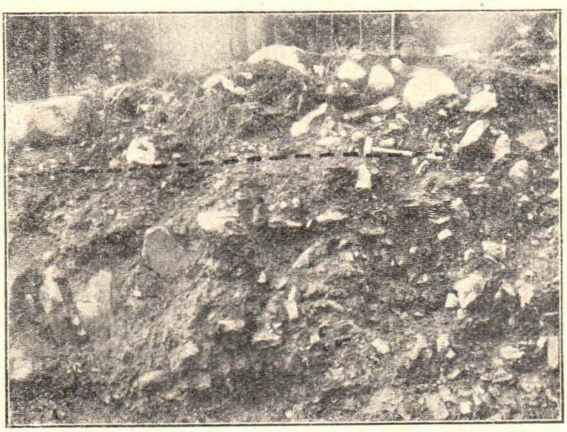

Fig. 7. Section in drift at Pitkäranta. The dotted line indicates the boundary between the lower drift sheet consisting mainly of micaschist and the upper granite-gneiss drift. Photo P. Eskola.

by strata whose sequence is the same as that of their occurrences in place in a direction contrary to the motion of the ancient land ice. The ore-bearing rocks that occur as a belt between the granite gneiss and micaschist areas are, in the drift, concentrated between the micaschist and the granite gneiss drift. At a distance of about two kilometres from the margin of the granite gneiss area the layer of granite gneiss drift is so thinned that it does not wholly cover the surface, and the upper layer of drift becomes enriched with materials from the ore-bearing zone, and, still farther south, micaschist alone constitutes the dominant material of the drift.

No boulders of the ore formation were found in the esker materials and sand plains east of the Old Mining Field. As usual, the esker drift consists largely, if not entirely, of material of distant derivation. The percentage composition of 125 esker boulders near the highroad 2 kilometres east of Ristaus was found to be:

Rapakivi	69.8 %
Granite gneiss	24.7 »
Amphibolites	0.9 »
Hornblende schist	1.4 »
Micaschist	2.4 »
Pegmatite	0.9 »
	100.0 %

Three boulders of iron ore with serpentine (marked by one cross on the map) were found east of the esker. They are of the Herberz ore type and apparently have their source in this part of the ore zone (the New Mining field). But no other boulders of the ore formation were found in the eastern part of the ore field, including the Hopunvaara and Lupikko fields, although unassorted drift is common. Their non-occurrence or scarcity in that part of the area still remains unexplained.

The Pitkäranta field lies near the southwestern boundary of that part of the large north-European area of Quaternary glaciation where glacial erosion dominated over accumulation and the old rock substratum is exposed in frequent outcrops. This boundary is well marked and may be said to be situated at Uuksu, about seven kilometres south of Lupikko. Southeast of Uuksu the whole coast region of Lake Laatokka (Ladoga) is covered with thick beds of drift, and rock exposures are very few. The drift there consists largely of materials derived from distant sources. This may be seen especially near the rock exposures. Thus, on the island of Mantsinsaari in L. Laatokka there are exposures of diabase of a peculiar type, the so-called Valamo diabase. Even near the exposures, in places where diabase undoubtedly forms the bedrock, this rock is but sparingly present in the drift whose greatest part consists of rocks of distant provenance. In those accumulation regions, therefore, the search for the source of boulders would always encounter great difficulties.

THE ORIJÄRVI ORE FIELD. [1]

The distribution of boulders in this field was studied by P. Eskola in 1919. The results are shown on the map, fig. 8. On this map are

[1] For the rocks and ores in the Orijärvi region we refer to the treatise of Pentti Eskola, On the Petrology of the Orijärvi Region in Southwestern Finland, Bull. de la Comm. Géol. de Finlande N:o 40, 1914; Fennia.

indicated, first, the boulders of cordierite- and andalusite-bearing rocks, including those of skarn (tremolite skarn, and hedenbergite-andradite skarn), found outside the area of their occurrence in place. The eastern part of the south shore of Lake Orijärvi was not explored with regard to boulders, while the north and east shore of the eastern part of Lake Määrijärvi was found almost devoid of such boulders, apparently owing to the fact that the high and steeply sloping rocky

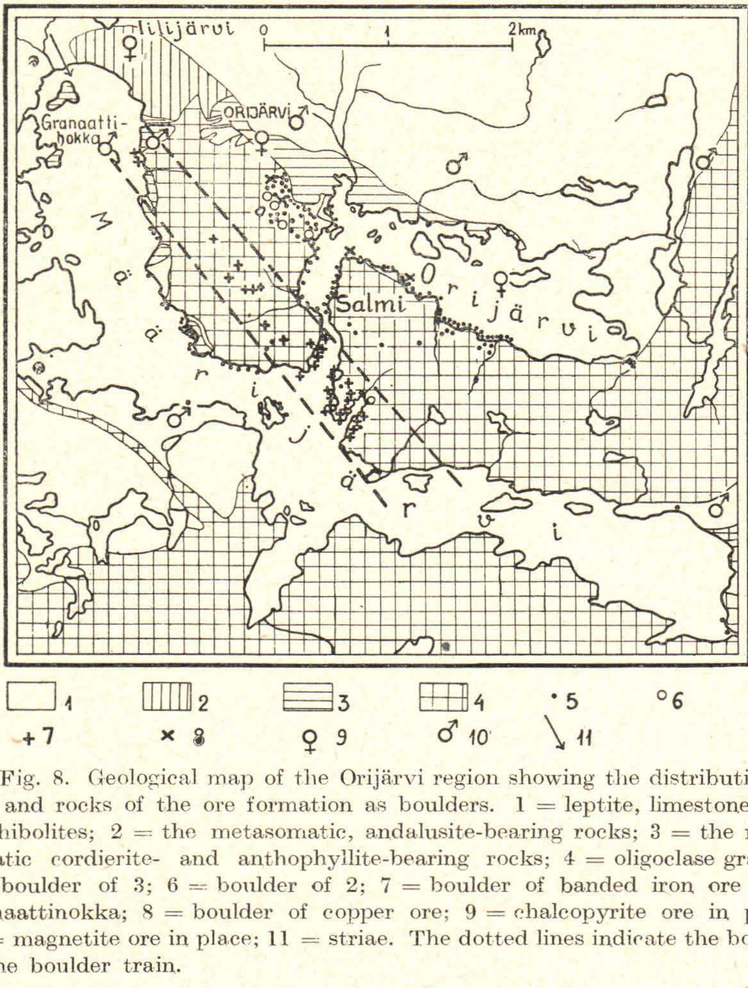

Fig. 8. Geological map of the Orijärvi region showing the distribution of ores and rocks of the ore formation as boulders. 1 = leptite, limestone, and amphibolites; 2 = the metasomatic, andalusite-bearing rocks; 3 = the metasomatic cordierite- and anthophyllite-bearing rocks; 4 = oligoclase granite; 5 = boulder of 3; 6 = boulder of 2; 7 = boulder of banded iron ore from Granaattinokka; 8 = boulder of copper ore; 9 = chalcopyrite ore in place; 10 = magnetite ore in place; 11 = striae. The dotted lines indicate the borders of the boulder train.

area between the lakes supplied nearly all the material of the shore drift existing there. The boulders of cordierite- and anthophyllite-bearing rocks on the shores of the northwest portion of Lake Määrijärvi may be concluded, from the similarity of their petrographic characters, to be derived from the northwest end of Määrijärvi.

Boulders of the andalusite-bearing quartz-mica rock of the Iilijärvi tract have been found in small numbers near the west shore of Lake Orijärvi and not at all on the shores of Lake Määrijärvi.

Only four examples of boulders of copper ore were found, though it is probable that more have been found in earlier times from the nearest vicinity of the Orijärvi mine. The boulder now found nearest the mine, south of it, consists of quartz-sericite rock, very much like that of the Iilijärvi rock, containing abundant chalcopyrite and octahedra of pyrite. The next ore boulder, a little farther south, is a large one which apparently originally measured several cubic metres, but it has been quarried into pieces and some ore has been taken off and exploited. It consists of quartz-sericite rock, in places containing aggregates of biotite and nodules of cordierite, but no andalusite. Otherwise it is much more like the Iilijärvi rock than that of the main Orijärvi mine. Its ore minerals are chalcopyrite which is very abundant, pyrrhotite, and pyrite in the form of octahedra, and some galena and zinc blende. Although these boulders therefore have most probably been derived from the Iilijärvi field, there are others found close by them that consist of tremolite skarn and may be said positively to belong to the rocks occurring in place at the main mine of Orijärvi.

The two boulders of copper ore found at the south shore of Lake Orijärvi northeast of Salmi belong to the »hard ore» of the Orijärvi mine. One of them is cordierite-and antophyllite-bearing »ore-quartzite», and the other a cordierite-anthophyllite rock, both richly impregnated with chalcopyrite.

The ore whose distribution in the form of boulders offers most interest in the Orijärvi tract is the banded iron ore of Granaattinokka, a well characterized and peculiar ore type. The well defined train of boulders extending from this locality toward the southeast may still be traced from numerous boulders south of Salmi, 2.8 kilometres from the ore in place. On the map, the south boundary of the train has been drawn to include the occurrence of the iron ore on the floor of Määrijärvi near Granaattinokka, supposing this to be of the same kind, though it must be remarked that this iron ore is not exposed at all and is only known from a magnetometric survey. It is remarkable, in fact, that the banded iron ore is represented by such great numbers of boulders, while the Orijärvi copper ore is extremely sparse. This fact may perhaps be accounted for by the larger areal exposure of the former, rather than by the greater decomposibility of the sulphide ore.

The investigation of the boulders in the Orijärvi region had the practical aim of looking for traces of new ore deposits, that might possibly exist unexposed and therefore undetected. Especially was the water-covered area of the northwest part of Määrjärvi suspected, because of the occurrence of well-developed cordierite-anthophyllite rocks in that tract. But no such traces of ore were found, excepting that some of the boulders on the shore of Määrijärvi contain a little chalcopyrite. Hence there seems to be no warrant for arousing expectation of new ore deposits here. But it is very certain, on the other hand, that some ore deposits still await disclosure in the wider neighbourhood of Orijärvi. This appears from the fact that some boulders of copper and zinc ore were found a few kilometres farther west, near Lake Isokiskojärvi. In this tract esker deposits cover the greater part of the area, and it was quite impossible to locate the ore deposit.

THE SANDSTONE OF KARSTULA.

In Central Finland, sandstone does not occur in place anywhere and very rarely in the form of boulders. Within a limited area southeast of Lake Vahankajärvi in the parish of Karstula, near the divide between Gulf of Bothnia and Gulf of Finland, however, great numbers of sandstone boulders were found by the writer.[1] The sandstone shows some variation in the boulders. Some of them consist of brownish-red, fine or coarse grained sandstone. The greatest number, however, belong to another type which is characterized by white or yellow colour and consist almost exclusively of quartz in well rounded grains of uniform size. Sometimes it is a typical quartzitic sandstone, hard and unweathered. Sometimes the rock is soft and porous, having apparently been cemented by calcite which has afterwards dissolved. This sandstone, called »sierakivi», is used by the farmers as grindstone.

The well defined fan of boulders extends from a small island in Lake Vahankajärvi toward the southeast. The boulders are most numerous in the northwest part of the area of their distribution. making here more than $^1/_3$ of the total coarser drift material. The boulders apparently have their source in the floor of the lake. The train coincides with the direction of the local striation.

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[1] Matti Sauramo, Über das Vorkommen von Sandstein in Karstula, Finnland, Fennia 39, N:o 7, 1916.

THE DACITE OF KÄRNÄSAARI.

Another occurrence of volcanic rock resembling that of Jänisjärvi is situated on an island, named Kärnäsaari, in the northern part of Lake Lappajärvi, East-Bothnia. The exposures and the whole probable area of this rock in place is shown on the map, fig. 9. The distribution of this dacite as boulders was studied in 1914 by Dr. A. Laitakari. These boulders are easily identified on the shores and islets, which are rich in pebbles, being most numerous close to the rock in place and also in a narrow belt south of it. To the east and west, boulders are but sparingly met with, and beyond a definite limit, shown on the map, they disappear entirely. Thus, there is a fair boulder train extending nearly in a southerly direction parallel to the striae observed on the south shore of Lake Lappajärvi.

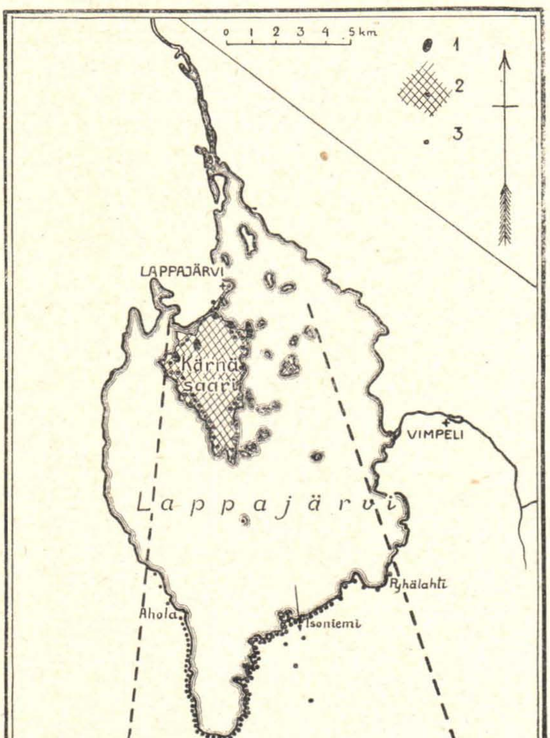

Fig. 9. Map of Lake Lappajärvi showing the distribution of the dacite of Kärnäsaari. 1 = exposures of the dacite; 2 = the probable area of the dacite in place; 3 = boulder of dacite. The arrow indicates the direction of the striae, and the dotted lines, the borders of the boulder train.

THE DOLOMITE AND THE ANDALUSITE-BEARING SCHIST OF ALA-TORNIO.

Glacial boulders of dolomite are very common in the parishes of Ala-Tornio and Kemi. They apparently have been derived from several large occurrences of dolomite in this region. The district between Kemi church and the occurrence of dolomite at Kalkkimaa was studied carefully by the writer in 1920, during an (unsuccessful) search for the source of a dolomite boulder containing native gold found in 1836 near Kemi. As the map in fig. 10 shows, a fan of dolomite boulders points to the occurrence of Kalkkimaa. Farther, near the Kemi river, its limits become more indefinite, as boulders of the same rock may possibly have been spread from other occurrences farther west of Kalkkimaa as well.

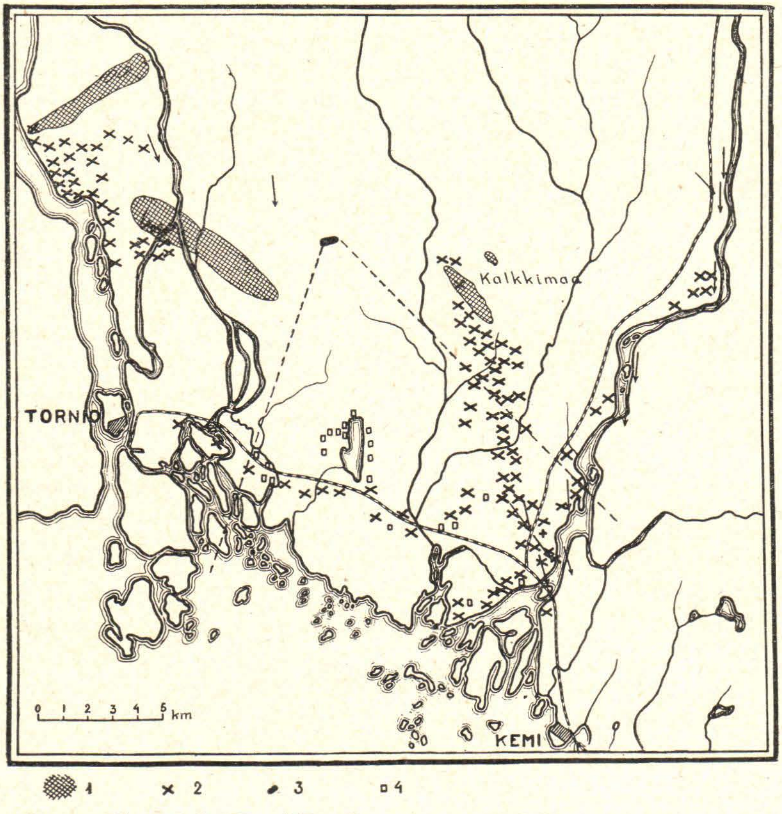

Fig. 10. Map of the Kemi-Tornio region. 1 = dolomite in place; 2 = boulder of dolomite; 3 = andalusite rock in place; 4 = andalusite rock as boulder. Arrows represent the striae, and the dotted lines, the borders of the train of andalusite rock.

Another peculiar rock, namely, a dark, fine phyllite containing small crystals of andalusite, was found as boulders in the same district. They are most numerous around Lake Laivajärvi. According to Hackman[1] such a characteristic rock forms the bedrock, in this region,

[1] V. Hackman, Geologisk öfversiktskarta öfver Finland, sektionerna C6 Rovaniemi, B5 Torneå och C6 Öfver-Torneå. 1918, p. 14.

only near Lake Hammasjärvi, north of the area of the distribution of boulders. It is, however, possible that the occurrence is larger than the known exposure. This is suggested by the wide spreading-angle of the boulders. — The striae observed in this region indicate an ice movement largely from the north, but in places also from the northwest.

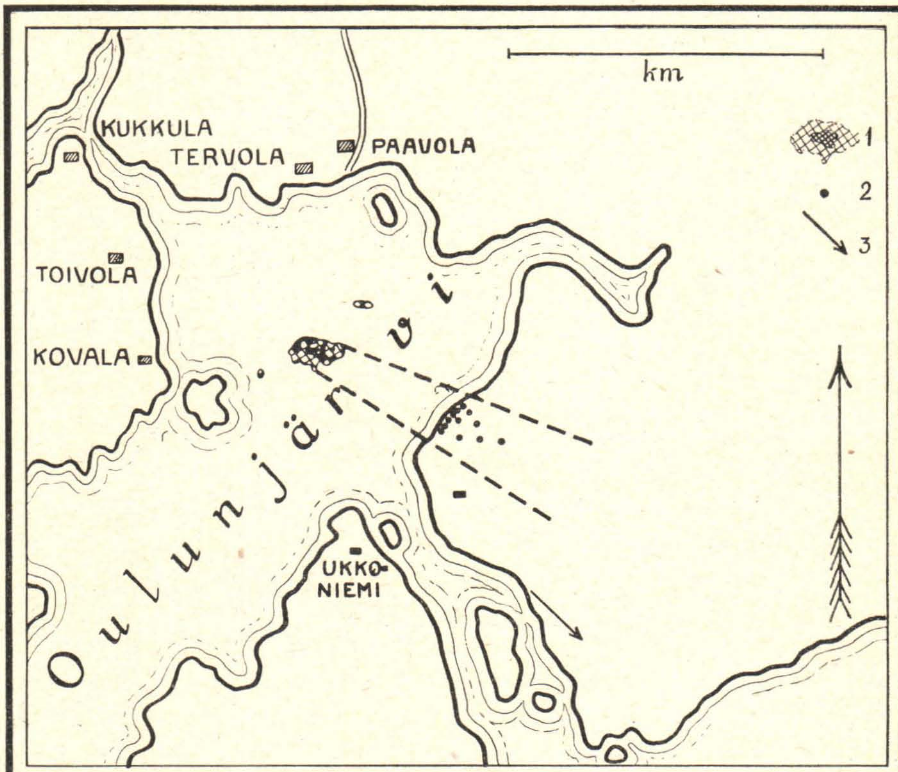

Fig. 11. Map of the Melalahti tract. 1 = area of magnetic deviation, the probable source of the boulders; 2 = ore boulder; 3 = striae. The dotted lines indicate the borders of the boulder train.

THE COPPER ORE OF MELALAHTI.

During prospecting work in 1918 Dr. Eskola found a great number of boulders containing pyrrhotite-chalcopyrite ore on the south shore of Melalahti bay in Lake Oulujärvi, in the parish of Paltamo. See the map, fig. 11.

Steep rocks of quartzite rise abruptly from the lake, and only small portions of the shore are covered with glacial drift. In one of these drift-covered parts of the shore, extending for 60 metres, nearly half the pebbles consist of ore which is a brecciated mixture of sulphides and quartzite and phyllite. Among them are at least 20 big boulders, some of which measure as much as one square metre in exposed surface. Outside this shore strip no ore boulders were found in the nearest drift banks, at a distance of a few tens of metres. The area to the southeast, in the direction of the striae, is rocky and wooded, and therefore inconvenient for the search for boulders; nevertheless, seven big ore boulders in all were found there by patient search. In the drift at the southeast shore of the peninsula where the locality is situated no ore boulders could be found, while a few boulders consist of rocks that are presumably connected with the ore.

The mode of occurrence and the great frequence of the ore boulders within a narrow train indicated clearly that their source was to be looked for close by, especially as no similar ore boulders were found northwest of Melalahti bay. The geological structure of the neighbouring tract was in favour of the supposition that the ore in place was lying at the floor of the bay. As the ore is rich in pyrrhotite, and considerably magnetic, it was thought possible that it might reveal itself by a magnetometric survey. In fact, preliminary trials made by boat gave a positive indication. A more exact survey was carried out in the following winter on the ice.[1] Magnetic attraction was found within a well-defined area in the midst of the bay where the depth of water is 12 metres. There is little doubt that the source of the ore boulders in question lies here.

SOME BOULDERS OF UNKNOWN DERIVATION.

In addition to these examples of boulders of known derivation, some attention may be paid to a few cases in which the sources have not yet been found.[2] Some ore boulders in the Orijärvi region have been mentioned above. Another case is represented by a gold-bearing dolomite boulder found near Kemi (pag. 22). It consists of vein dolomite, and not of the common dolomite rock. Very probably this boulder has not been derived from the large dolomite deposits of the

[1] Suomen Geologinen Komissioni, vuosikertomus 1918. — Geologiska Komissionen i Finland, årsberättelse 1918.

[2] Suomen Geologinen Komissioni, vuosikertomus 1919—1922. — Geologiska Komissionen i Finland, årsberättelse 1919—1922.

neighbourhood, but from some small dolomite vein, such as are common in large parts of Lapland. The boulder in question, moreover, does not necessarily belong to a primary drift deposit, but may have been transported by other agencies, as by floating ice on the Kemi river or by sea ice in earlier times when this region lay at a lower level.

A boulder of copper ore (quartz-pyrite-chalcopyrite), found in 1919 in the village of Selkie, parish of Kontiolahti, 25 kilometres east of the town of Joensuu in Karelia, deserves special mention. The Geological Commission has during several years devoted much labour to the endeavour to trace its source. The tracts near the boulder and also those farther away, in northwesterly and northnorthwesterly direction, have been surveyed geologically, magnetometrically and electrometrically, but the mother rock has not been revealed, though the search has led to the discovery of some other ore boulders by Dr. H. Väyrynen and others, and in 1923 another copper ore boulder was found near the first boulder. It has not even been ascertained, whether this lack of success is due to the beds of drift which hide the bedrock widely in the areas near the boulder locality, or to its far-distant and so far unknown derivation. At all events the search will still be continued.

STRIAE AS INDICATORS OF THE ICE MOVEMENT.

The direction of the movement of the Quaternary land ice is, in any tract, shown by the striae and by the dispersion of boulders. These distinctive marks, in general, indicate the same direction, but many deviations from this regularity appear. As an example may be cited the fact that most of the striae near Kivisalmi point not in the direction of Outokumpu but more westward. It is therefore an interesting question, how the relationship between the striae and boulder fans is to be understood.

For the discussion of this question the Tampere—Ikaalinen district in western Finland is very suitable, as it displays splendidly developed glacial formations. It exhibits more divergent striae than any other part of Finland, and the annual positions of the receding ice edge have been studied by the writer by means of the varve sediments.[1] The map in fig. 12 shows this area, with several ice border lines. These are but roughly parallel to each other; in detail there

[1] Matti Sauramo, Studies on the Quaternary Varve Sediments in Southern Finland. Bull. de la Comm. Géol. de Finlande N:o 60, and Fennia 44, N:o 1, 1923.

appear numerous incongruences. The ice cover, as a rule, extended farther upon high ground, or in shallow water, than in lower places, or in deeper water. This means that the sea bounding the ice sheet has here been the controlling factor determining the course of the ice border. In other words, the land ice has calved, and the breaking away of ice has been more intense in deeper than in shallower water.

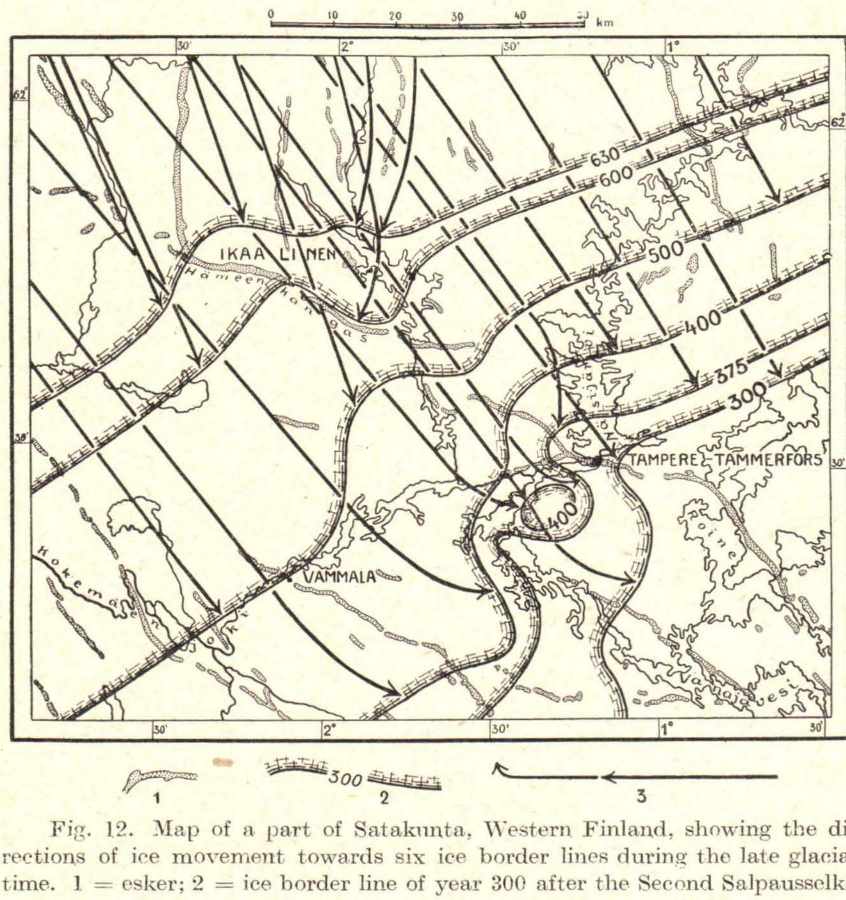

Fig. 12. Map of a part of Satakunta, Western Finland, showing the directions of ice movement towards six ice border lines during the late glacial time. 1 = esker; 2 = ice border line of year 300 after the Second Salpausselkä stage; 3 = the direction of movement at the edge (point of arrow near the ice border line), and behind the front (tails of arrows).

Furthermore, the active movement of the thin ice near its outer margin was also dependent upon the relief. The existence of basins under the land ice and their position, whether parallel or transverse to the approaching ice border, apparently influenced the ice supply and the velocity of the ice masses moving toward the front. This flow always turned nearly at right angles to the edge, thus converging in the ice bays and diverging in the ice capes. This statement is not a mere theoretical conslusion, but a fact, as indicated by striae in every case where the varve sediments witness to curves in the ice border lines.

As the ice border receding from year to year met with land areas of different relief, the direction of the flow of ice was always adjusting itself to the local topography. Now most of the striae have been carved, in each locality, at this last stage of movement. The main ice dispersion, again, or the flow of the thicker ice sheet farther behind the front, has in this region moved all the time toward the southeast, at right angles to the general course of the ice border line, and it was independent of the small details of the relief. Striae belonging to those earlier stages have been preserved at a few localities only, as most of them were obliterated by the carving of ice at the later stages. This earlier or general direction may, however, be recognized still more exactly by the distribution of glacial boulders derived from definite, known sources.

The map gives an exact account of the directions of the ice movement toward the six border lines, years 300, 375, 400, 500, 600, and 630 after the end of the Second Salpausselkä stage. In the last-mentioned year, 630, when the ice border, which at that time trended chiefly east and west, was situated north of Lake Kyrösjärvi, the general flow was toward the south. The marginal part, adjusting itself to the small features of relief, moved toward the south and southwest, as indicated by the youngest striae observed along the ice border line in question. These directions have, however, prevailed for a short time only. This may be recognized from the fact that there are well-developed roches moutonnées and older striae formed by an ice flow which passed over these places from the northwest toward the border lines of year 600 and 500. The direction of the movement near the outer margin was meanwhile repeatedly changed according to the local topographical features, as seen from the map. But still earlier, in the years 400, 375, and 300, these areas were covered with a thicker ice sheet moving in a general southeasterly direction. Striae showing this are to be found only in protected places, where they have escaped the carving and smoothing work of the next following younger ice-flow. The direction in question is, moreover, indicated by the distribution of glacial boulders. Near Tampere, for instance, more than 90 per cent of the boulders are derived from the north-west. And it is a striking fact that no boulders of the Jotnian sandstone or diabase occurring in place in the region west and southwest of Tampere were found here, in spite of striae pointing in these directions.

In those tracts where the ice sheet ended on dry land the course of its border was dependent on the supply only. The ice sent out protruding tongues and lobes in the valleys, while on higher ground it extended less far. Otherwise the movement at the edge and behind the front of the ice, as also the distinctive marks left by it, were quite analogous to those of ice that ended in the sea.

Thus, the striae, in each larger area, are of varied age and do not indicate the direction of a contemporaneous movement of an ice sheet covering the whole area. As a rule, they show only the youngest directions at the ice margin during its recession in each locality. The direction of the main ice dispersion can only be inferred from the distribution of glacial boulders of known provenance. This is a well-known circumstance, but in view of its importance for the ploblem of tracing glacial boulders, it deserves special attention here. (See map fig. 1).

FORMATION OF THE BOULDER TRAINS.

At its greatest extension, the ice sheet of northwestern Europe spread from the gathering ground in Scandinavia and Lapland radially toward the distant ice border. At that time the central part of glaciation, including Finland, represents the area of glacial erosion. The ice sheet incorporated in its lower part much of the loose rock debris, picked out masses of solid rock over which it passed and carried them away. From each source the material has been transported in fairly straight trains toward the periphery, where deposition took place. Here the Fennoscandian boulders mingled with other drift material were spread over broader areas, and thus indicate the distinct ice flows which have existed in each locality during these periods. Concerning the distribution of certain indicator-boulders, it is only necessary to refer to studies by De Geer[1], Milthers[2], Hausen,[3] and Ramsay[4].

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[1] G. de Geer, Några ord om bergarterna på Åland och flyttblocken derifrån. Geol. Fören. Förhandl. 1881.

[2] V. Milthers, Scandinavian Indicator-Boulders in the Quaternary deposits. Danmarks Geol. Undersögelse, Raekke II N:o 23, 1909.

[2] H. Hausen, Über die Entwicklung der Oberflächenformen in den Russischen Ostseeländern und angrenzenden Gouvernements in der Quartärzeit. Fennia 34, N:o 3, 1913.

[4] W. Ramsay, Über die Verbreitung von Nephelinsyenitgeschieben und die Ausbreitung des nordeuropeischen Inlandeises im nördlichen Russland. Fennia 33, N:o 1, 1912.

The studies of Tanner[1] are, in view of our purpose, worthy of special mention.

In Finland only the lowest, very tough, hard-packed part of the ground moraine can be referred to the earlier stage of the last glaciation, i. e. it has been deposited beneath the ice while this still covered the whole region. The deposition of the greatest part of the drift sheet has apparently taken place during the late glacial time at the edge of the ice, as it was successively receding. The composition of the drift is largely determined by the nature of the bedrock upon and near which it lies. In the areas underlain by crystalline rocks, which are most usual almost all over the country, the drift contains great quantities of coarse material, gravel, pebbles, and boulders, mainly because the finer-grained materials at the surface have been washed away. The greater part of the boulders, as a rule, is of local derivation. They have apparently been transported to their respective localities with the last flow of the marginal ice which, as set forth above, adjusted itself to the local relief. The boulder fan close to its source is therefore always parallel to the youngest striae. This is exemplified by boulder fans of small length, such as those of Lappajärvi, Melalahti, Karstula, Orijärvi, and also by more extensive fans near their sources. When the direction of ice movement upon level ground has remained almost constant, the borders of fans become almost parallel to each other. See for example the train of iron ore boulders at Orijärvi, page 21. If, however, the direction has changed during the recession of the ice border, in consequence of the relief, the angle of spread has become greater, as in case of Jalonvaara and Kemi.

There occur among material of local origin also boulders of more or less distant derivation. Most of them have been transported, in the latest part of their course, in the marginal part of the ice sheet, and therefore parallel to the striae near them. During the earlier part of their journey, however, far behind the front, they have moved along the straight train with the main ice dispersion. As the ice sheet successively melted away, all material plucked by it from a definite point was left on an elongated but gradually broadening belt, or fan-shaped area, whose apex lies at that point. Thus, the long boulder fans in fact indicate, on the whole, the direction of the general ice movement. This direction may, in places, be almost parallel to the

[1] V. Tanner, Studier öfver kvartärsystemet i Fennoskandias nordliga delar, III, Om landisens rörelser och afsmältning i finska Lappland och angränsande trakter. Bull. de la Comm. Géol. de Finlande N:o 38, pp. 12—54, 1915.

striae within the fan in question, as shown, for example, from the distribution of the dacite boulders at Jänisjärvi. The ore boulder from Kivisalmi represents a case of a different nature. Its position, some metres below the surface of the ground moraine, suggests that it has been deposited beneath the ice sheet, while this still stretched farther to the southwest. Its track from Outokumpu is exactly parallel to the general direction of the main ice dispersion indicated by other boulder fans and also distinct glacial marks. The striae crossing this older direction in many places in eastern Finland inside the Salpausselkä moraines show only the radiating ice flow at the edge.

A quite analogous case occurs in the distribution of certain boulders from the iron ore field of Kiirunavaara in Sweden. According to Geijer,[1] boulders of that ore and other related rocks have been found at Äijärova, Mertainen, and Svappavaara, at a distance of 40 to 50 kilometres southeast of their source. Boulders from Mertainen, again, have been carried forward in the same direction, to Svappavaara. Apparently this boulder dispersion has been parallel to the older, general ice movement, which has been later crossed by the younger ice flow indicated by most of the striae observed in that region.

In southern and southeastern Finland the long boulder trains, as mentioned above, are parallel to each other. The departure of the fan of Jalonvaara (see map pag. 15) from this parallelism makes no exception to the general rule. Here the distribution of boulders is only known close to their source, and their spreading has taken place, in consequence of the local relief, in an easterly direction. The extension of this fan farther away, if looked for, would probably be found in the southeast and not in the east, in the direction of the striae. Thus the boulder in the upper part of the ground moraine would be distributed on an area which has, near the source, a bend toward the east and then a straight southeasterly elongation.

The different materials of the drift deposit are not always so perfectly mixed with each other. It may sometimes consist of several layers, each of which has been derived chiefly from a definite source, as is seen from Eskola's account of the Pitkäranta district. It is a striking fact that these layers have the same sequence from the bottom upward as their respective sources, or rocks in place, going against the movement of the land ice. Thus the stratification of this deposit resembles, in some degree, the overlapping structure characteristic of the varve sediments.

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[1] Per Geijer, Bidrag till frågan om blocktransportriktningarna inom Jukkasjärvi malmtrakt. Sveriges Geol. Unders. Ser. C. N:o 282, 1917.

It has been observed in many tracts that there are, within trains of certain boulders of distant derivation, portions where the frequence of the boulders is exceptionally great compared to other surrounding parts. Hence such drift deposits may be comparable and, in some degree, related to the esker gravels, characterized even by materials of distant source.

HOW TO TRACE A GLACIAL BOULDER.

When a glacial boulder is to be traced back to its source, the first question of importance is, whether the boulder is (1) of local, or (2) of distant derivation. To solve this first problem several points must be taken into consideration, first of all the frequency of the boulders. Not only those of exactly the same rock as that in question should be looked for but also others related to it and therefore probably of a common source. Many ores, especially, are known to occur in connection with certain characteristic rocks, as skarn, cordierite-antophyllite rocks, or certain »ore quartzites». Further, the products of ore decomposition, as gossan in the case of sulphide ore, are also to be considered. If boulders and related rocks are found abundantly, the source of them is, as a rule, not far off, in a direction indicated by the striae. The boulders are then to be precisely located on the map and the apex of the fan thus defined. The source then lies within a limited area, and may eventually either be found directly, if it happens to be exposed, or otherwise disclosed by magnetometric or electric prospecting, excavations or diamond drilling. This is exemplified by the cases of Jänisjärvi, Karhunsaari, Melalahti, and Jalonvaara.

Though a great frequency of boulders, as a rule, means nearness of the source, their scarcity does not, however, always imply a distant derivation. Around the great pyrite field of Otravaara, for example, but a few big boulders of ore and a few more of gossan were found. All these lay quite close to their sources. The same is apparently the case in the distribution of boulders from the Orijärvi field, as appears from Eskola's account.

If the boulders are but few and their source is not found near them, there remains only the possibility that they have been derived from a distant source. Its tracing may then be subject to more difficulty. The striae are in that case of little value. They and the local physiography, as it was during late glacial time, may only aid the reconstruction of the ice flows at the edge of the ancient land ice with which the boulder in question has been transported on the short, latest part of its track. And this, moreover, only if the boulder belongs to the younger, upper part of the drift deposit. The source lies, as experience has shown, in a direction parallel to the general ice movement at the time when the boulder was carried, and this can be deduced only from the distribution of other boulders of distant, known provenance in the same region. Going thus against the main ice dispersion, the distribution of the rock in question as boulders must continuously be considered for further location of its source. Special attention must be directed to those regions where rocks related to the boulder which is the subject of the search occur in place. A succesful tracing of a boulder therefore implies reliable geological maps and an accurate knowledge of the existing rocks. In their absence a hunt for the source is merely a matter of hazard. Without previous detailed surveying of the general geology of eastern Finland the famous discovery of the Outokumpu ore field would very probably never have been made.

There are in the distribution of the boulders several points which render one cautious in the tracing of sources. Some observations by Eskola support the theoretically very probable assumption that a big boulder embedded in the moving land ice might have been broken up into smaller pieces, as a flying shrapnel that explodes in its trajectory. The fan of these »secondary» boulders left in the drift deposit does not indicate the true points of their source.

It may be recalled that the esker material frequently met with in prospecting differs from the drift in its relation to their respective sources in the bedrock, being almost entirely composed of material of far-distant derivation. The well developed boulder fan of Outokumpu, for instance, disappears totally toward the south, where it meets with the great esker of Jaamankangas. In the materials of the esker and sand plain near the Pitkäranta ore field no boulders of ore or related rocks were found. Most of them are of far-distant derivation, as seen from Eskola's account, pag. 20. Experience has shown that the esker gravels and sands are of very little value in tracing the source of blocks.

In searching for the source of glacial boulders in areas which became covered by the sea when the ice sheet disappeared, the possibility must be taken into account that erratic boulders lying on the earth's surface may have been transported by floating icebergs. The direction of this movement is in that case quite independent of the movements of the land ice, and may be variable. Generally the icebergs in southern Finland seem have moved toward the west and southwest. In Uusimaa (Nyland) for instance, the rapakivi which forms a wide area in the eastern part of this province may be found very commonly as boulders in western Uusimaa outside of the Salpausselkä moraines. In eastern Finland no positive facts concerning the transport of boulders by floating ice are so far known, but it is not impossible that e. g. the Selkie boulders which were found on the surface may have been forwarded in this manner during part of their course.

As far as may be concluded from the material collected, no definite relation can be recognized between the frequency of the boulders found and the dimensions of their source in the bedrock. The pyrite ore of Jalonvaara, for instance, is perhaps not greater than that of Otravaara, where, however, but a few boulders were found. This may be accounted for by several circumstances. In the first place, the amount of material picked of by the ice is dependent upon the outcropping area of the rock in place. The frequency or sparsity of boulders, therefore, is not always proportional to the size of the source. In the case of Otravaara the sparsity may, perhaps, be explained by assuming such deep-reaching preglacial decomposition of the ore that the glacial erosion did not reach the surface of the unweathered rock. This assumption is supported by the fact that there have been found many boulders of gossan that appear to have been worked out of a larger (preglacial) body of gossan, rather than to have originated by decomposition in separate boulders, after the ice-age. Boulders of such preglacial gossan have been found in other tracts also. — The possibility of preglacial weathering to so great a depth that its products may have protected the fresh ore from detraction by the land ice would lessen the chances of pospecting by means of glacial boulders.

Furthermore, the frequency of boulders is also dependent upon the nature of the rock in question. Most of the crystalline rocks might, of course, have resisted the glacial erosion and postglacial weathering better than other softer rocks. Boulders of ores are especially liable to be destroyed by decomposition. It is, however, surprising how well the sulphide boulders of, for example, Jalonvaara, Karhunsaari, and Melalahti have escaped weathering all through the 10,000 years that have elapsed since the disappearance of the ice sheet from southern Finland.

In connection with the discussion of methods of prospecting based upon glacial boulders, attention may be also directed to the following practical point. Most of the ore boulders that have given rise to discoveries of important ore deposits have been first found by chance, by farmers and other working men not employed in prospecting or geological surveying. It is a matter of course that this should be so. A few geologists have less chance of meeting with boulders than a large number of persons throughout the country who deal with rocks and soils in their daily work. It would seem probable that much greater numbers of such indicator boulders of use in prospecting might be noted, if knowledge of rocks and minerals were more common among the people. To this end, the Geological Commission of Finland has published and distributed popular articles and pamphlets and sends small collections of rocks and minerals to primary schools and technical colleges. For identification of boulders containing ores, the persons finding them are referred to the Geological Commission or to private enterprisers engaged in prospecting or exploitation of the mineral resources of the country.

N:o 22. Granitporphyr von Östersundom, von L. H. Borgström. Mit 3 Figuren im Text und einer Tafel. Juni 1907 .... 6: —

N:o 23. Om granit och gneis, deras uppkomst, uppträdande och utbredning inom urberget i Fennoskandia, af J. J. Sederholm. Med 8 taflor, en planteckning, en geologisk öfversiktskarta öfver Fennoskandia och 11 figurer i texten. English Summary of the Contents: On Granite and Gneiss, their Origin, Relations and Occurrence in the Pre-Cambrian Complex of Fenno-Scandia. With 8 plates, a coloured plan, a geological sketch-map of Fenno-Scandia and 11 figures. Juli 1907 .... 16: —

N:o 24. Les roches préquaternaires de la Fenno-Scandia, par J. J. Sederholm. Avec 20 figures dans le texte et une carte. Juillet 1910 .... 7: —

N:o 25. Über eine Gangformation von fossilienführendem Sandstein auf der Halbinsel Långbergsöda-Öjen im Kirchspiel Saltvik, Åland-Inseln, von V. Tanner. Mit 2 Tafeln und 5 Fig. im Text. Mai 1911 .... 5: —

N:o 26. Bestimmung der Alkalien in Silikaten durch Aufschliessen mittelst Chlorkalzium, von Eero Mäkinen. Mai 1911 .... 4: —

N:o 27. Esquisse hypsométrique de la Finlande, par J. J. Sederholm. Avec une carte et 5 figures dans le texte. Juillet 1911 .... 6: —

N:o 28. Les roches préquaternaires de la Finlande, par J. J. Sederholm. Avec une carte. Juillet 1911 .... 6: —

N:o 29. Les dépôts quaternaires de la Finlande, par J. J. Sederholm. Avec une carte et 5 figures dansle texte. Juillet 1911 .... 6: —

N:o 30. Sur la géologie quaternaire et la géomorphologie de la Fenno-Scandia, par J. J. Sederholm. Avec 13 figures dans le texte et 6 cartes. Juillet 1911 .... 10: —

N:o 31. Undersökning af porfyrblock från sydvästra Finlands glaciala aflagringar, af H. Hausen. Mit deutschem Referat. Mars 1912 .... 6: —

N:o 32. Studier öfver de sydfinska ledblockens spridning i Ryssland, jämte en öfversikt af is-recessionens förlopp i Ostbaltikum. Preliminärt meddelande med tvenne kartor, af H. Hausen. Mit deutschem Referat. Mars 1912 .... 5: —

N:o 33. Kvartära nivåförändringar i östra Finland, af W. W. Wilkman. Med 9 figurer i texten. Deutsches Referat. April 1912 .... 6: —

N:o 34. Der Meteorit von St. Michel, von L. H. Borgström. Mit 3 Tafeln und 1 Fig. im Text. August 1912 .... 9: —

N:o 35. Die Granitpegmatite von Tammela in Finnland, von Eero Mäkinen. Mit 23 Figuren und 13 Tabellen im Text. Januar 1913 .... 10: —

N:o 36. On Phenomena of Solution in Finnish Limestones and on Sandstone filling Cavities, by Pentti Eskola. With 15 figures in the text. February 1913 .... 7: —

N:o 37. Weitere Mitteilungen über Bruchspalten mit besonderer Beziehung zur Geomorphologie von Fennoskandia, von J. J. Sederholm. Mit einer Tafel und 27 Figuren im Text. Juni 1913 .... 9:

N:o 38. Studier öfver Kvartärsystemet i Fennoskandias nordliga delar. III. Om landisens rörelser och afsmältning i finska Lappland och angränsande trakter, af V. Tanner. Med 139 figurer i texten och 16 taflor. Résumé en français: Études sur le système quaternaire dans les parties septentrionales de la Fennoscandia. III. Sur la progression et le cours de la récession du glacier continental dans la Laponie finlandaise et les régions environnantes. Oktober 1915 .... 50:

N:o 39. Der gemischte Gang von Tuutijärvi im nördlichen Finland, von Victor Hackman. Mit 4 Tabellen und 9 Figuren im Text. Mai 1914 .... 6: —

N:o 40. On the Petrology of the Orijärvi region in Southwestern Finland, by Pentti Eskola. With 55 figures in the text, 27 figures on 7 plates and 2 coloured maps. October 1914 .... 26: —

N:o 41. Die Skapolithlagerstätte von Laurinkari, von L. H. Borgström. Mit 7 Figuren im Text. August 1914 .... 5: —

N:o 42. Über Camptonitgänge im mittleren Finnland, von Victor Hackman. Mit 3 Figuren im Text. Aug. 1914 .... 5: —

N:o 43. Kaleviska bottenbildningar vid Mölönjärvi, af W. W. Wilkman. Med 11 figurer i texten. Résumé en français. Januari 1915 .... 6: —

N:o 44. Om sambandet mellan kemisk och mineralogisk sammansättning hos Orijärvitraktens metamorfa bergarter, af Pentti Eskola. Med 4 figurer i texten. With an English Summary of the Contents. Maj 1915 .... 12: —

N:o 45. Die geographische Entwicklung des Ladogasees in postglazialer Zeit und ihre Beziehung zur steinzeitlichen Besiedelung, von Julius Ailio. Mit 2 Karten und 51 Abbildungen. Dezember 1915 .... 15: —