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1. PREFACE

At several places in Fennoscandia among the Archean supracrustal rocks there are dark, often black schists usually containing abundant sulphides and graphite. These schists are well known in all Fennoscandian countries. They are sedimentogenous, but often also contain much volcanic material. As they are strongly schistose and contain abundant sulphides and often also graphite, they are readily weathered, and due to weathering outcrops of these black schists are not very common. Judging, however, from the fact, that among the rusty boulders sent by people as »ore-bearing» to the Geological Survey, very many belong just to these black schists, or sulphide-schists, as they will be named in the present paper, they must be widely distributed thoroughout the Archean area.

The sulphide-schists usually contain large amounts of pyrrhotite, and often also valuable sulphides. This fact has made these schists well known among ore prospectors.

They cause also strong anomalies when using magnetic and electrical prospecting methods. Therefore the sulphide-schists have been well investigated in Sweden and in Norway in the efforts to find true ores perhaps connected with them (Boliden in Sweden may be mentioned, where valuable ores have been found in the vicinity of sulphide-schists).

In the present paper some sulphide-bearing schists of Finland and especially their sulphides will be described. This investigation was carried out predominantly by microscopic study of the ore minerals. Naturally no theoretical conclusions concerning the connections between the sulphide-schists and true ores can be drawn here. In the discussion, however, some new opinions will be presented, based on observations in the field and under the microscope.

2. THE SULPHIDE-BEARING SCHISTS

The name sulphide-schists will be used in the present paper for black, fine-grained, schistose, sedimentary rocks consisting of argillaceous and/or volcanic material and containing sulphides, predominantly pyrrhotite. Often they are also graphite-bearing or contain carbon not yet altered into graphite.

In Finland such sulphide-bearing schists have been previously described by several authors. Usually they are called simply »black schists». Saksela (1933, p. 18) has described such rocks from Keski-Pohjanmaa and discussed also the mineralassociations in the »black schists». As they are often penetrated by pegmatitic and granitic material, and then resemble the gneissose rocks, the name »sulphide-bearing mica

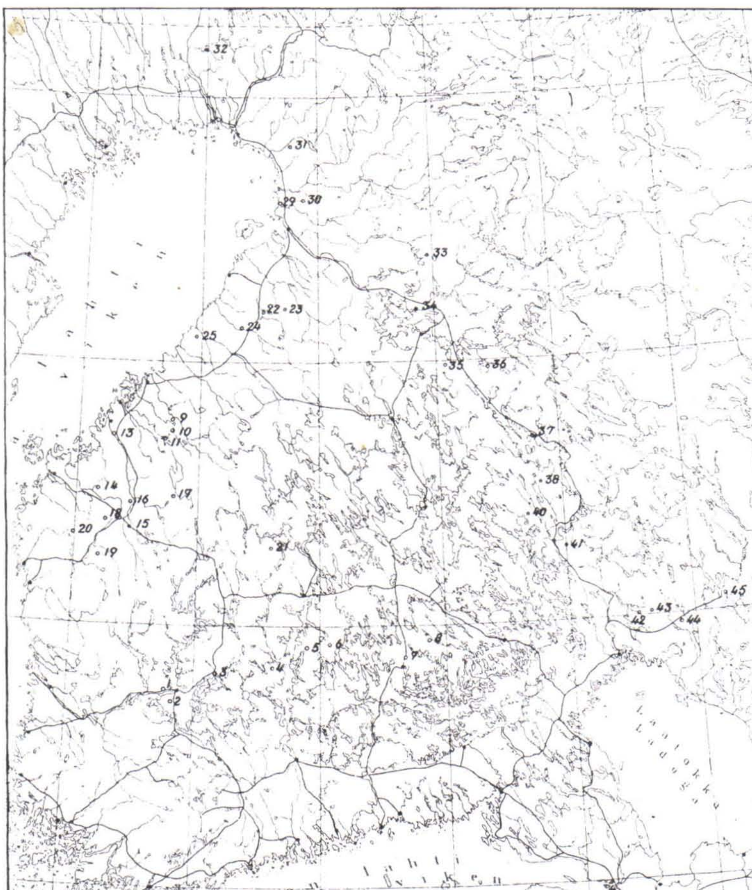

Fig. 1. Location of the sulphide-schists, considered in the present paper. 1—8 belong to svecofennidic area in Southern Finland. 9—21 to Etelä-Pohjanmaa, 22—25 to Keski-Pohjanmaa an 29—45 to the Karelidic zone.

gneiss» has also been used (Wilkman, 1931). In Sweden the common name »black schists» (svarta skiffrar) is used. Also in Norway similar schists (but much of younger age) connected with ores are widely distributed, and called there »bituminous phyllites» (Skordal, 1948).

The distribution of the sulphide-schists, considered in our investigation, is seen on figure 1.

These schists are usually impregnated by sulphides, which also occur as veins cutting the schistosity of the schists. The primary material of the sulphide-schists is not very easy to determine, because the schists are always strongly metamorphosed. Probably this primary material has been very heterogenous, and while skarn is commonly associated with the sulphide-schists, and especially in such cases where ore-minerals are more abundant, one can imagine that pyritization has been strongest when the PT-conditions were suitable for the formation of skarn.

Usually such black schists are supposed to be graphite-bearing. In the samples we examined, graphite is common, but not present in all occurrences. Further it may be mentioned, that wherever sulphide-schists occur, then common slates will also always be met in vicinity. Here and there the sulphide-schists are cut by younger rocks. Basic veins are then common, as in case at Nokia (p. 8), where the cutting veins consist of actinolite-bearing rock. There are cases, where the sulphide-schists have become migmatitized, resulting in a sulphide-bearing mica gneiss, still containing beds or only remainders of true sulphide-schists.

3. MICROSCOPIC STUDIES OF ORE MINERALS IN THE SULPHIDE-SCHISTS

a) *Some sulphide-schists of the Svecofennidic area in Southern Finland.*

N o k i a, near the town of Tampere (1 in Fig. 1). The schists of the Tampere area were previously described in detail by Sederholm (1929). In southern part of this area, on both sides of the river Nokia, are dark coloured schists belonging to the same formation. They occur between granitic and granodioritic rocks.

The schists of Nokia are predominantly phyllites containing quartz, mica and a little plagioclase. Near the river, however, there are schists evidently of volcanic origin, including also thin beds of true agglomerate (Fig. 2). These schists are sulphide-bearing and cut by several veins of actinolite-rock often containing abundant calcite. The volcanic schists are very black in colour. The Nokia River has cut a deep channel across the schists making good exposures for accurate investigations. Observations made in this gorge together with magnetic anomalies (Fig. 6) have established a strong but regular folding of these schists. They are

Fig. 2. Agglomeratic structure in the suphide-schists. Nokia, Lerunvuori. Photo V. Marmo.

greatly impregnated by sulphides, and especially in such places where the folding has been strongest (compare with the connection between folding and sulphides in the Haukipudas area, p. 24). Where the strata have not been folded, the schists are lighter in colour and sulphides are often lacking. Where the actinolite-bearing lodes cut the schists, the sulphide content is increased, and the lodes themselves are also sulphide-bearing.

P y r r h o t i t e is the main sulphide in these schists. Their black colour is evidently due to the very fine, dispersed dissemination of pyrrhotite, because graphite is met only occasionally in some polished sections, as small sparse flakes, and in connection with lamellae of pyrrhotite. In most graphite-bearing parts of the schists of Nokia there is 3,8 percent carbon. The graphite occurs here also (occassionally only) together with calcite, and then coating the cracks and fissures of the rock.

The pyrrhotite in these schists has two different kinds of origin. The older primary generation is represented by small thin lamellae occurring between silicates and foliated concordant to the schistosity of the schists. This generation of pyrrhotite is met in all sulphide-bearing schists described in this paper, and will be discussed in more detail in chapter 6. The younger, second generation of pyrrhotite brecciates the silicates.

The most interesting thing about these schists, however, is that sphalerite also occurs in two generations. The earlier of these occurs together and closely connected with the primary generation of pyrrhotite. Its texture is also similar to that of pyrrhotite forming scales, which are orientated together with the lamellae of pyrrhotite. In such sphalerite its conformity with the stratification and with the pyrrhotite lamellae is evident. The authors consider it probable, that both minerals in question have a similar origin, and that they represent the oldest generation of sulphidic minerals of these schists. This sphalerite is usually very pure containing only in few cases very minute inclusions of lamellar pyrrhotite.

The younger sulphides are granular and penetrate other minerals as veins or brecciate them. Pyrite is the earliest of them and occurs in euhedral crystals, that have been corroded along their margins. It may be pointed out here, that such pyrite is not very common in the Nokia sulphide schists, but when occurring, the pyrite is cataclastic and replaced by the pyrrhotite of the second generation. In some cases a very resorbed grains of pyrite are surrounded by pyrrhotite or they are broken into small pieces, all embedded in pyrrhotite. Here one could imagine that the pyrite has altered into pyrrhotite. The main part of the pyrrhotite, however, must have been transfered into the rock after the deposition of pyrite. The alteration of pyrite into pyrrhotite from Pitkäranta and Outokumpu has previously been described as due to replacement processes by Laitakari (1931) and from the boulders of Röksä and Selkie by Marmo (1950).

Sphalerite and chalcopyrite occur together with the pyrrhotite of second generation being, however, crystallized evidently later than the pyrrhotite. The sphalerite of this second generation is granular, and contains small inclusions of pyrrhotite and chalcopyrite. There can also be two different kinds of inclusions: 1) true inclusions (usually of pyrrhotite) indicating that pyrrhotite is older than sphalerite. There are instances when the sphalerite has replaced the pyrrhotite and finally enclosed the remainders as small inclusions. 2) Small laths or grains (usually of chalcopyrite), tabular or lenticular, which have been orientated parallel to the crystallographic planes of the sphalerite. Undoubtedly such particles have originated by the ex-solution of chalcopyrite (Plate I, 1). Such chalcopyrite is also met in other sulphide-schists described in this paper, and it is also well known in sphalerite from Boliden in Sweden. Furthermore sphalerite can be replaced by the chalcopyrite along thin fissures (Plate I, 2), which do not continue into the adjacent pyrrhotite crystals. In the whole chalcopyrite occurs in very small amounts.

In one polished section a mineral has been found, which is distinctly lighter than pyrrhotite, isotropic and forms elongated, narrow grains. It occurs on the boundary between sphalerite and pyrrhotite, and the grains are corroded along their margins. On treatment with HNO_3 the mineral remained unaltered, as also by treatment with KOH and H_2O_2. This mineral was supposed to be a mineral belonging to the linneite group (Plate I, 3). Therefore a microtest for cobalt, according to Short (1940) was made: After decomposing of the mineral with 1 : 1 HNO_3

and leaching of residue with 1 : 7 HNO_3, a drop of potassium mercuric thiosyanate solution was added. A precipitate of brownish mass containing blue prisms was got. The lastmentioned prisms prove cobalt.

Due to the smallness of the grains the error in determination of mineral is easy, and then the cobaltite could be in question. Therefore also a microtest for arsenic, using ammonium molybdate, was made, but no yellow crystals occurred, and the arsenic is consequently absent.

The latest event among the sulphides of the sulphide-schists in question is the decomposition of pyrrhotite and alteration into fine-grained pyrite (consequently there are also two generations of pyrite). This alteration is visible in Plate I, 4, where we can see pyrite crystal surrounded by pyrrhotite, being itself surrounded by a rim consisting of fine-grained pyrite of a younger generation. The marcasite occurs only in »bird's eyes» and then together with the fine-grained pyrite of younger generation.

Consequently the sulphides of the sulphide-bearing schists of Nokia can be arranged according to age, in the following manner:

1. Primary sulphides (on p. 16 they will be explained as sedimentogenous): pyrrhotite and sphalerite.

2. Pyrite of earlier generation (large, euhedral, crystals).

3. The younger generation of pyrrhotite and sphalerite, crystallization of chalcopyrite.

4. Pyrite of younger generation and (marcasite).

It seems, that the sulphides became mobilized during the folding. The pyrrhotite of younger age, together with younger sphalerite and chalcopyrite, belong to this stage of tectonic development. Therefore concentrations of these sulphides are also always connected with the points corresponding to the minimum of pressure (See curves in fig. 7), and even there also actinolite-bearing rock will occur. This rock occurs as veins, perhaps occupieing the cracks, opened during the folding of strata. Therefore these veins often penetrate the schistosity, and are usually met with, when folding have been strongest. Usually this actinolite-rock contains in abundant similar sulphides as the schist in closest vicinity of the lode. It may be pointed out, that miniature folds are in such cases very common (Plate II, 1).

The pyrite of younger generation is not very common at Nokia, and it is found especially in such rocks, which are exposed or near the surface.

On the southern shore of Lake Pyhäjärvi, not far from the church of Etelä-Pirkkala (2 in fig. 1), there are similar schists again, and obviously belonging to the area of Nokia schists. This occurrence of sulphide-schists is relatively small and entirely enclosed by gneissose granite. In all details the schists are similar to those described from Nokia. Here also the main sulphides are pyrrhotite of two generations, pyrite, chalcopyrite and sphalerite. Graphite is only met as very thin scales and in insignificant amounts, and then together with lamellar, primary pyrrhotite. Both minerals are then closely grown together, often forming mixed lamellae. The contemporaneous origin of graphite and pyrrhotite is here very probable. Also in the pyrrhotite of second generation the graphite has been met with, but then as distinct inclusions, evidently of earlier origin than the pyrrhotite.

5 km N of the church of Kuhmoinen (4 in fig. 1) boulders of true sulphide-schists are abundant. There, however the main sulphide in the boulders is pyrite. It is euhedral, but under the microscope a very slight anisotropy is seen. Pyrrhotite is met only as a few grains, which have obviously originated by the alteration of the pyrite. Small grains of magnetite are also met, but no graphite can be ascertained with certainty.

At Luhanka (5 in fig. 1) sulphide-schists are also met, but the assemblage of their sulphides differs essentially from that described above by the presence of arsenopyrite. The schists mainly consist of phyllitic material with volcanogenous intercalations. The colour is dark, but graphite is only met as small, sparse flakes.

Pyrrhotite is the principal sulphide, and it occurs, as is the case at Nokia, in two generations. Arsenopyrite is as abundant as chalcopyrite and sphalerite. The last mentioned is very pure differing from that at Nokia by the absence of pyrrhotite and chalcopyrite inclusions, which are characteristic of the sphalerite at Nokia. There are, however, also horisons containing arsenopyrite as main sulphide, and then it occurs often in compact veins.

Kivisuo in the Parish of Leivonmäki (6 in fig. 1). This occurrence of sulphide-schists has been investigated by Mr. V. Pääkkönen, Geological Surwey of Finland, who has kindly placed his investigations at our disposal to be used with our ore-microscopical observations.

The country rock of Kivisuo is a dark, stratified. comparatively basic and strongly metamorphosed schist. Here the pyrrhotite and magnetite occur in equal amounts, but each mineral in separate layers of the rock. The schists containing magnetite are phyllitic, but those containing pyrrhotite are obviously skarn-like rock perhaps corresponding to a bed of marl. Both ore minerals are fine-grained and disseminated parallel to the schistosity of the rock. Chalcopyrite occurs only in small amounts together with pyrrhotite. In the layers containing much quartz the sulphides often are lacking, but in basic ones the sulphide content is greatly increased.

Hiirola in the Parish of Mikkeli (7 in fig. 1). The country rock here is commonly mica-schist with abundant migmatitized areas. In these mica-schists there are several small occurrences of limestone, which is nearly pure calcite. The skarn occurs in connection with limestone and accompanied by sulphide-bearing mica-schists. The area is strongly folded and two strips of sulphide-bearing skarn and schists are met. Both strips run E—W, and the area between them, 2 km in width, consists of mica-gneiss containing no sulphides. The limestone is only met in connection with the southern strip, which gives much weaker magnetic anomalies than the northern one, where limestone is lacking. Both strips are bent at their western end, the southern slightly, but the northern shows a true fold. Also here, the main impregnation of sulphides is connected with the most folded part of the strips.

The limestone contains according to Laitakari (Eskola—Hackman—Laitakari—Wilkman 1919) 82.9 % $CaCO_3$ and 2.7 % $MgCO_3$. The accessory minerals are graphite, chondrodite, phlogopite and pyrrhotite. The rock adjacent to the limestone is skarn containing abundant pyrrhotite, often also graphite in abundant. A third strip of magnetic anomalies is met 1 km S of the central limestone-bearing area. There is also skarn together with sulphide-bearing mica-schists. Similar schists are also met in the railway cuttings N of the town of Mikkeli, and near the station of Hietanen, SW of Mikkeli.

These sulphide schists (and skarn) contain pyrrhotite and small amounts of sphalerite. The pyrrhotite belonging to two generations is unaltered, very pure and similarly to that of younger origin is slightly lamellar. On its margins are small grains of sphalerite, which also occur enclosed by pyrrhotite. Graphite is often met in the schists, and not seldom connected with pyrrhotite, which then represents the primary generation of the sulphides. Concerning to the occurrence of primary pyrrhotite and graphite, it may be mentioned also a small occurrence of sulphide-bearing schists at Roitto, 6 km N from Hiirola. There the rock is mica-schist containing biotite and quartz, but together with biotite the primary, lamellar pyrrhotite often occurs, and then always strongly parallel to the scales of mica and grown together with them. In same together grown lamellae there is often as third component the graphite, also parallel to biotite and pyrrhotite lamellae. Similar occurrence of pyrrhotite together with graphite and biotite has been observed in schists at Hiirola also, but not in so evident manner, as in the case of Roitto.

At Hiirola there are also rocks containing the graphite in abundant, and then not in lamellar form, but forming masses. Such kind of occurrence of the graphite, however, is connected to the skarn, and together with assumptions of Laitakari (1925), its origin is not the same as that of graphite described above.

In the Parish of J u v a (8 in fig. 1) several sulphide-bearing boulders are met, but only a few, small outcrops, and then in a very weathered condition. The gossan is not very suitable for chalcographic investigation, and therefore in the present work the polished sections have been made chiefly from boulders. Not far from the boundary between the Parishes of Juva and Virtasalmi a few boulders were found, consisting of fine-grained plagioclase-amphibole-gneiss, earlier called leptite. These boulders were collected by Mr. V. Pääkkönen (Geological Survey of Finland) and kindly placed at our disposal. The rock contains amphibole, plagioclase (20 % An), biotite, quartz, sphene, apatite and much pyrrhotite. All mafic minerals are conspiciously light in colour, the hornblende being nearly colourless ($\gamma/c = 18°$). Its optical character is negative. The biotite is pale as is also the euhedral sphene, which often has a centre of ilmenite.

In addition to the pyrrhotite, the fine-grained pyrite as an alteration product, and sphalerite are also met. Pyrrhotite brecciates the silicates. Ilmenite, surrounded by sphene, often contains very thin lamellae of ex-soluted hematite.

Another kind of boulders in the same area consist of pyroxene-bearing skarn or of true sulphide-schists. In these the pyrrhotite, belonging to second generation, is often strongly resorbed containing »bird's eyes» of fine-grained pyrite, but in the boulders consisting of schist the lamellae of pyrrhotite belonging to the primary generation are also present, together with small scales of sphalerite.

b) *Sulphide-schists of Etelä-Pohjanmaa.*

Characteristic of all sulphide-schists of this area is the high content of graphite, so that often the name graphite-schist can be used.

At Teerijärvi (9 in Fig. 1) large numbers of boulders of sulphide-schist have been found, but only very few outcrops. However, this area was accurately investigated 1936—37 and 31 drill-holes have been made. Fig. 3 presents geologic data according to Saksela (in Laitakari 1936). The main rock of the sulphide-bearing strips is mica-schist together with sericite-quartzite, all usually graphite-bearing. Intercalated in these sulphide-schists is a strip of amphibolite, also containing sulphides.

The drill cores, investigated also by the present authors often show a comparatively low pyrrhotite (and pyrite) content.

Among the loose boulders those consisting of sericite-quartzite, often graphite-bearing, predominate. In a boulder collected near Långveka lake, pyrite is the main sulphide, but is strongly resorbed and the grains are crushed. Boulders from the southern shore of the same lake also contain pyrrhotite and sphalerite, and then the pyrite is usually very fresh. The pyrrhotite usually contains small inclusions of silicate-minerals, and is often replaced along the fissures by sphalerite or chalcopyrite. Occasional »bird's eyes» of fine-grained pyrite are met. Graphite is always present.

A very peculiar occurrence of pyrite is met at Raisjoki. There the pyrite is anhedral and occurs in veinlets cutting the schistosity of the rock. The form of single grains of the pyrite in the veinlets is quite

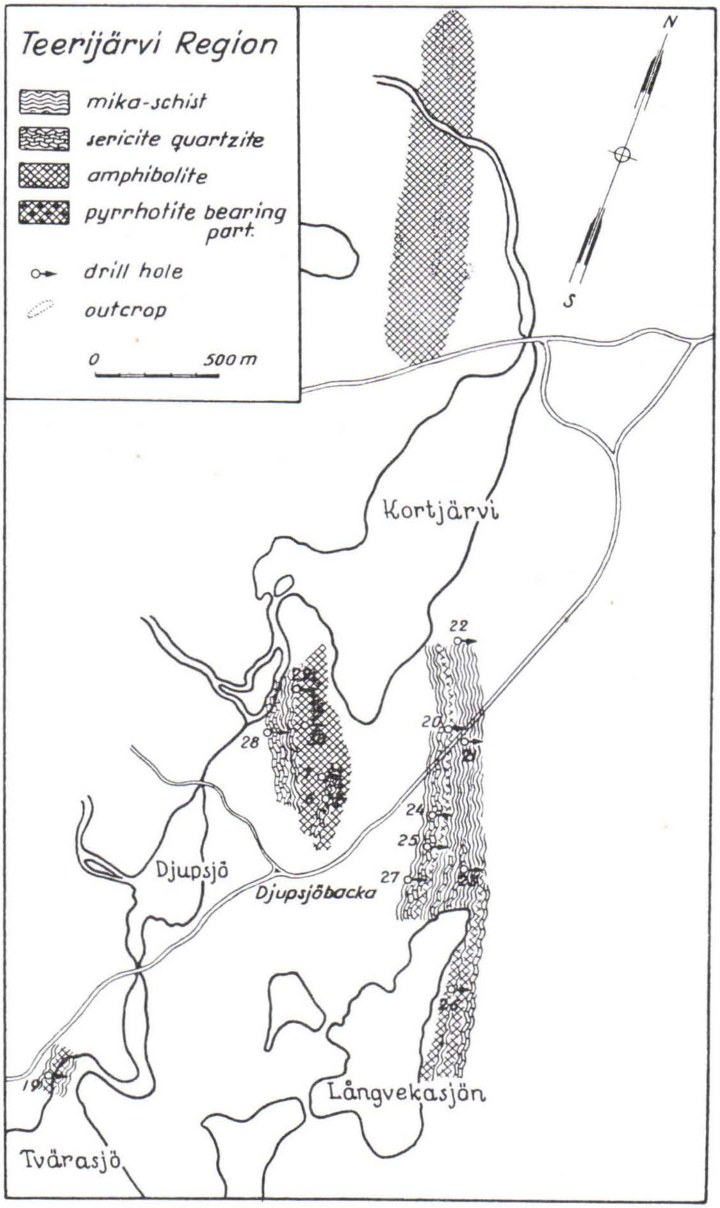

Fig. 3. Geologiceal map of the Teerijärvi Region (according to M. Saksela).

uncommon for the pyrite usually met with in the schists in question. It resambles most the form of pyrrhotite grains. Also the veinlets are acording to their form better similar to those of pyrrhotite. Therefore the pyrite in question probably has originated by the alteration of pyrrhotite (Plate II, 2). In this occurrence thin flaky graphite occupies only thin strips.

In the boulders from Nattvik in contrary the abundant pyrite is almost entirely replaced by pyrrhotite, which is often accompanied by small amounts of sphalerite. A few grains of chalcopyrite are also met.

The three drill-holes (28, 29 and 30 in fig. 3), described in following, penetrate nearly vertical schists of different kinds. In hole 28 the sericite-quartzite is intercalated with graphite schists, often containing sulphide. The main sulphide of these schists is finely impregnated and resorbed pyrite, further replaced by pyrrhotite along the fissures and margins. The later alteration of both sulphides is often accompanied by »limonite». Graphite is as abundant as pyrrhotite. In holes 29 and 30 amphibolite is met. The type of occurrence of sulphides is rather different. Pyrrhotite belonging to two generations is present. When pyrite occurs, it is surrounded or replaced by fresh pyrrhotite, which is abundant forming often a massiv ore. Often the pyrrhotite is filled by small silicate inclusions. In places sphalerite also occurs in abundance, but chalcopyrite only in few sparce grains. »Bird's eyes» containing well polishable, fine-grained pyrite are rare. It seems that together with increase of depth (in a southernly direction) the sphalerite content will be increased. Pyrite is not very abundant, when spahalerite and chalcopyrite occur. There is also a sulphide mineral, which has not been determined. It is usually enclosed by pyrrhotite, being softer than this. When its grains occur parallel to the direction of pyrrhotite-lamellae, the colour of both minerals is some what similar, that of the undetermined mineral perhaps some lighter, but when directions are perpendicular, then the pyrrhotite is lighter and the enclosed mineral becomes slightly olive-grayish (compared with colour of pyrrhotite). Between crossed nicols the unknown mineral shows a very weak anisotropy. Graphite occurs only as a few small flakes.

The pyrrhotite occurs at Teerijärvi corresponding to two different generations, but sphalerite, corresponding to the primary generation cannot be established with certainty. It seems that the sphalerite only occurs together with pyrrhotite of a second generation. When graphite occurs in abundance, the scales of this mineral are usually parallel and in connection with primary pyrrhotite, but it seems to have no genetical connection with that of second origin.

At Kaustinen (10 in fig. 1) very similar graphite-bearing sulphide-schists are met, and it seems here, that the predominant rocks are argillaceous schists intercalated with narrow volcanic layers and these contain graphite in greater abundance. The principal sulphide here is also pyrrhotite, now howewer, altered into fine-grained pyrite (and marcasite) along the margins and cracks of its crystals.

At Särkilä in the Parish of Evijärvi (11 in fig. 1) several sulphide-bearing boulders are met, but only very few exposures of the corresponding schists. One of these is at an old quarry. There the sulphide-schist contains graphite in a similar way as at Teerijärvi. Parallel to the schistosity the pyrrhotite occurs as small, thin, and well orientated scales (the primary generation). But filling the spaces between the silicates as euhedral grains it forms nearly massiv sulphide ore (later generation). Along fissures it is often altered into fine-grained pyrite and also cracks occupied by the fine-grained pyrite are often met. Chalcopyrite is found occassionally.

Not far from this quarry several boulders of strongly schistose sulphide-bearing boulders are met. In these the pyrrhotite occurs in thin lamellae exactly following the planes of schistosity. The second generation of pyrrhotite is lacking here, but contrary to observations at Teerijärvi and Kaustinen, sphalerite (obviously corresponding also to the primary generation) is met together with pyrrhotite. It occurs as lamellae parallel to those of pyrrhotite.

It is very peculiar, that even in such schistose boulders chalcopyrite, usually as thin ex-solutions in sphalerite is also present. As in most cases described above, when the pyrrhotite of primary generation occurs, it is pure, and no inclusions are met. The same trait is characteristic also of sphalerite belonging to the earlier generation. In the boulders of Särkilä however, ex-soluted chalcopyrite occurs in sphalerite, which occurs quite in similar manner as in the cases, when it have been explained to belong to the earlier generation of sulphides.

The lamellae of pyrrhotite in these boulders are always strongly corroded along their margins, but no alteration can be observed. In few boulders, however, segregations of »limonite» with a core of pyrrhotite are met, but these boulders belong perhaps to such parts of rock, where the action of surface agents have been present.

As seen from descriptions above, the pyrrhotite of primary generation usually occurs grown together with graphite, and as in the case of Roitto (p. 12), together with biotite of mica-schist. Further it occurs, as also in the case of boulders at Särkilä, as thin and very small lamellae, situated along the planes of schistosity. In the boulders of Särkilä, due to heterogenous material of the schist, also stratification of the schists can be determined, and it is parallel to the schistosity. Such the lamellae of pyrrhotite are disseminated also along the planes of stratification. It is very difficult to imagine in such cases, that the pyrrhotite would have been transfered into the schist. As difficult is to explain, why graphite and pyrrhotite will occur together, if not suppose, that both minerals in question have quite the same source — the sediment self. Such the sulphides of our primary generation will be here explained to be of sedimentogenous origin. If also sphalerite is in the same generation present, so will it only indicate, that there have been ancient, zinc-bearing rocks. later disintegrated. Similarly ex-soluted chalcopyrite in the primary sphalerite mentioned above is due to the copper-content of ancient, disintegrated rocks (p. 16).

At Oravainen (13 in fig. 1) a similar sulphide-schist occurs. It contains coarse-grained pyrrhotite surrounded and penetrated by abundant graphite-flakes. Further minute euhedral grains of chalcopyrite are disseminated evenly thorough the rock, usually enclosed by pyrrhotite. Sphalerite is lacking.

At Palonkylä in the Parish of Isokyrö (14 in fig. 1) only boulders are met. Their rock is similar to those described above, but there are other boulders consisting of skarn. The euhedral grains of pyrrhotite are disseminated abundantly thorough the rock, often penetrating other minerals cataclastically. Chalcopyrite is abundant and occurs replacing the pyrrhotite in narrow veinlets beginning from the margins of pyrrhotite crystals. Sphalerite is rare. Graphite occurs as flakes surrounding and penetrating the pyrrhotite. In the mentioned boulders the occurrence of the graphite is often very similar to that at Hiirola, when occurring in skarn (p. 12), but often it occurs also occupying in strata, very poor in sulphides.

At Autionkylä in the Parish of Nurmo (15 in fig. 1) outcrops of sulphide-schist are connected with skarn, striking E—W. All exposures are here pyrrhotite-rich. On both sides of them granodiorites occur, but only few km to the S there is a large area of pegmatites (containing graphic feldspar, quartz, biotite, tourmaline and accessory apatite, beryl, topaz). The most sulphide-bearing parts of the dark schists contain very abundant diopside, often serpentinized along the margins of euhedral crystals. Other minerals are plagioclase (50 per cent anorthite), sphene, apatite and calcite — consequently a mineralassociation characteristic of true skarn. The pyrrhotite occupies cracks and fissures in diopside or occurs as idiomorphic grains often together with graphite (Plate II, 3), and it is always very fresh. Here we have quite different kind of black schist from those described above. The megascopical features, however, are very similar. To distinguish between the phyllite and skarn in the field is difficult. Both kinds of rock are strongly schistose and black in colour, usually covered by a thick gossan. The only clear difference observable in the field is their different sulphide-content which is almost neglible in the phyllite. Sphalerite is not met with. Here we have pyrrhotite belonging to second generation only. Thus also occurrence of graphite is of another kind as that in most cases described above, but it is similar to graphite at Hiirola and at Palonkylä. Probably the graphite in these cases is not of sedimentary origin, but originated due to metasomatic processes in conditions corresponding to the origin of skarn.

Further, the occurrence of sulphides in the schists in question, predominantely connected to the skarnous rock, will indicate, that also the source of sulphides is in this case in metasomatic processes, produced the skarn.

In the Parish of Lapua (16 in fig. 1), N of the occurrence of Nurmo, sulphide-schists occur on the slopes of the hills Simsiö and Ritanmäki (Hietanen 1938). There the beds of black schists are embedded in quartzite, and they are narrow, rusty and coarse-grained, usually phyllitic. Their minerals — quartz, feldspar, mica, graphite and sulphides — are almost always strongly orientated parallel to the strike of the rock. The principal sulphide is pyrrhotite, usually surrounded by a narrow rim of fine-grained pyrite and probably of marcasite. The graphite is common and it occurs as elongated flakes and lamellae closely connected to the pyrrhotite. Here again the sphalerite occurs corresponding to two generations. The primary one occurs as lamellae together with pyrrhotite and graphite. Often there are flakes of graphite together with sphalerite enclosed by pyrrhotite of a second generation. The secondary sphalerite fills the cracks and fissures in pyrrhotite and replaces it. Chalcopyrite is rare, but the pyrite is abundant in some veins. The adjacent quartzite contains similar sulphides. It may be mentioned further, that the quartzite also contains manganese-bearing minerals, as has been described by Hietanen (1938).

At Hoisko in the Parish of Alajärvi (17 in fig. 1) the sulphide-schists consist of slightly quartzitized phyllite without any marks of skarn. The pyrrhotite is also there the main sulphide. Some of the grains of it are surrounded by fine-grained pyrite containing small »bird's eyes». It seems that these define the boundaries of the completely altered crystals of pyrite (Plate II, 4), which occurs also as fresh, unaltered grains.

At Tammelankoski in the Parish of Ylistaro (18 in fig. 1) the black sulphide-bearing schists are often cut by several pegmatitic veins containing quartz, feldspar (also plagioclase), tourmaline and/or garnet. The strike of the schists is N 70° W. Graphite is present, but not very characteristic of the schists in question. The principal sulphide is the pyrrhotite, but some veins are filled by pyrite alone. Sphalerite is scanty. Also here the presence of pyrrhotite and sphalerite belongine to the primary generation can be easily stated. There are, excepting the primary generation of sulphides, several direct similarities with the schists described from Nurmo. Also in Sotkamo (p. 29) very similar rocks are met, but there often containing shungite besides graphite and this has never been met by the present authors in the schists of Keski-Pohjanmaa.

At Toukanneva in the Parish of Kurikka (19 in fig. 1) is a small quarry of limestone (calcite with 92.6 per cent $CaCO_3$). Calcite is inbedded in sulphide-schists, and it contains small amounts of grainy pyrite, pyrrhotite, and thin scales of graphite. 1 1/2 km from the quarry there is a small outcrop of sulphide-schist. The sulphide-bearing zone has there been followed by magnetometric measuring, and it can be stated that its direction is N—S. The rock is mica-schist with quartz, mica, and oligoclase as principal minerals. Fine-grained sulphides impregnate all minerals of the schist excepting the quartz. Pyrrhotite is the main sulphide also in this case, but sphalerite and chalcopyrite occur at Toukanneva in greater abundance than in occurrences described above from the region of Etelä-Pohjanmaa. Chalcopyrite seems to replace the pyrrhotite, but the sphalerite is usually separated from it by the silicates. In the outcrop in question no traces of skarn are met, but the occurrence of calcite in neighbourhood might indicate, that the skarn is occurring. In that case the comparision with the sulphides of Nurmo can be made.

In the Parish of J u r v a (20 in fig. 1) several sulphide-bearing boulders have been found. They are originated evidently from the dark schists occurring within the Parish, but most of the boulders in question belong, however, to pyroxene-skarn. Graphite is commonly present in the skarn, and the main sulphide is pyrrhotite, sometimes forming nearly compact masses. Another kind of boulder, also pyroxene-bearing, contains only thin lamellae of pyrrhotite as described above. Sphalerite is also met. The younger generation of pyrrhotite differs here from the earlier being better polishable.

Among the grains of pyrrhotite there are few which are less pleochroic, but highly polishable (compare Schneiderhöhn—Ramdohr 1931, p. 136). The undetermined mineral described on the page 15 is also met with among the minerals of the boulders in question.

M a h l u in the Parish of S a a r i j ä r v i (21 in fig. 1). There are no outcrops of sulphide-schists, and the country rock consists of porphyritic granodiorite, so common in most places of Middle-Finland. Several kilometres N of the village of Mahlu occur volcanics described by Wilkman (1938). W from Mahlu are low-lying areas without any outcrops of rocks, but boulders gathered there are very interesting. Among them those of granodiorite are predominant, but also clastic sediments and volcanics have been found, as also several rusty boulders belonging to the sulphide-schists. The last mentioned boulders are most abundant between the farms of Junttimäki and Saari.

Very interesting are the boulders consisting of sulphide-rich, arkose-like rock (Fig. III, 3). The main mineral of such boulders is quartz, which occurs as well rounded grains embedded in a fine-grained, quartz cement containing thin scales of biotite. The larger grains of quartz are often surrounded by a rim of biotite. Further there are some granular grains of plagioclase, also usually surrounded by thin flakes of biotite, but often also by a rim of very small blebs of sphene, distinctly elongated. Remainders of pyroxene are also met with.

The sulphides occur cementiating the granular grains of quartz and plagioclase. The principal sulphide is pyrrhotite being, however, often altered into small aggregates of pyrite. Often one can see only strongly corroded and ragged remainders of pyrrhotite surrounded by a mixture of a fine-grained pyrite and marcasite and containing aggregates of small grains of the youngest pyrite (Plate III, 2). These aggregates occur usually along the boundaries of the unaltered part of pyrrhotite against their altered marginal parts. Such alteration products consisting of brownish masses together with small remainders of pyrite and pyrrhotite, containing sometimes also small particles of marcasite, are very common among the Finnish sulphides. According to Lokka (1943) these products contain always water in considerable amounts, and therefore, together with Dana and Saksela (1947) the name »Wasserkies» or »hydropyrite» (Finnish »vesikiisu») have been used.

Minute grains of sphalerite occur, and then filling the spaces between silicaceous minerals. Only in few cases the sphalerite connected with pyrrhotite has been seen. There are no inclusions in this sulphide. Few and sparse, minute scales of graphite are also met with, and then together with pyrrhotite.

Both pyrrhotite and sphalerite together with graphite seem to belong to the primary generation, but probably also pyrrhotite of second generation is present. The whole structure of the rock leaves no doubt as to its sedimentary nature. There are also the beds of tuffic materials intercalated with argellaceous ones pointing out to the volcanic activity during the sedimentation period. Chalcopyrite is not present in the boulders, which were at the disposal of the present authors.

c) *Sulphide-schists of Keski-Pohjanmaa*

These schists are intermediate between the schists containing graphite described above and the schists belonging to the Karelidic zone, which will be described later on. The schists of Keski-Pohjanmaa are always graphite-bearing, and pyrrhotite is the main sulphide in them. Often they are accompanied by skarn.

The best known occurrence of ore minerals within this area is that at Lampinsaari in the Parish of Vihanti (22 in Fig. 1). There the sulphide-schists occur adjacent to an ore deposit of economical importance, thus offerring an excellent object for accurate investigations.

During drilling of Lampinsaari in the village Alpua, a sedimentogenous series of a granitic and gneissose country rock was discovered. True clastic quartzites occur besides another kind of rock, which was, may be, primarily an acid volcanic. Further, there are slates and limestone intercalated with the quartzites and with each another. The later metamorphism has caused skarn reaction between the limestone and acid sediments. The slates are of two different kinds according to the different degree of metamorphism. One of them belongs to the true black schists, being very fine-grained and containing carbon in the form of very fine dispersed graphite. Another type is gray and medium-grained. Its texture is more gneissose, and it always contains graphite as small flakes, which are orientated parallel to the schistosity. Boulders of these schists are met together with some consisting of skarn in the village Korvenkylä too, 10 km W from Alpua, and have caused ore prospecting also in this village.

Both kinds of the schists contain sulphides in a similar manner. The true ore, however, occurs in the skarn rock, and it will not be discussed in this connection.

Pyrrhotite always occurs as a fine dissemination. Its lamellae together with flakes of graphite are parallel to the main schistosity. The grains are corroded and completely anhedral. Often they contain inclusions of graphite. As separated grains there are also small amounts of chalcopyrite. No replacing features have been observed, and both minerals seem to be of the same age corresponding the earliest sulphide generation. Sphalerite is rare.

Schist impregnated by pyrrhotite as described above has further been penetrated by sulphide veins of later generation, filling cracks and fissures of the schist. Of the younger sulphides the pyrite is predominant, being medium- or coarse-grained. These sulphide veins have also caused a slight impregnation in their immediate vicinity in the country rock. Pyrite is always more or less cataclastic, and cracks are usually filled by pyrrhotite. The replacement is here a common feature and similar to that described in another connection in this paper (i. e. Haukipudas, p. 23). Sphalerite in connection with fissures of pyrite is very abundant, and chalcopyrite, too, is more abundant in veinlets as as impregnation of the rock. Both last mentioned sulphides have crystallized later than the pyrrhotite and pyrite. Probably the origin of these veins is connected to that of the true ore, which is situating in the adjacent skarn rock. The behaviour of the sulphides in the ore body is very similar to that described above in the veins of the sulphide-schists.

The secondary alteration of pyrrhotite into fine-grained pyrite, »hydropyrite», containing also small grains of marcasite is of the main type, and will be described accurately later (Kiiminki, p. 27).

From the Parish of R a n t s i l a (23 in fig. 1) many boulders of black schists containing sulphides have been sent to the Geological Survey of Finland. The rock is medium-grained and more acid than the sulphide-schists are usually. They are owing to their chemical composition rather gneisses or leptites. Very often they contain sphene with kernel of ilmenite (p. 13). Together with them often skarn occurs containing pyroxene and plagioclase. Graphite flakes are always present.

Also in the case of Rantsila two different generations of the main sulphide, pyrrhotite, are present. The older generation occurs as a homogenous dissemination of subhedral grains orientated parallel to the schistosity, with a few euhedral grains of pyrite also. The younger generation is represented by veins cutting the schistose rock. The relation between pyrrhotite and pyrite is not clear. Both are resorbed in a similar manner, and no replacement features have been observed. Very probably they are of the same age. In the pyrrhotite of the second generation distinct lamellae have been observed. They are more distinctly anisotropic than the usual pyrrhotite in the schists in question. Further, these lamellae are softer than the main part of the grain of pyrrhotite. Owing to facts mentioned above, and also to the etching tests these lamellae are cubanite, which has been mentioned also in the sulphide occurrences in Karelia (Marmo 1950).

Further we have observed in the pyrrhotite of the boulders of Rantsila the same undetermined mineral as mentioned on p. 15. It is greenish gray-olive in colour. Its pleochroism is distinct, but it is slightly less anisotropic than the pyrrhotite, and forms anhedral, but distinct grains. Chalcopyrite and sphalerite are scanty in a true schist, but are more abundant in skarn.

The secondary alteration is characterized by rims of fine-grained pyrite with »bird,s eyes» around the grains of unaltered pyrrhotite.

At Petäjäkoski in the Parish of Oulainen (24 in fig. 1) several sulphide-bearing boulders have been collected, and also has been established a zone of magnetic anomalies 1 000 m in lenght and 300 m in width (Fig. 7). The rocks in this zone are sedimentary, the volcanics intercalating with quartzites, slates and minor limestone. The sediments have become gneissose, and their strike is NW, which is also the strike of the magnetic anomaly.

The sulphides can be studied only in few outcrops. Nearly exclusively sulphide is pyrrhotite, occurring either as a fine-grained impregnation and large subhedral grains or brecciating other minerals. Large grains are often elongated in the direction of the schistosity. The cataclastic features have been seldom observed. Only a very few euhedral grains of pyrite have been met with, being of the same age as pyrrhotite. In such parts of the schist, where the rock is poor in pyrrhotite, small corroded scales of chalcopyrite occur replacing then the pyrrhotite. Sphalerite is very rare. The alteration of pyrrhotite into fine-grained pyrite has been observed. Graphite is very common and occurs in similar way as described in Vihanti and Rantsila.

In the Parish of Kalajoki (25 in fig. 1) the bedrock, according to the descriptions of Mäkinen (1916) and Saksela (1933), is mainly granitic. Only in the coastal part of the Parish there is a small area of gneiss. Some boulders of sulphide-schist, however, have been found.

The schists of these boulders are intensely folded and partly fragmented. Their main minerals are: quartz, biotite, partly altered into chlorite, minute remnants of light-coloured amphibole, and sphene. Graphite has not been observed.

The sulphides of these boulders are pyrrhotite, chalcopyrite and in rims fine-grained pyrite and marcasite. Ilmenite occurs in abundance together with sphene. The occurrence of the pyrrhotite is quite similar to that described above. The alteration into fine-grained pyrite has occurred along the margins and cracks of the pyrrhotite. Chalcopyrite is very scanty. Sphene with a core of ilmenite is abundant, and the elongation of its grains is parallel to the schistosity. It may be pointed out, that even pyrrhotite occurs as inclusions in the sphene.

d) *Sulphide-schists of the Karelidic zone*

The characteristic feature of the sulphide-schists investigated in the Karelidic zone is their s c h u n g i t e -content. This variety of carbon occurs alone or together with graphite, and is always very finely disseminated throughout the schists.

It differs from the graphite in many properties. At first it was supposed that a variety of an ancient anthracite would be in question. Later, however, also signs of crystals in the schungite were observed. Therefore the schungite is to be explained as a variety of crystalline carbon, closely related to the graphite, but corresponding to a lower grade of metamorphism (Laitakari, 1925).

The schungite burns much easier than the graphite. Further it occurs as a fine dissemination, black in colour, and similar to that of graphite when seen in thin sections. In polished sections, however, no optical properties characteristic for the graphite are to see. Its sligthly brownish colour and an anisotropy, vizible by strong magnification will indicate, that also the graphite is present among the flakes of schungite.

In the Parish of H a u k i p u d a s (29 in fig. 1) the dominant rocks are slates, limestone, and volcanics. This area is the westernmost part of the Utajärvi—Kiiminki schists-area described by Mäkinen (1916). Only slates and volcanics are exposed, but limestone is known to exist by the occurrence of a few boulders in the area.

The most common type of slate is a very fine-grained schist varying in colour from gray to black, depending on its biotite or graphite content. With the increase of feldspar the rock grades into arkose. True quartzite does not occur in Haukipudas. The biotite has more or less altered into chlorite. The black slate contains mainly quartz, very fine scales of graphite, and small amounts of biotite. Fine scales of sericite are present in varying amounts in both kinds of slate, which alternate with each on other as beds, often several hundred metres in width. The typical feature in the slates of Haukipudas is that they are penetrated by numerous quartz veins, usually a few cm in width. These veins are parallel to the bedding of the schist, as can be easily seen in small folds (Fig. 4).

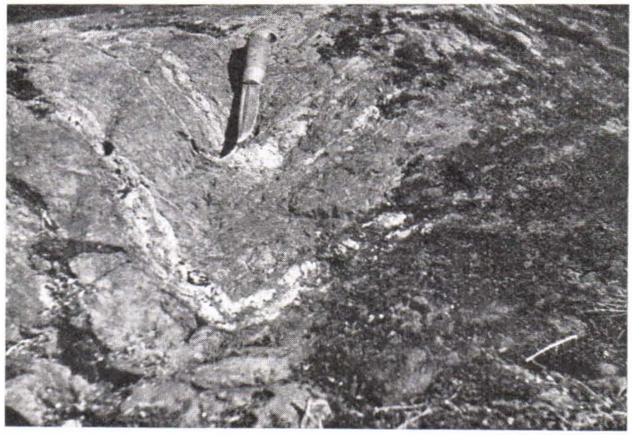

Fig. 4. The miniature folds at Haukipudas.
Photo A. Mikkola.

The quartz forms also lenses from 5 to 20 cm in thickness. When veins and lenses increase, the rock grades into veined gneiss. On the coast of the Gulf of Bothnia boulders of a different kind are met with. They are some coarser than graphite-bearing sulphide-schists, but finer than arkoses. Further, in addition to quartz, plagioclase and biotite they also contain abundant tourmaline, occurring in euhedral prisms, parallel to the schistosity of the rock. The false cleavage is a conspicuous feature.

The schistosity of the Haukipudas-slates is caused by very strong metamorphism. Its strike crosses the bedding, which is also visible here and there. Within the investigated area the strike is in general about N 50° W and the dip varies from 60°/SW to vertical. About 2 km from the coast the strike turns to E—W with a nearly vertical dip.

Slates are intensely folded into small folds. The quartz has accumulated in the troughs and crests, making these folds easily visible. This small folding does not affect the main features of the area, but as seen from the geophysical maps (Fig. 7) the beds have nearly straight boundaries.

The geophysical properties agree well with the geological picture of the area. The sulphide-schists containing pyrrhotite can be followed by the magnetic anomalies. They occupy several parallel zones, which have been also ascertained by investigations of outcrops. The map of magnetic anomalies does not indicate the pyrite-graphite-schists. These, however, have caused additional anomalies, parallel to the magnetic, when measured by electrical methods.

The sulphides of the black slates of Haukipudas occur in three different generations. The oldest (primary) generation consists of very fine-grained, slight dissemination of pyrrhotite, sphalerite and very little chalcopyrite. The pyrrhotite of this generation is seldom hypidiomorphic, the grains usually being elongated in the direction of schistosity. A very conspicuous and common feature of this generation is the complete lack of alteration into fine-grained pyrite or into marcasite, as is the case when the pyrrhotite of later origin is in question. Small accumulations of sphalerite occur often together with pyrrhotite, but not as separated, independent grains. Only a few grains of chalcopyrite in connection with the primary pyrrhotite are met with. Hematite is also met, especially in the tourmaline-bearing schists, found as boulders.

The samples gathered in Haukipudas also always contain carbon in the form of very fine, black pigment, consisting of thin scales orientated parallel to the false cleavage (Plate III, 3). This form of carbon can be easily separated by flotation in water. It has been ascertained to be s c h u n g i t e. There are also bigger scales of graphite, always connected with pyrrhotite.

The second generation of sulphides in these schists can be divided in two stages. The earlier one is represented by coarse-grained pyrite forming veins and filling the fracture cleavages and cracks of the rock. Such veins can be from a few cm. to half a metre in width. Often such veins will follow the main schistosity of the rock, but when filling the cracks they usually cut it. In the same way as the quartz veins, (Fig. 4) the pyrite of the second generation has also accumulated in troughs and crests of small folds (Fig. 5). The thickness of the pyrite-veins has often increased by ten times in the troughs of the folds. The coarse and euhedral, often catalastic pyrite can not be polished well due to alteration into fine-grained pyrite along the cracks and margins. Small inclusions of pyrrhotite has been observed in pyrite. They may be residuals of pyrrhotite of first generation replaced by pyrite. The pyrrhotite of the second generation is distinctly later than pyrite.

The earlier stage of the second generation will here be named pyrite-stage. In some case it is characterized by pegmatitic veins indicating its forming under the hydrothermal conditions. Bugge (1948) has given a preliminary report on the sulphides of Norwegian graphite-schists. For the veined pyrite he used the name »gangkis» (a common Norwegian mining term), which is obviously similar to the pyrite-stage, described above.

The later stage of the second generation will here be called pyrrhotite-stage, because this mineral is the principal sulphide of this stage. Sulphides belonging to this stage are most important in the Haukipudas-area, and they often form sulphide ores. Sulphides of the pyrrhotite-stage always occur brecciating and replacing other minerals of the earlier

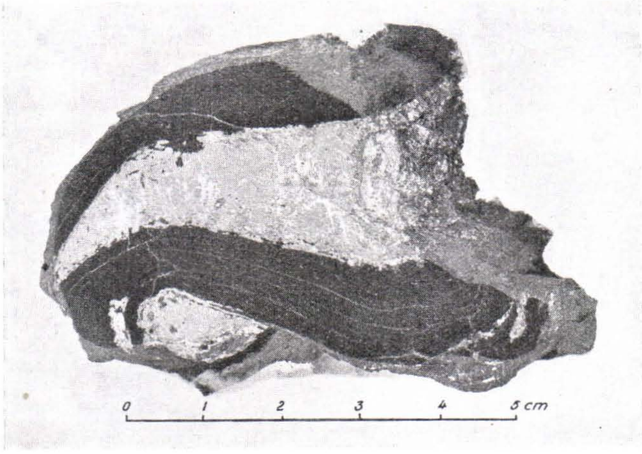

Fig. 5. A miniature fold with concentration of pyrite. Haukipudas. Photo B. Knekt.

stage, and have often impregnated the wall-rocks. In addition to the principal pyrrhotite there is also sphalerite and chalcopyrite. All these sulphides occur replacing the pyrite as described by Laitakari (1931) for the Outokumpu ore. Chalcopyrite has evidently crystallizated after the pyrrhotite. Replacement similar to that between pyrrhotite and pyrite, has been observed also between chalcopyrite and pyrrhotite (Plate III, 4).

The anhedral grains of sphalerite usually occur in connection with the pyrite, but in veins the sphalerite is usually surrounded by pyrrhotite. The replacement of pyrite by sphalerite is observed, and this phenomenon will be described later in connection with sulphides of Ylitornio. At Haukipudas the replacement of pyrrhotite or chalcopyrite by the sphalerite has not been observed.

In the Parish of K i i m i n k i (30 in fig. 1) the rocks are similar to those of the Haukipudas area, and they also belong to the same supracrustal formation. The only difference between the rocks of these areas is that quartzites and carbonates also are met in Kiiminki. Further the sulphides within the Haukipudas area are usually in connection with the black schists, but in Kiiminki the most important sulphide-bearing rocks are the skarns. A sulphide-rich boulder, found in the NE part of the parish, will now be described. It consists of a coarse-grained skarn containing pale green tremolite predominantly, and smaller amounts of pyroxene and carbonate. Graphite occurs as small flakes together with sulphides. The primary generation of pyrrhotite as found in the sulphides of Haukipudas, has not been met in the boulder in question, but there are, however, several other boulders from the same area containing the primary pyrrhotite. The pyrrhotite of the skarn differs from that of Haukipudas by including large flakes of graphite, which show its belonging to the second generation. The subhedral pyrrhotite grains are often surrounding the pyrite. No replacement between these minerals has been observed. The chalcopyrite occurs as abundant small grains and veinlets replacing the pyrrhotite, but sphalerite, as in most investigated occurrences of sulphide-schists, has not been met at all in the boulders of Kiiminki area. The alteration of pyrrhotite into fine-grained pyrite along its margins and fissures forming concentric »bird's eyes», is a common feature. There are also grains of nearly completely altered pyrrhotite, with the primary sulphide only in the centre. The altered margin is later surrounded by »limonite», which often follows the lamellae of the primary pyrrhotite (Plate IV, 1). It is further surrounded by a rim of »hydropyrite» containing marcasite and fine-grained pyrite. At a later stage the »limonite» has spredd further into other fissures and cracks of the rock, representing with marcasite and fine-grained pyrite the most young generation of ore mineralization.

In the Parish of Kuivaniemi (31 in fig. 1), in the village of Jokikylä, several boulders of sulphide-schists have been colleted, but no outcrops are met due to the thickness of the Quaternary deposits. By statistical investigation of the till stones, sulphide-schists are found to be the principal type of country rock. Most of the boulders consist of black slate containing biotite, quartz and plagioclase. Sometimes the schists have become veined gneiss owing to thin quartz veins, which have obviously originated from the microcline granite occupying large areas in the Parish of Kuivaniemi. The black colour of these schists is caused by very fine dissemination of pyrrhotite. No graphite has been observed either in thin or in polished sections of the examined boulders.

There are two different assemblages of sulphides: 1) the most common is pyrrhotite, chalcopyrite and sphalerite; 2) in a minor part of the boulders arsenopyrite or pyrite occurs together with the sulphides mentioned above in (1). The total content of sulphides, however, is inconsiderable. The alteration of pyrrhotite into fine-grained pyrite, often containing small grains of marcasite is common. Small grains of chalcopyrite are usually accompanied by pyrrhotite. Sphalerite on the contrary never occurs together with pyrrhotite but always alone, separated from other sulphides by silicate minerals.

When arsenopyrite and/or pyrite occurs, the grains are euhedral. Sometimes in such specimens pyrrhotite is absent, but sphalerite always occurs associated with pyrite. The arsenopyrite represents here probably the youngest generation of sulphides. Differing from other occurrences of sulphide-schists, investigated by the present authors, black-schists of the last mentioned type also contain very small amounts of gold.

At Merivaara in the Parish of Ylitornio (32 in fig. 1) is a small occurrence of sulphides, situated between migmatitic granite and mica-schists (Hackman, 1914). The principal mineral composition of these sulphide-schists is quartz, biotite, amphibole and graphite, the latter being abundant and coarse-flaked.

Again there are two generations of sulphides: the earlier generation is represented by disseminated pyrrhotite with small amounts of pyrite and chalcopyrite, along the planes of schistosity, and the later generation often occurs as almost compact brecciating veins. The sulphides of the second generation are: pyrrhotite, pyrite, sphalerite and chalcopyrite. The gangue minerals are quartz and abundant graphite. In the country rock the carbon is, however, in the form of very finely disseminated schungite. The euhedral pyrite is oldest of the sulphides of second generation. It is replaced and enclosed by pyrrhotite. In the contact of pyrrhotite and enclosed pyrite is often a rim of lamellar marcasite. The pyrrhotite is anhedral and fine-grained, containing abundant flakes of graphite, which has preserved its primary orientation parallel to the schistosity of the rock. Chalcopyrite and sphalerite are the latest crystallization products. They fill cracks in the pyrite which is partly replaced especially by sphalerite. The later is also more abundant than chalcopyrite and as it fills fissures in the chalcopyrite, it is younger (Plate IV, 2). The following generalization can be made about the sulphides of the schists in question: The sphalerite of the second generation usually occurs together with pyrite and chalcopyrite, but only occasionally in connection with pyrrhotite.

In the Parish of P u o l a n k a (33 in fig. 1) the schist area belongs to the Karelidic schists, described in detail by Väyrynen (1928). There is a continuous series beginning from the coarse-grained basal formations to the pelitic slates. According to Väyrynen the slates can be divided into three sub-divisions. The mica-schists belonging to the middle subdivision are most important for our investigations, because the sulphide-schists are met within them. The quartzites are interstratified with dolomites (Väyrynen, 1928), and both sides of them are black carbon- and sulphide-bearing, fine-grained slates, containing quartz, mica (from brown to pale), sphene, sulphides and fine disseminated schungite. The amount of carbon is considerable and occurs as a microscopic dissemination. According to Väyrynen the carbon content can be up to 15.72 per cent. Owing to this disseminated carbon the rock is opaque in thin sections. In the polished sections the carbon dissemination can be seen only with the highest magnification.

Nevertheless sulphide-bearing schists within the Puolanka area are widespred, and ore prospecting has been carried there out, but excepting a few sulphide-rich erratic boulders no economic ore deposits have been found. Väyrynen mentions pyrite as the principal sulphide, but the investigations of the present authors show, that pyrrhotite is the main sulphide in the probes, which were of their disposal. It has a distinct lamellar texture when somewhat altered. Pyrite has been observed here and there as small, euhedral crystals in pyrrhotite. When completely altered grains of pyrrhotite occur, the fine-grained pyrite is found to be slightly anisotropic. Marcasite has not been established. The alteration of sulphides is very similar to that in the Haukipudas area. Chalcopyrite occurs as well as some smaller amounts of sphalerite in two generations. The earlier generation is fine-grained and occurs together with pyrrhotite and graphite, parallel to the schistosity, while the younger generation is represented by large, isolated grains, separated from other sulphides by silicate minerals. In the example described above, the second generation of pyrrhotite is lacking.

The Parish of P a l t a m o (34 in fig. 1) N and E of Lake Oulujärvi. This schist area has previously been described by Wilkman (1921, 1931) and Väyrynen (1928). The black, carbon-bearing schists are abundant. Prospecting has been carried out within this area due to their sulphide ore content, but no deposits of importance have been found, although several small quarries have been worked. The best known exposures of sulphide-schists occur in the village of M e l a l a h t i. The country rock consists of strongly metamorphozed quartzites, slates, dolomites and ultrabasic rocks. The richest deposits of sulphides occur brecciating the slate. The euhedral pyrite forms beds parallel to the main stratification of the rock. In the schists themselves the finely disseminated pyrrhotite predominates, and occurs throughout all carbon-bearing schists. The grains of pyrrhotite are commonly altered along their margins into fine-grained pyrite, probebly containing grains of marcasite, which surrounds the pyrrhotite as thin rims. At Melalahti the sphalerite is more abundant than in other sulphide-schists belonging to the Karelides, and here (in contrast to Haukipudas, Ylitornio and others) it is usually connected with pyrrhotite. In the investigated specimens chalcopyrite is less abundant than sphalerite, but there are also boulders containing considerable amounts of chalcopyrite. The carbon-(schungite-) rich dark layers of slate are intercalated with paler and coarse-grained ones. True graphite has not been met in the present schists.

The schist zone occurring in the Parishes of Puolanka and Paltamo continues southwards through the Parish of S o t k a m o as a narrow belt. Quartzites and slates are the predominant rocks of this zone, both containing sulphides. There are two well-known occurrences, which have been the reason for ore prospecting in the region. The westernmost is situated SSE of the small lake K o l m i s o p p i (35 in fig. 1). The rock is a fine-grained slate with dark, carbon-bearing layers intercalated with light ones. The rocks are folded, and the long breccia zones, described by Wilkman (1931), are parallel to the strike. In the southernmost deposit at T a l v i v a a r a the adjacent slate is serpentinized ultrabasic rock.

The primary sulphide generation is a fine-grained dissemination in the black schist. Pyrrhotite is the predominant sulphide being always anhedral and corroded. Chalcopyrite and sphalerite are in small amounts. The second generation, however, is the most important with pyrite as chief mineral occuring either as large scattered grains or as compact veins, 0.5—5 cm. in thickness. The large euhedral grains often contain inclusions of the pyrrhotite of the primary generation. These inclusions have the same orientation as disseminated pyrrhotite. The pyrite of the large grains is always cataclastic and corroded, the cracks being filled with other sulphides. The centre of the compact veins is formed of coarse-grained pyrite grains, but the borders are composed of fine, mechanically grounded one being orientated parallel to the borders of the vein. The fine-grained pyrite differs from the coarse-grained one in habit resembling often an alteration product of pyrrhotite. The study with highest magnification shows a slight anisotropy. The pyrrhotite in veins has always crystallized after the pyrite. It fills the carcks of the cataclastic pyrite being itself, too, slightly cataclastic. Its cracks are filled by chalcopyrite and sphalerite. Chalcopyrite occurs in nearly the same amounts as the pyrrhotite including small grains of the latter. Replacement between pyrite and pyrrhotite is not a conspicuous feature, but the chalcopyrite replaces pyrite as well as pyrrhotite. The sphalerite occurs in smaller amounts than the former sulphides. In places it includes small chalcopyrite grains, which could be products of ex-solution and in other places, the chalcopyrite seems to replace the sphalerite, thus being younger.

The alteration of pyrrhotite into fine-grained pyrite, marcasite, »hydropyrite», and »limonite» is very interesting. Only the centre of the large grains is unaltered pyrrhotite (Plate IV, 3). The alteration has begun at the edges and extended along the lamellae to the centre. Adjacent lamellae have altered in a different way thus forming a lamellar or radial figures. The dark zone between the fine-grained pyrite-marcasite rims and the unaltered pyrrhotite centre shows the beginning of alteration. »Limonite» surrounds the fine-grained pyrite and marcasite and fills the cracks.

The other sulphide deposit in the Parish of Sotkamo is at Lake T i p a s j ä r v i (36 in fig. 1) situating about 40 km. E. of Lake Kolmisoppi. There is a small schist area in the wide gneissose granite one. According to the general geological map the schists are basic, but quartzite and slate are also found there. The ore deposit is situated in the quartzite, which is intercalated with slate. A zone about 300 m. in length and 60 m. in width, is composed of many separate elongated lenses of pyrite ore, parallel to the strike.

Pyrite is the chief mineral brecciating the quartzite. The different generations can be seen very distinctly. Pyrrhotite corresponds to the oldest one. It forms a slight fine-grained dissemination in the slate. The pyrrhotite grains are elongated in the direction of the schistosity. Large pyrite grains having well developed crystal faces cut this direction. Though the pyrite is cataclastic, the pyrrhotite does not occur filling its cracks. Marcasite has not been observed. In the true ore beds there is only coarse-grained pyrite occurring in the same way as in the veins at Lake Kolmisoppijärvi. The Tipasjärvi pyrite deposit differs from that at Lake Kolmisoppijärvi by the absence of pyrrhotite belonging to the later generation. Sphalerite, however, is abundant occurring often on the borders of the pyrite veins. Chalcopyrite is less common than at Kolmisoppijärvi. Both last mentioned sulphides have crystallized later than the pyrite. The sphalerite includes small grains of chalcopyrite, as ex-solution products.

In the Parish of L i e k s a (37 in fig. 1) the country rock consists of old gneiss-granite (Wilkman, 1921). Embedded in the country rock there occur, however, also dark schists, often containing sulphides in abundance. The principal sulphides are pyrite and pyrrhotite, and chalcopyrite is also always present, but sphalerite has been met only in exceptional cases. Graphite is absent, but very fine-grained, submicroscopic particles of schungite are abundantly disseminated through the rock. Pyrrhotite occurs both as disseminated lamellae orientated parallel to the schistosity and as veins cutting it. Pyrite occurs in the same way as at the Lake Kolmisoppijärvi.

The Parish of J u u k a (38 in fig. 1) is situated in the northernmost part of the Karelidic zone in Karelia. Many ore investigations have been carried out due to sulphide-bearing boulders found there. Sulphide-schists are in this region very abundant, and all kinds of Karelidic rocks are met. Among the sulphide-schists two different kinds can be distinguished. The pyrrhotite type contains a similar primary impregnation of sulphides as described from Haukipudas (p. 25). In the sphalerite, belonging to this kind of schist, an alteration has been observed, not known in the schists described above. In a large grain only small resorbed residuals of sphalerite have been preserved. The other part of the grain has altered into a dark, unpolished matter. This product of alteration is probably a result of the oxydation of zinc sulphide.

Another type of schists is characterized by the predominance of pyrite, and it is similar to that described by Väyrynen (1935) from the Parish of P o l v i j ä r v i. The pyrite occurs as a fine, euhedral impregnation through the whole schist, or it forms compact veins, which conform to the layering and small folding. Chalcopyrite is abundant and is connected with the pyrite. The very fine dissemination of schungite is similar to that described in several connections above.

In the Parish of P o l v i j ä r v i (40 in fig. 1) pyrite is the main sulphide, and often occurs as veins, parallel to the schistosity of the folded slates. Väyrynen (1935) has described this occurrence in detail and has discussed the paragenesis of the minerals in sulphide ores. Due to his accurate investigations this occurrence will be passed only with a short mention in the present paper.

In the Parish of Kiihtelysvaara (41 in fig. 1) the carbon of the sulphide-schists is also in the form of schungite. Graphite has not been observed. The slates are strongly metamorphosed and penetrated by numerous narrow quartz veins as in Haukipudas. The occurrence of pyrite is similar to that of Polvijärvi. The large crystals of pyrite are cataclastic, but never filled by pyrrhotite as is in Northern Finland, described above. On the other hand pyrite always includes small pyrrhotite grains, which have the same orientation as the fine-grained disseminated pyrrhotite in the country rock.

A few grains of chalcosite have been observed as a product of a supergene alteration of chalcopyrite.

The least metamorphosed type of sulphide-schists occurs in the Parish of Soanlahti (42 in fig. 1). The country rocks of this area, now belonging to Russia, have been described by Hausen (1930) and by Hackman (1933). The sulphide-schist of Soanlahti is very fine-grained, black and slightly metamorphosed. It contains carbon in the form of schungite. According to Hackman (1933) the carbon content is about 10 per cent. The ore minerals form fine dissemination, mainly of pyrrhotite. Only very few grains of chalcopyrite and sphalerite are met with.

As a new characteristic, the sulphide-schists here contain hematite similarly disseminated and in equal amounts with pyrrhotite. Both these minerals belong to the primary generation. Sulphides belonging to the second generation have not been observed.

Very different is the sulphide deposit at Jalonvaara in the Parish of Suistamo, now also belonging to Russia (43 in fig. 1). The pyrite ore occurs in the metamorphosed quartzite, in which the pyrite-bearing layers intercalate with ones containing magnetite. The later is the earliest ore mineral in the rock in question. Pyrite occurs either in the form of small corroded grains surrounding the silicate minerals, or as large euhedral crystals replacing other minerals. Pyrrhotite has been observed only as small inclusions in the pyrite. Chalcopyrite occurs in small amount as scales between pyrite grains. The carbon is graphite in connection with sulphides, but others it is schungite.

The pyrite deposit of Jalonvaara is similar to that of Tipasjärvi (p. 30), differing, however, from the last mentioned in the absence of pyrrhotite belonging to the second generation and in magnetite-content.

At Loimola in the same parish (44 in fig. 1) a boulder has been collected, which consists of compact pyrrhotite. This sulphide is here always cataclastic and often contains small inclusions of small, resorbed grains of pyrite. The replacement of pyrite by pyrrhotite is in this boulder a common feature and similar to that observed in the sulphides of Northern Finland. Between the grains of pyrrhotite are a few elongated, scaly grains of chalcopyrite. Small particles of marcasite together with fine-grained pyrite occur along the margins of the subhedral or euhedral crystals of pyrrhotite.

Also the well-known black schists in the Parish of Suojärvi (45 in fig. 1) have caused ore prospecting. These schists have been described in detail by Metzger (1924). Drilling in the village of Varpakylä has revealed a bed of sediments also containing sulphide-schists, very similar to those of Soanlahti, discussed above. Schungite is disseminated through the whole rock, and pyrrhotite occurs as fine dissemination, but also forming very thin veins in the slate, together with pyrite. These veins are usually parallel to the strike of the rock, but often they also cut the schistosity, obviously following cracks in the schists. Probably the fine impregnation of the pyrrhotite represents the primary generation, and the small veinlets with pyrite the later one. Pyrite is usually surrounded by pyrrhotite, which again, due to supergene alterations, is often surrounded by narrow rim of fine-grained pyrite and marcasite. Chalcopyrite and sphalerite are scanty.

4. GEOPHYSICAL ANOMALIES IN THE SULPHIDE-SCHISTS

The areas occupied by the sulphide-schists are always characterized by magnetic and electrical anomalies. As seen from the foregoing description pyrrhotite, often lamellar, is the main sulphide. When graphite occurs, it is as flakes parallel to the lamellae of the pyrrhotite. It seems that the pyrrhotite lamellae have become more or less polarized, causing therefore strong magnetism. The magnetic anomalies are always elongated, occurring as long, narrow strips, often several kilometres in length. This fact has been used by geologists to map areas covered by glacial deposits. For instance the Skellefteå area in Sweden has been mapped by considering the magnetic and electrical anomalies of black schists (Gavelin and Grip, 1946).

The same strong parallelism of the pyrrhotite lamellae will also cause a considerable increase in the conductivity of the rock. At Nokia a short (18 m) drill core was investigated. It contained only poor disseminations of lamellar pyrrhotite, which caused a strong decrease in resistivity compared to that in pure schist.

The form of the anomaly curves of the sulphide-schists is very characterictic. They are long and narrow following exactly all changes in the strike of the country rock. Fig. 6 and 7 show the curves of magnetic anomalies of some sulphide-schist occurrences. In Fig. 7 is the magnetic anomaly curve of the Haukipudas area, where graphite and especially fine schungite impregnations together with pyrrhotite are abundant; there is also the curve from Oulainen, where graphite occurs in flakes.

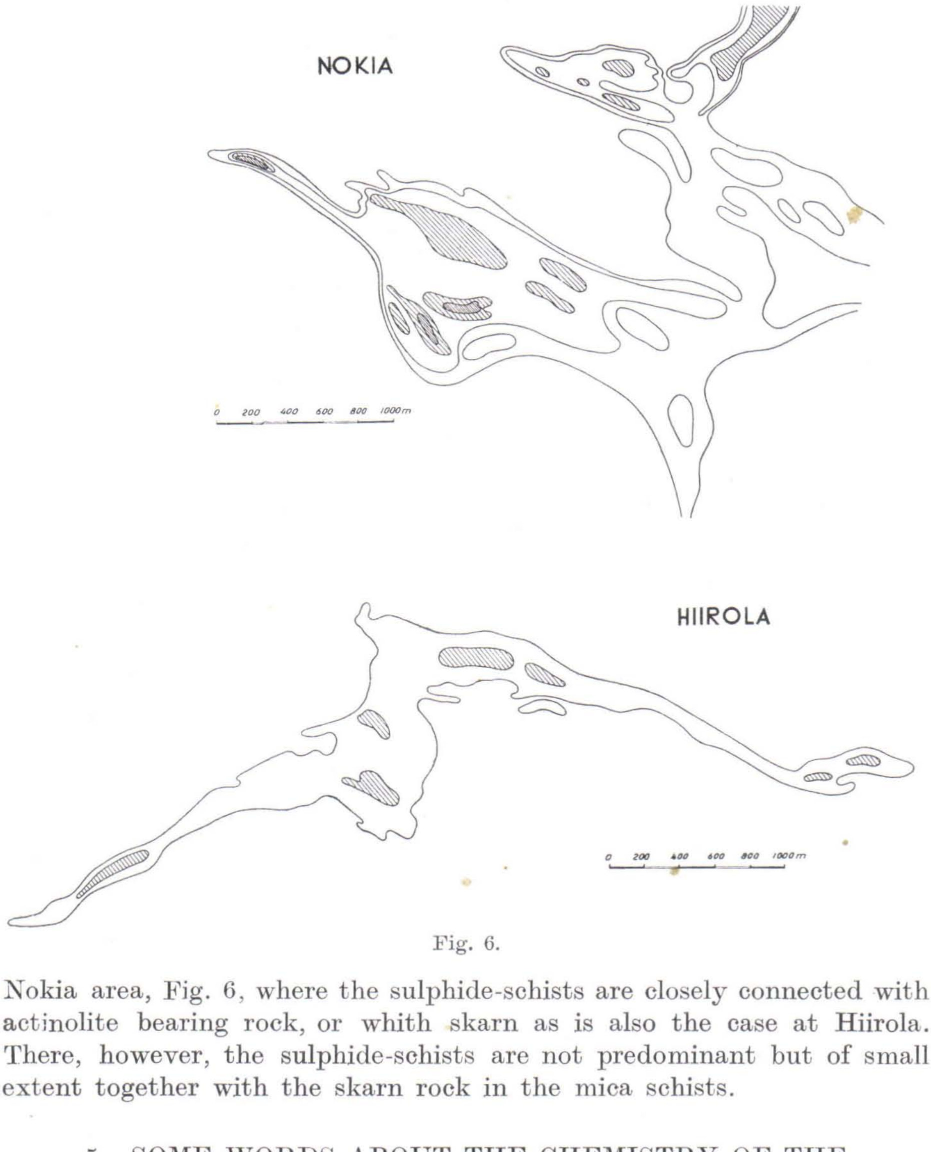

Fig. 6.

Nokia area, Fig. 6, where the sulphide-schists are closely connected with actinolite bearing rock, or whith skarn as is also the case at Hiirola. There, however, the sulphide-schists are not predominant but of small extent together with the skarn rock in the mica schists.

5. SOME WORDS ABOUT THE CHEMISTRY OF THE PYRRHOTITE OF THE SULPHIDE-SCHISTS

In order to find possible differences between the pyrrhotite of earlier and later generation, the pyrrhotite of different occurrences has been separated magnetically, washed with water, and analyzed by Mr. M. Tavela at the Chemical Laboratory of the Geological Survey of Finland. Unfortunately owing to the intimately mixed impurities, and to the secondary minerals closely connected with the primary material, it was not possible to obtain material pure enough for exact analysis. Com-

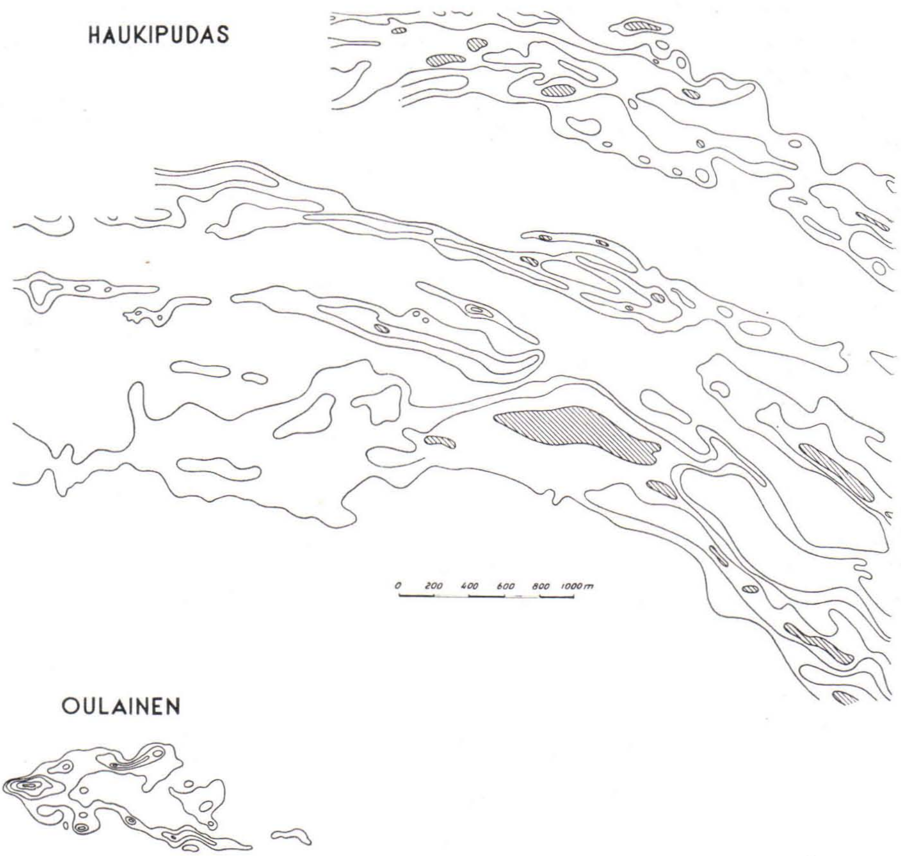

Fig. 7.

paratively pure pyrrhotite was separated from the sulphide-schists of Sotkamo, Tipasjärvi and of Juva, but in following some other analyses of pyrrhotites from other occurrences described above will also be given, because in spite of impurities the probable formula of the sulphide can be calculated accurately enough:

	Sotkamo, Tipasjärvi (p 30)	Juva, Ukkola (p 12)	Alajärvi, Hoisko (p 18)	Vihanti, Korvenkylä (p 20)	Ylistaro Munakka (p 18)
Fe	60.10 %	60 50 %	59.50 %	58.90 %	58.10 %
S	39.4 »	38.6 »	38.4 »	37.8 »	39.0 »
Ni	0.004 »	0.15 »	0.00 »	0.28 »	0.10 »
Co	0.000 »	0.04 »	0.002 »	0.03 »	0.002 »
$\Sigma =$	99.504 %	99.29 %	97.902 %	97.01 %	97.202 %
Calculated formula of pyrrhotite ..	$Fe_{11}S_{12}$	$Fe_{11}S_{12}$	$Fe_{11}S_{12}$	$Fe_{11}S_{12}$	$Fe_{11}S_{12}$

Ni and Co contents are often very characteristic of pyrrhotites. From the point of view of ore prospecting this contents are of importance. It may be mentioned in this connection, that very often the sulphide-schists contain Ni about 0.10—0.14 per cent, exceptionally, however, up to 0.25 per cent. The contents of these elements in our pyrrhotites according to the analyses made by Mr. M. Tavela, arranged in order of decrease of Ni, are as following:

Occurrence	Generation		Ni	Co
Sotkamo, Kolmisoppi	younger (second)	.....	0.65 %	0.004 %
Ylitornio	» »	.....	0.48 »	0.002 »
Vihanti, Korvenkylä	» »	.....	0.28 »	0.03 »
Teerijärvi	» »	.....	0.17 »	0.005 »
Vihanti, Alpua	» »	.....	0.15 »	0.000 »
Juva, Ukkola	» »	.....	0.15 »	0.04 »
Ylistaro, Tammelankoski	» »	.....	0.10 »	0.002 »
Haukipudas	» »	.....	0.09 »	0.005 »
Nokia, Koskenmäki	» »	.....	0.06 »	0.01 »
Haukipudas	older (primary)	.....	0.01 »	0.000 »
Sotkamo, Tipasjärvi	» »	.....	0.004 »	0.000 »
Teerijärvi, Långviken	» »	.....	0.004 »	0.004 »
Alajärvi	» »	.....	0.000 »	0.002 »
Vihanti, Alpua, Lampinsaari	» »	.....	0.000 »	0.000 »
Leivonmäki	» »	.....	0.000 »	0.004 »

The pyrrhotites of the younger (second) generation, in upper part of the table, have distinctly higher values of nickel than the older (primary) ones. The same tendenz is shown also in cobalt contents, although with some exceptions. Our analyses material is, however, too scanty to allowe any definitively conclusions.

The contents of minor elements in ore minerals determined spectrochemically, have been used to indicate the conditions during their formation. Hegemann (1950 preliminary notice) has ascertained great material differences between different sulphide deposits of sedimentary origin, and an extensive literature exists dealing with the minor components incorporated in sphalerite (see Rankama and Sahama 1950 p. 709). In this same meaning spectrochemical analyses were carried out from pyrrhotites by Mr. N. Lounamaa in the Laboratory of the Institut of Technology, Helsinki. He determined Zn, Cd, and Pb-contents. They, however, did not give any significant differences between the different pyrrhotite generations. Zinc and cadmium occur together and mostly in pyrrhotites of the younger (second) generations. Lead occurs very irregularly in both generations.

6. CONCLUSIONS

The carbon bearing sulphide schists, described above, occur always primarily bedded in sedimentary country rocks, which vary from fine slate to quartzites. In several cases volcanics, too, are adjacent. Metamorphic (and metasomatic) processes have caused different alterations both in carbon- bearing schists and country rock (skarn, sericite quartzite). Thus the investigated material is petrografically very inhomogenous.

A common feature for all such schists is, however, their pyrrhotite content, which is often very considerable. Pyrite, chalcopyrite, and sphalerite occur in most cases, but the two last mentioned in small amounts only.

Owing to the carbon content the investigated sulphide-schists have been divided in three different types:

1) On the both sides of Lake Päijänne the carbon in most cases is scarce being always in form of graphite (p. 8).

2) In Etelä- and Keski-Pohjanmaa graphite is always in abundant (p. 13).

3) In the Karelidic zone of east and north Finland carbon is abundant both as graphite, and as schungite (p. 23). The schungite indicates a lower grade of metamorphism, as has explained Laitakari (1925) in his discussion about the origin of Finnish graphite.

Concerning the sulphides of the schists in question there are three different generations observed:

1) The oldest (primary) generation contains fine-grained, lamellar pyrrhotite together with sphalerite and in few cases (p. 16) with chalcopyrite, too. Graphite or schungite is always of that age, excepting the graphit belonging to skarn (p. 17).

2) The second generation contains two distinctly separated stages (p. 25). The older one consists of euhedral pyrite, and the younger one of coarse-grained pyrrhotite, sphalerite and chalcopyrite. The minerals of this generation contain graphite as inclusions (p. 27).

3) The latest generation is characterized by fine-grained pyrite, sometimes together with marcasite (i. g. p. 27).

The relations between these different generations are very interesting leading the authors to the following conclusions. The primary generation is supposed to be of a sedimentary origin. Newhouse (1927) found that pyrite is the common form of iron sulphide occurring as concretions along certain stratigraphic horizons in the sedimentary rocks. Ferrous sulphide, being formed in sapropelic muds, is rich in organic remains at the present time. The presence of hydrogen sulphide causes the precipitation of sulphides of iron, copper and other metals. Rocks of sapropelic origin contain often pyrite, pyrrhotite, chalcopyrite and other sulphides. Ferrous iron is considered to be the precursor of pyrite (Rankama and Sahama 1950 p. 750). It seems to depend on the sulphure pressure during the metamorphism which of iron sulphides is present in the schists. Pyrrhotite is formed after reaction:

(1) $Fe(OH)_2 + H_2S = FeS + 2H_2O$

If the sulphur pressure is stronger, the reaction may be written:

(2) $Fe(OH)_2 + H_2S + S = FeS_2 + 2H_2O$

If the concentration of hydrogen becomes strong enough, the concentration of sulphure will contemporaneously decrease according to the following formula (Väyrynen 1935):

(3) $$\frac{S}{4} = \frac{K.\,[H_2S]}{2^2.\,[H]^2}$$

Then the reaction rate will increase in favour of the formula (1), and the replacement of pyrite by pyrrhotite occurs.

The lacking of pyrite in the primary stage will consequently indicate that in such cases the concentration of hydrogen must have been relatively strong, which a condition is very probable in the sediments buried in enough depth.

Where the iron oxydes occurs besides the primary sulphides (Leivonmäki and Soanlahti) the processes have caused an oxydation of iron hydroxide showing thus that the sulphure pressure has not been high enough.

The microscopic observations show that sphalerite and chalcopyrite of the primary generation are very closely connected to pyrrhotite (p, 16). Further it may be pointed out, that the sphalerite grains belonging to the primary generation are always conspicuously pure. They contain no inclusions and occur as distinctly separated scales. Their origin has to be similar to that of pyrrhotite. Due to the easy solubility of zinc sulphide, zinc is present in recent sediments (i. g. Robinson—Lakin—Reichen 1947) and in groundwater (i. g. at Nokia the zinc content of rocks is 0.5 per cent, the groundwater contains up to 0.008 per cent. Marmo 1950 b). From groundwater the zinc salts will later be deposited into the soils (compare i. g. Hawkes and Lakin 1949). Very extensive literature deals with the concentration of zinc and copper in the plants (see bibliography in Robinson with others 1947).

The later behavior of zinc in sediments during the metamorphism follows that of iron. When a sufficient pressure of sulphur is present the zinc is deposited as sphalerite.

Regarding to the second generations two different opinions can be expressed. The magmatic origin under the hydrothermal conditions seems to be acceptable in cases, where pyrite is connected with pegmatitic veins (or where it occurs alone without pyrrhotite as massive ore bodies i. g. Sotkamo, Tipasjärvi). But where the pyrite is followed and replaced by distinctively later pyrrhotite, sphalerite, and chalcopyrite, the origin seems to be of an other kind. As mentioned in foregoing description the second generation occurs as narrow veins and lenses or impregnation which are concordant to the bedding or schistosity of country rock. In other cases the veins follow small fractures cutting the parallel structure. But in these cases, too, it is obvious that the fracturing is originated during the same metamorphic process as the schistosity. The silicatic vein material is almost palingenetic (venitic). Also the sulphidic material of the same age could be originated from the primary sedimentary material by palingenesis. During the metamorphism sulphides became mobile and concentrated in the structurally favorable places (Fig. 5). That the pyrite is deposited before pyrrhotite is depending on the high sulphur pressure (formula 2), which is possible in the strong metamorphism. After the deposition of pyrite the sulphur pressure decreased and the other sulphides became able to deposite (formula 3).

In the cases, where the second generation occurs in the vicinity of skarn rocks, its origin is more difficult to determine. The skarn is a contact metamorphic product caused usually by an intrusive body. Thus the hydrothermal origin of such ores seems to be very possible. But it has been shown (Magnussom 1930), that skarn can be formed by reaction between silicates and carbonates without any direct intrusive action. The conditions during this reaction are favorable for concentration of ore minerals. Thus it is possible that the sulphides of skarn bearing schist can be originated from the primary generation as showed above.

In the contents of minor elements in pyrrhotites differencies occur. According to our scanty analysis material the pyrrhotites of second generation has higher nickel and cobalt contant than the pyrrhotites of primary one.

The fine-grained pyrite of youngest generation, marcasite, »hydropyrite», and »limonite», the minerals of the third generations are products of supergene alteration in the weathering zone. They are originated from the iron sulphides of the primary and second generation.

In this connection may be pointed out that Hegemann (1950b) has recently published a short preliminary notice concerning the origin of sulphide ores. Basing on the geochemical studies he consideres some zinc, lead, and other ores as sedimentary. The sedimentation has taken place in the geosyncline in connection of an iniatile volcanic action. According to him the greatest part of the material in the sedimentary sulphide deposits is originated from exhalations beneath the see. — In some cases described in the present paper volcanics are present, but not as a conspicuous feature.

If possibilities to find true ores connected to the sulphide schists should finally be discussed, so according to the opinion of the present authors, any answer cannot be given. We can only point out that besides economically insignificant pyrrhotite always also valuable sulphides, as sphalerite, chalcopyrite, and pyrite occur. The facts that the sulphide concentrations favor skarn rocks and skarn rocks occur often with the sulphide-bearing schists, allow an assumption, that true ores connected to the sulphide schists can be found, perhaps, not in sulphide schists themselves, but in their nearest vicinity.

REFERENCES

BUGGE, C.: Kisene i fjellkjeden. Norsk Geol. Tidsskr. 27. pp. 97—102. 1948.

ESKOLA, P., HACKMAN, V., LAITAKARI, A., WILKMAN, W.: Suomen kalkkikivi. Geotechn. pap. of Finl. 21. pp. 1—265. 1919.

GAVELIN, S., GRIP, E.: Skellefte- och Arvidsjaurfälten. Geol. Fören. Förh. 68. pp. 152—170. 1946.

HACKMAN, V.: The General Geological Map of Finland. Sheets C 6, B 5, B 6. Explanation to the geological map (in Swedish). Geol. Surv. of Finl. pp. 1—86. 1914.

—»— The General Geological Map of Finland. Sheet D 12, Savonlinna. Explanation to the geological map (in Finnish). Geol. Surv. of Finl. pp. 1—175. 1933.

HAGEMANN, FR.: Geochemische Untersuchungen über die Herkunft des Stoffbestandes sedimentärer Kieslager. Fortschr. d. Min. Band 27. p. 45. 1950.

—»— Über sedimentäre Lagerstätten mit submarines vulkanischen Stoffzufuhr. — Fortschr. d. Min. Band. 27. p. 54. 1950.

HAUSEN, H.: Geologie des Soanlahti — Gebietes im südlichen Karelien. Bull. Comm. géol. Finl. 90. pp. 1—105. 1930.

HAWKES, H. E., LAKIN, H. W.: Vestigal Zinc in Surface Residuum Associated with Primary Zinc Ore in East Tennessee. Econ. Geol. 44. pp. 286—295. 1949.

HIETANEN, A.: On the Petrology of Finnish Quartzites. Bull. Comm. geol. Finl. 122. pp. 1—113. 1938.

LAITAKARI, A.: Die Graphitvorkommen in Finnland und ihre Entstehung. Geotechn. pap. of Geol. Surv. of Finl. N:o 40, pp. 1—96. 1925.

—»— Veränderungen in Sulphidmineralien von Pitkäranta und Outokumpu. Bull. Comm. géol. Finl. 93. pp. 55—63. 1931.

LOKKA, L.: Beiträge zur Kenntnis des Chemismus der finnischen Minerale. Bull. Comm. géol. Finl. 129. p. 48. 1943.

MAGNUSSON, N. H.: Långbans malmtrakt, geologisk beskrivning. Sveriges Geol. Undersökning. Ser. Ca. N:o 23. 1930.

MARMO, V.: A Comparison Made by Means of Chalcographic Investigations of Some Ore-bearing Boulders with the Ores of Outokumpu and Polvijärvi. Bull. Comm. géol. Finl. 150. pp. 23—29. 1950.

—»— Kasveista alustan kallioperän indikaattoreina. Terra 62. pp. 49—60. 1950.

METZGER, A.: Die jatulischen Bildungen von Suojärvi in Ost-Finnland. Bull. Comm. géol. Finl. 64. pp. 1—86. 1924.

MÄKINEN, E.: Översikt av de prekambriska bildningarna i mellersta Österbotten i Finland. Bull. Comm. géol. Finl. 47. pp. 1—132. 1916.

NEWHOUSE, W. H.: Some Forms of Iron Sulphide Occurring in Coal and other Sedimentary Rocks. J. of. Geol. 35. p. 73. 1927.

RAMDOHR, P.: Die Erzmineralien und ihre Verwachsungen. Berlin 1950.

RANKAMA, K., SAHAMA, TH. G.: Geochemistry. Chicago 1950.

ROBINSON, W. O., LAKIN, H. W., REICHEN, LAURA: The Zinc Content of Plants on the Friedenswille Zinc Slime Ponds in Relation to Biogeochemical Prospecting. Econ. Geol. 42. p. 752. 1947.

SAKSELA, M.: Über eine Antimonreiche Paragenese in Ylöjärvi. Bull. Comm. géol. Finl. N:o 140, p. 208. 1947.

—»— The General Geological Map of Finland. Sheet B 4, Kokkola. Explanation to geological map (in Finnish). Geol. Surv. of Finl. pp. 1—55. 1933. (With English Summary).

—»— in Laitakari, A: Geologisen Toimikunnan Vuosikertomus 1936.

SCHNEIDERHÖHN, H., RAMDOHR, P.: Lehrbuch der Erzmikroskopie. Berlin 1931.

SEDERHOLM, J. J.: On the Sub-Jothnian Unconformity and on Archaean Rocks Formed by Secular Weathering. Bull. Comm. géol. Finl. 95. pp. 1—81. 1929.

SHORT, M. N.: Microskopic Determination of the Ore Minerals. U. S. Geol. Surv. Bull. 914. 1—296. 1940.

SKORDAL, A. J.: Vulkanitter og sedimenter på den sørøstre del av Stord. — Univ. i Bergen Årsbok. Naturvet. rekke N:o 2. pp. 1—58. 1948.

TURNEAURE, F. S.: The Tin Deposits of Hallagua, Bolivia. Econ. Geol. Vol. 30. N:o 1—2. 1935.

WILKMAN, W. W.: The General Geological Map of Finland. Sheet D 4, Nurmes. Explanation to geological map (in Finnish). Geol. Surv. of Finl. pp. 1—126. 1921.

—»— The General Geological Map of Finland. Sheet C 4, Kajaani. Explanation to geological map (in Finnish). Geol. Surv. of Finl. pp. 1—247. 1931.

—»— The General Geological Map of Finland. Sheet C 3, Kuopio. Explanation to geological map (in Finnish). Geol. Surv. of Finl. pp. 1—171. 1938.

VÄYRYNEN, H.: Geologische und Petrographische Untersuchungen im Kainuugebiete. Bull. Comm. géol. Finl. N:o 78. pp. 1—127. 1928.

—»— Weiteres vom Auftreten des Konglomerates beim Gehöft Olli Partanen. Soanlahti. Bull. Comm. géol. Finl. 85. pp. 67—69. 1929.

—»— Über die Mineralparagenesis der Kieserze in den Gebieten von Outokumpu und Polvijärvi. Bull. Comm. géol. Finl. 109. pp. 128—158. 1935.

EXPLANATIONS TO THE PLATES

Plate I.

Fig. 1. The ex-soluted chalcopyrite in sphalerite (gray). Light mineral surrounding sphalerite is pyrrhotite. Nokia, Koskenmäki. x40. Polished section.

Fig. 2. Veinlets of chalcopyrite in the sphalerite (sp), not continuing into pyrrhotite (py). Nokia, Koskenmäki. x168. Polished section.

Fig. 3. A light mineral (1) belonging to the linneite group in the pyrrhotite (py). Nokia, Koskenmäki. x300.Pol.sect.

Fig. 4. Pyrite surrounded by pyrrhotite, which is altered along its margins into fine-grained pyrite. Nokia, Koskenmäki. x40.Pol.sect.

Plate II.

Fig. 1. Miniature folds in phyllite. Nokia, Koskenmäki. x30.Thin. sect.

Fig. 2. Veinlets of pyrite in sulphide-schist. Teerijärvi, Raisjoki. x30.Pol.sect.

Fig. 3. Pyrrhotite (py) and graphite (g) in the skarnous sulphide-schist. Nurmo, Autionkylä. x60.Pol.sect.

Fig. 4. „Bird's eyes" defining the boundaries of crystals of pyrite, completely altered into pyrrhotite. In the right upper corner fresh pyrite. Alajärvi, Hoisko. x60.Pol.sect.

Plate III.

Fig. 1. Quartzite with cement of pyrrhotite (black). Saarijärvi, Mahlu. x30.Thin sect.

Fig. 2. Fine-grained pyrite, marcasite, „hydropyrite" and unaltered pyrrhotite (py) in the quartizite-like rock. Saarijärvi, Mahlu. x60.Pol.sect.

Fig. 3. The fine disseminated carbon (shungite) orientated parallel to the false cleavage. Haukipudas. x30.Thin sect.

Fig. 4. The chalcopyrite (ch) replacing the pyrrhotite (py). The gray mineral is sphalerite, dark gray is silicate (s). Haukipudas. x60.Pol.sect.

Plate IV.

Fig. 1. Pyrrhotite (py) surrounded by a mixture of fine-grained pyrite, marcasite, „hydropyrite" and „limonite". Kiiminki. x30.Pol.sect.

Fig. 2. Sphalerite (sp) fills the fissures in pyrite (p). Ylitornio, Merivaara. x30.Pol.sect.

Fig. 3. A network of the fine-grained pyrite, and „hydropyrite". Well polished parts in the centres of nets are pyrrhotite. Sotkamo, Talvivaara. x30.Pol.sect.

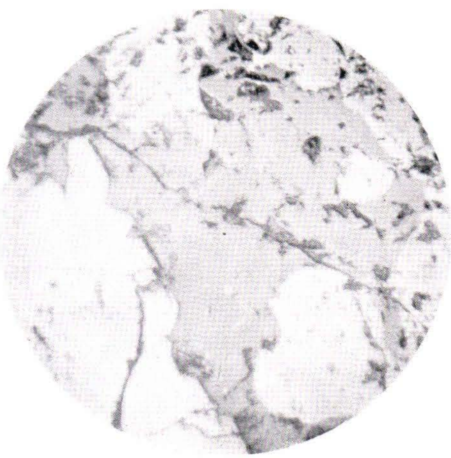
Fig. 1

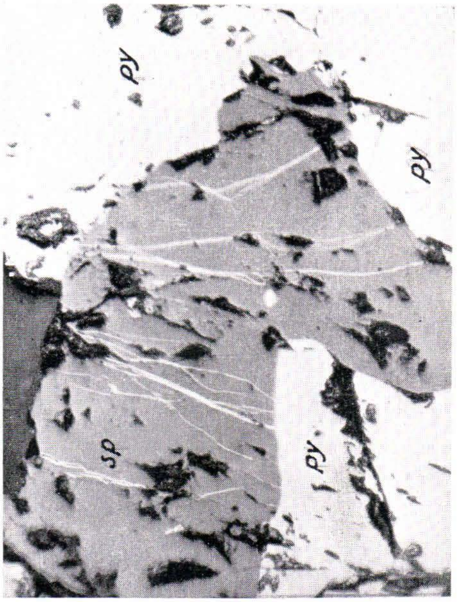

Fig. 2

Fig. 3


Fig. 4


Fig. 2

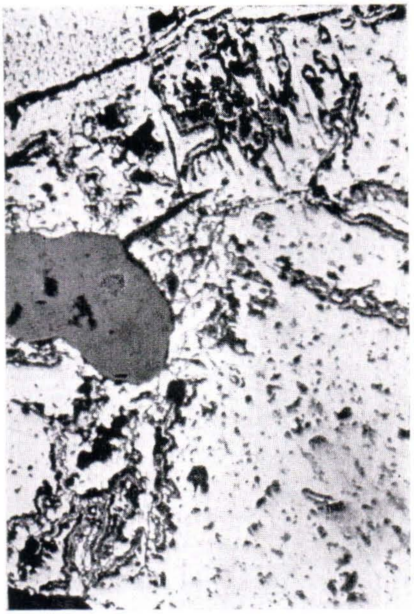
Fig. 4


Fig. 1

Fig. 3

Fig. 1

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Fig. 4

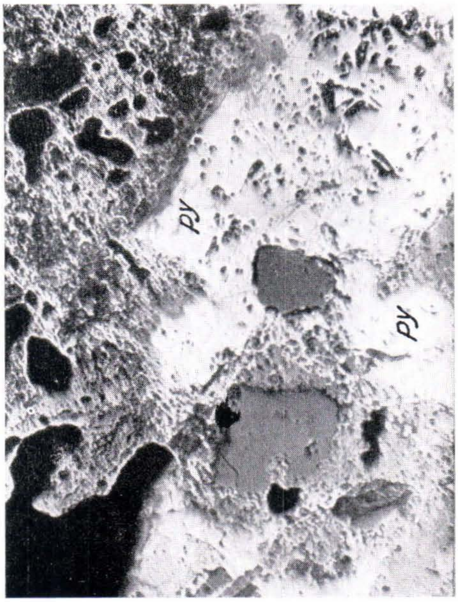

Fig. 1

Fig. 2

Fig. 3

Bulletin de la Commission géologique de Finlande.

*N:o 1. Ramsay, Wilhelm und Nyholm, E. T. Cancrinitsyenit und einige verwandte Gesteine aus Kuolajärvi. S. 1—12. 4 Fig. 1895 .... 60: —

*N:o 2. Sederholm, J. J. Ueber einen metamorphosirten praecambrischen Quarzporphyr von Karvia in der Provinz Åbo. S. 1—16. 12 fig. 1895 .... —

N:o 3. Ramsay, Wilhelm, jemte Bihang 1 af Hackman, Victor och 2 af Sederholm, J. J. Till frågan om det senglaciala hafvets utbredning i Södra Finland. S. 1—44. 1 karta. Résumé en français: La transgression de l'ancienne mer glaciaire sur la Finlande méridionale. 1896 .... 100: —

*N:o 4. Frosterus, Benj. Ueber einen neuen Kugelgranit von Kangasniemi in Finland. S. 1—38. 11 Fig. 2 Taf. 1896 .... —

*N:o 5. Berghell, Hugo. Bidrag till kännedomen om Södra Finlands kvartära nivåförändringar. S. 1—64. 16 fig. 1 plansch. 1 karta. Deutsches Referat: Beiträge zur Kenntniss der quartären Niveauschwankungen Süd-Finlands. 1896 .... —

*N:o 6. Sederholm, J. J. Über eine archäische Sedimentformation im südwestlichen Finland und ihre Bedeutung für die Erklärung der Entstehungsweise des Grundgebirges. S. 1—254. 97 Fig. 5 Taf. 2 Karten. 1897 .... —

*N:o 7. Ailio, Julius. Über Strandbildungen des Litorinameeres auf der Insel Mantsinsaari. S. 1—43. 8 Fig. 1898 .... —

*N:o 8. Andersson, Gunnar. Studier öfver Finlands torfmossar och fossila kvartärflora. S. 1—210. 21 fig. 4 tafl. Deutsches Referat: Studien über die Torfmoore und die fossile Quartärflora Finlands. 1898 .... —

N:o 9. Sederholm, J. J. Esquisse hypsométrique de la Finlande. P. 1—17. 1 carte. 1899 .... 100: —

N:o 10. Sederholm, J. J. Les dépôts quaternaires en Finlande. P. 1—28. 2 fig. 1 carte. 1899 .... 100: —

*N:o 11. Hackman, Victor. Neue Mitteilungen über das Ijolithmassiv in Kuusamo. S. 1—45. 7 Fig. 1 Taf. 2 Karten. 1899 .... —

*N:o 12. Ramsay, Wilhelm und Borgström, L. H. Der Meteorit von Bjurböle bei Borgå. S. 1—28. 20 Fig. 1902 .... —

*N:o 13. Frosterus, Benj. Bergbyggnaden i sydöstra Finland. S. 1—168. 18 fig. 8 tafl. 1 karta. Deutsches Referat: Der Gesteinsaufbau des südöstlichen Finland. 1902 .... —

*N:o 14. Borgström, Leon. H. Die Meteoriten von Hvittis und Marjalahti. S. 1—80. 8 Taf. 1903 .... —

N:o 15. Hackman, Victor. Die chemische Beschaffenheit von Eruptivgesteinen Finlands und der Halbinsel Kola im Lichte des neuen amerikanischen Systemes. S. 1—143. 3 Tab. 1905 .... 120: —

*N:o 16. Sundell, I. G. On the Cancrinite-Syenite from Kuolajärvi and a Related Dike Rock. P. 1—20. 1 plate. 1905 .... —

*N:o 17. Fircks, Curt. On the Occurrence of Gold in Finnish Lapland. P. 1—35. Frontispiece. 15 fig. 1 map. 1906 .... 80: —

*N:o 18. Tanner, V. Studier öfver kvartärsystemet i Fennoskandias nordliga delar. I. Till frågan om Ost-Finmarkens glaciation och nivåförändringar. S. 1—165. 23 fig. 6 tafl. Résumé en français: Études sur le système quaternaire dans les parties septentrionales de la Fenno-Scandia. I. Sur la glaciation et les changements de niveau du Finmark oriental. 1906 .... 200: —

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*) Loppuunmyyty.
Out of print.

*N:o 19.	Trüstedt, Otto. Die Erzlagerstätten von Pitkäranta am Ladoga-See. S. 1—333. 80 Fig. 19 Taf. 1 Karte. 1907	—
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N:o 21.	Tanner, V. Studier öfver kvartärsystemet i Fennoskandias nordliga delar. II. Nya bidrag till frågan om Finmarkens glaciation och nivåförändringar. S. 1—127. 10 fig. 6 tafl. Résumé en français: Études sur le système quaternaire dans les parties septentrionales de la Fenno-Scandia. II. Nouvelles recherches sur la glaciation et les changements de niveau du Finmark. 1907	200: —
N:o 22.	Borgström, L. H. Granitporphyr von Östersundom. S. 1—20. 3 Fig. 1 Taf. 1907	60: —
*N:o 23.	Sederholm, J. J. Om granit och gneis, deras uppkomst, uppträdande och utbredning inom urberget i Fennoskandia. S. 1—110. 11 fig. 8 tafl. 1 planteckn. 1 karta. English Summary of the Contents: On Granite and Gneiss, their Origin, Relations and Occurrence in the Pre-Cambrian Complex of Fenno-Scandia. 1907	—
*N:o 24.	Sederholm, J. J. Les roches préquaternaires de la Fennoscandia. P. 1—39. 20 fig. 1 carte. 1910	—
N:o 25.	Tanner, V. Über eine Gangformation von fossilienführendem Sandstein auf der Halbinsel Långbergsöda-öjen im Kirchspiel Saltvik, Åland-Inseln. S. 1—13. 5 Fig. 2 Taf. 1911	60: —
*N:o 26.	Mäkinen, Eero. Bestimmung der Alkalien in Silikaten durch Aufschliessen mittelst Chlorkalzium. S. 1—8. 1911	—
N:o 27.	Sederholm, J. J. Esquisse hypsométrique de la Finlande. P. 1—21. 5 fig. 1 carte. 1911	80: —
*N:o 28.	Sederholm, J. J. Les roches préquaternaires de la Finlande. P. 1—27. 1 carte. 1911	—
*N:o 29.	Sederholm, J. J. Les dépôts quaternaires de la Finlande. P. 1—23. 5 fig. 1 carte. 1911	80: —
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N:o 31.	Hausen, H. Undersökning af porfyrblock från sydvästra Finlands glaciala aflagringar. S. 1—34. 9 fig. Deutsches Referat. 1912 ..	80: —
N:o 32.	Hausen, H. Studier öfver de sydfinska ledblockens spridning i Ryssland, jämte en öfversikt af is-recessionens förlopp i Ostbaltikum. Preliminärt meddelande med tvenne kartor. S. 1—32. Deutsches Referat. 1912	80: —
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N:o 34.	Borgström, L. H. Der Meteorit von St. Michel. S. 1—49. 1 Fig. 3 Taf. 1912	100: —
N:o 35.	Mäkinen, Eero. Die Granitpegmatite von Tammela in Finnland und ihre Minerale. S. 1—101. 23 Fig. 1913	120: —
N:o 36.	Eskola, Pentti. On Phenomena of Solution in Finnish Limestones and on Sandstone filling Cavities. P. 1—50. 15 fig. 1913	100: —
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N:o 38.	Tanner, V. Studier öfver kvartärsystemet i Fennoskandias nordliga delar. III. Om landisens rörelser och afsmältning i finska Lappland och angränsande trakter. S. 1—815. 139 fig. 16 tafl. 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. 1915	600: —
N:o 39.	Hackman, Victor. Der gemischte Gang von Tuutijärvi im nördlichen Finnland. S. 1—41. 9 Fig. 1914	80: —
*N:o 40.	Eskola, Pentti. On the Petrology of the Orijärvi region in Southwestern Finland. P. 1—277. 55 fig. 6 plates. 2 maps. 1914	—
N:o 41.	Borgström, L. H. Die Skapolithlagerstätte von Laurinkari. S. 1—30. 7 Fig. 1913	60: —

*) Loppuunmyyty.
Out of print.

N:o 42. Hackman, Victor. Über Camptonitgänge im mittleren Finnland. S. 1—18. 3 Fig. 1914 .... 60: —
N:o 43. Wilkman, W. W. Kaleviska bottenbildningar vid Mölönjärvi. S. 1—36. 11 fig. Résumé en français. 1915 .... 80: -
N:o 44. Eskola, Pentti. Om sambandet mellan kemisk och mineralogisk sammansättning hos Orijärvitraktens metamorfa bergarter. S. 1—145. 5 fig. English Summary of the Contents. 1915 .... 120: —
N:o 45. Ailio, Julius. Die geographische Entwicklung des Ladogasees in postglazialer Zeit und ihre Beziehung zur steinzeitlichen Besiedelung. S. 1—158. 51 Abb. 2 Karten. 1915 .... 200: —
N:o 46. Laitakari, Aarne. Le gisement de calcaire cristallin de Kirmonniemi à Korpo en Finlande. P. 1—39. 14 fig. 1916 .... 80: —
N:o 47. Mäkinen, Eero. Översikt av de prekambriska bildningarna i mellersta Österbotten i Finland. S. 1—152. 25 fig. 1 karta. English Summary of the Contents. 1916 .... 200: —
N:o 48. Sederholm, J. J. On Synantetic Minerals and Related Phenomena (Reaction Rims, Corona Minerals, Kelyphite, Myrmekite, &c.). P. 1—148. 14 fig. in the text and 48 fig. on 8 plates. 1916 .... 240: —
N:o 49. Wilkman, W. W. Om en prekalevisk kvartsitformation i norra delen af Kuopio socken. S. 1—18. 7 fig. Résumé en français. 1916 .... 60: —
N:o 50. Sauramo, Matti. Geochronologische Studien über die spätglaziale Zeit in Südfinnland. S. 1—44. 5 Abb. 4 Taf. 1918 ...... 120: —
N:o 51. Laitakari, Aarne. Einige Albitepidotgesteine von Südfinnland. S. 1—13. 5 Abb. 1918 .... 60: —
N:o 52. Brenner, Th. Über Theralit und Ijolit von Umptek auf der Halbinsel Kola. S. 1—30. 4 Fig. 1920 .... 60: —
N:o 53. Hackman, Victor. Einige kritische Bemerkungen zu Iddings' Classifikation der Eruptivgesteine. S. 1—21. 1920 .... 60: —
N:o 54. Laitakari, Aarne. Über die Petrographie und Mineralogie der Kalksteinlagerstätten von Parainen (Pargas). S. 1—113. 40 Abb. 3 Taf. 1921 .... 120: —
N:o 55. Eskola, Pentti. On Volcanic Necks in Lake Jänisjärvi in Eastern Finland. P. 1—13. 1 fig. 1921 .... 60: —
N:o 56. Metzger, Adolf A. Th. Beiträge zur Paläontologie des nordbaltischen Silurs im Ålandsgebiet. S. 1—8. 3 Abb. 1922 .... 60: —
*N:o 57. Väyrynen, Heikki. Petrologische Untersuchungen der granitodioritischen Gesteine Süd-Ostbothniens. S. 1—78. 20 Fig. 1 Karte. 1923 .... —
*N:o 58. Sederholm, J. J. On Migmatites and Associated Pre-Cambrian Rocks of Southwestern Finland. Part I. The Pellinge Region. P. 1—153. 64 fig. 8 plates. 1 map. 1923 .... —
N:o 59. Berghell, Hugo und Hackman, Victor. Über den Quartzit von Kallinkangas, seine Wellenfurchen und Trockenrisse. Nach hinterlassenen Aufzeichnungen von Hugo Berghell zusammengestellt und ergänzt von Victor Hackman. S. 1—19. 19 Fig. 1923 .... 60: —
N:o 60. Sauramo, Matti. Studies on the Quaternary Varve Sediments in Southern Finland. P. 1—164. 22 fig. in the text. 12 fig., 1 map and 2 diagrams on 10 plates. 1923 .... 200: —
N:o 61. Hackman, Victor. Der Pyroxen-Granodiorit von Kakskerta bei Åbo und seine Modifikationen. S. 1—23. 2 Fig. 1 Karte. 1923 .... 60: —
N:o 62. Wilkman, W. W. Tohmajärvi-konglomeratet och dess förhållande till kaleviska skifferformationen. S. 1—43. 15 fig. 1 karta. Deutsches Referat. 1923 .... 80: —
N:o 63. Hackman, Victor. Über einen Quartzsyenitporhyr von Saariselkä im finnischen Lappland. S. 1—10. 2 Fig. 1923 .... 60: —
N:o 64. Metzger, Adolf A. Th. Die jatulischen Bildungen von Suojärvi in Ostfinnland. S. 1—86. 38 Abb. 1 Taf. 1 Karte. 1924 .. 120: —
N:o 65. Saxén, Martti. Über die Petrologie des Otravaaragebietes im östlichen Finnland. S. 1—63. 13 Abb. 5 Fig. auf 1 Taf. 2 Karten. 1923 .... 120: —
N:o 66. Ramsay, Wilhelm. On Relations between Crustal Movements and Variations of Sea-Level during the Late Quaternary Time, especially in Fennoscandia. P. 1—39. 10 fig. 1924 .... 80: —

*) Loppuunmyyty.
Out of print.

N:o 67. S a u r a m o, M a t t i. Tracing of Glacial Boulders and its Application in Prospecting. P. 1—37. 12 fig. 1924 .... 80: —
N:o 68. T a n n e r, V. Jordskredet i Jaarila. S. 1—18. 2 fig. 10 bild. Résumé en français. 1924 .... 60: —
N:o 69. A u e r, V ä i n ö. Die postglaziale Geschichte des Vanajavesisees. S. 1—132. 10 Fig. 10 Taf. 11 Beil. 1924 .... 200: —
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N:o 71. W i l k m a n, W. W. Om diabasgångar i mellersta Finland. S. 1—35. 8 fig. 1 karta. Deutsches Referat. 1924 .... 80: —
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N:o 76. H a u s e n, H. Über die präquartäre Geologie des Petsamo-Gebietes am Eismeere. S. 1—100. 13 Fig. 2 Taf. 1926 .... 120: —
N:o 77. S e d e r h o l m, J. J. On Migmatites and Associated Pre-Cambrian Rocks of Southwestern Finland. Part II. The Region around the Barösundsfjärd W. of Helsingfors and Neighbouring Areas. P. 1—143. 57 fig. in the text and 44 fig. on 9 plates. 1 map. 1926 .. 240: —
N:o 78. V ä y r y n e n, H e i k k i. Geologische und petrographische Untersuchungen im Kainuugebiete. S. 1—127. 37 Fig. 2 Taf. 2 Karten. 1928 .... 160: —
N:o 79. H a c k m a n, V i c t o r. Studien über den Gesteinsaufbau der Kittilä-Lappmark. S. 1—105. 23 Fig. 2 Taf. 2 Karten. 1927 .... 160: —
N:o 80. S a u r a m o, M a t t i. Über die spätglazialen Niveauverschiebungen in Nordkarelien, Finnland. S. 1—41. 8 Fig. im Text. 11 Fig., 1 Karte und 1 Profildiagr. auf 7 Taf. 1928 .... 60: —
N:o 81. S a u r a m o, M a t t i and A u e r, V ä i n ö. On the Development of Lake Höytiäinen in Carelia and its Ancient Flora. P. 1—42. 20 fig. 4 plates. 1928 .... 60: —
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N:o 83. S e d e r h o l m, J. J. On Orbicular Granite, Spotted and Nodular Granites etc. and on the Rapakivi Texture. P. 1—105. 19 fig. in the text and 50 fig. on 16 plates. 1928 .... 200: —
N:o 84. S a u r a m o, M a t t i. Über das Verhältnis der Ose zum höchsten Strand. S. 1—17. 1928 .... 40: —
N:o 85. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, I. P. 1—88. 1 stéréogramme. 1929 .... 160: —
N:o 86. S a u r a m o, M a t t i. The Quaternary Geology of Finland. P. 1—110. 39 fig. in the text and 42 fig. on 25 plates. 1 map. 1929 .... 240: —
N:o 87. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, II. P. 1—175. 48 fig. 8 planches. 1929 ...... 280: —
N:o 88. T a n n e r, V. Studier över kvartärsystemet i Fennoskandias nordliga delar. IV. Om nivåförändringarna och grunddragen av den geografiska utvecklingen efter istiden i Ishavsfinland samt om homotaxin av Fennoskandias kvartära marina avlagringar. S. 1—589. 84 fig. 4 tavl. 1 karta. Résumé en français: Études sur le système quaternaire dans les parties septentrionales de la Fennoscandie. IV. Sur les changements de niveau et les traits fondamentaux du développement géographique de la Finlande aux confins de l'océan Arctique après l'époque glaciaire et sur l'homotaxie du quaternaire marin en Fennoscandie. 1930 .... 600: —
N:o 89. W e g m a n n, C. E. und K r a n c k, E. H. Beiträge zur Kenntnis der Svecofenniden in Finnland. I. Übersicht über die Geologie des Felsgrundes im Küstengebiete zwischen Helsingfors und Onas. II. Petrologische Übersicht des Küstengebietes E von Helsingfors. S. 1—107. 4 Fig. 16 Taf. mit 32 Fig. 1 Übersichtskarte. 1931 ...... 160: —

N:o 90. Hausen, H. Geologie des Soanlahti-Gebietes im südlichen Karelien. Ein Beitrag zur Kenntnis der Stratigraphie und tektonischen Verhältnisse der Jatulformation. S. 1—105. 23 Fig. im Text und 12 Fig. auf 4 Taf. 1930 .... 200: —

N:o 91. Sederholm, J. J. Pre-Quaternary Rocks of Finland. Explanatory Notes to accompany a General Geological Map of Finland. P. 1—47. 40 fig. 1 map. 1930 .... 120: —

N:o 92. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, III. P. 1—140. 29 fig. 3 planches. 1930 ...... 200: —

N:o 93. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, IV. P. 1—68. 12 fig. 6 planches. 1931 ...... 160: —

N:o 94. Brenner, Thord. Mineraljordarternas fysikaliska egenskaper. S. 1—159. 22 fig. Deutsches Referat. 1931 .... 280: —

N:o 95. Sederholm, J. J. On the Sub-Bothnian Unconformity and on Archæan Rocks formed by Secular Weathering. P. 1—81. 62 fig. 1 map. 1931 .... 200: —

N:o 96. Mikkola, Erkki. On the Physiography and Late-Glacial Deposits in Northern Lapland. P. 1—88. 25 fig. 5 plates. 1932 .... 200: —

N:o 97. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, V. P. 1—77. 15 fig. 1932 .... 160: —

N:o 98. Sederholm, J. J. On the Geology of Fennoscandia. P. 1—30. 1 map. 1 table. 1932 .... 120: —

N:o 99. Tanner, V. The Problems of the Eskers. The Esker-like Gravel Ridge of Čahpatoaiv, Lapland. P. 1—13. 2 plates. 1 map. 1932 .. 60: —

N:o 100. Sederholm, J. J. Über die Bodenkonfiguration des Päijänne-Sees. S. 1—23. 3 Fig. 1 Karte. 1932 .... 200: —

N:o 101. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, VI. P. 1—118. 17 fig. 5 planches. 1933 .... 200: —

N:o 102. Wegmann, C. E., Kranck, E. H. et Sederholm, J. J. Compte rendu de la Réunion internationale pour l'étude du Précambrien et des vieilles chaînes de montagnes. P. 1—46. 1933 .... 120: —

N:o 103. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, VII. P. 1—48. 2 fig. 1933 .... 100: —

N:o 104. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, VIII. P. 1—156. 33 fig. 7 planches. 1934 .... 220: —

N:o 105. Lokka, Lauri. Neuere chemische Analysen von finnischen Gesteinen. S. 1—64. 1934 .... 120: —

N:o 106. Hackman, Victor. Das Rapakiwirandgebiet der Gegend von Lappeenranta (Willmanstrand). S. 1—82. 15 Fig. 2 Taf. 1 Analysentab. 1 Karte. 1934 .... 140: —

N:o 107. Sederholm, J. J. † On Migmatites and Associated Pre-Cambrian Rocks of Southwestern Finland. Part III. The Åland Islands. P. 1—68. 43 fig. 2 maps. 1934 .... 160: —

N:o 108. Laitakari, Aarne. Geologische Bibliographie Finnlands 1555—1933. S. 1—224. 1934 .... 200: —

N:o 109. Väyrynen, Heikki. Über die Mineralparagenesis der Kieserze in den Gebieten von Outokumpu und Polvijärvi. S. 1—24. 7 Fig. 1 Karte. 1935 .... 80: —

N:o 110. Saksela, Martti. Über den geologischen Bau Süd-Ostbothniens. S. 1—35. 11 Fig. 1 Titelbild. 1 Taf. 1 Karte. 1935 .... 100: —

N:o 111. Lokka, Lauri. Über den Chemismus der Minerale (Orthit, Biotit u. a.) eines Feldspatbruches in Kangasala, SW-Finnland. S. 1—39. 2 Abb. 1 Taf. 1935 .... 100: —

N:o 112. Hackman, Victor. J. J. Sederholm. Biographic Notes and Bibliography. P. 1—29. With a vignette. 1935 .... 80: —

N:o 113. Sahama (Sahlstein), Th. G. Die Regelung von Quarz und Glimmer in den Gesteinen der finnisch-lappländischen Granulitformation. S. 1—110. 5 Fig. 80 Diagr. 3 Taf. 1936 .... 160: —

N:o 114. Haapala, Paavo. On Serpentine Rocks in Northern Karelia. P. 1—83. 21 fig. 2 maps. 1936 .... 120: —

N:o 115. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, IX. P. 1—505. 83 fig. 20 planches. 1936 .... 400: —

N:o 116. Väyrynen, Heikki. Petrologie des Nickelerzfeldes Kaulatunturi—Kammikivitunturi in Petsamo. S. 1—198. 71 Abb. 36 Tab. 1 Karte. 1938 .... 200: —

N:o 117. Kilpi, Sampo. Das Sotkamo-Gebiet in spätglazialer Zeit. S. 1—118. 36 Abb. 3 Beil. 1937 .... 200: —

N:o 118. Brander, Gunnar. Ein Interglazialfund bei Rouhiala in Südostfinnland. S. 1—76. 7 Fig. im Texte u. 7 Fig. auf 2 Taf. 1937 160: —

N:o 119. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, X. P. 1—170. 30 fig. 4 planches. 1937 .... 200: —

N:o 120. Hyyppä, Esa. Post-Glacial Changes of Shore-Line in South Finland. P. 1—225. 57 fig. 21 tab. 2 append. 1937 .... 200: —

N:o 121. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XI. P. 1—166. 47 fig. 8 tab. 2 cartes. 1938 200: —

N:o 122. Hietanen, Anna. On the Petrology of Finnish Quartzites. P. 1—118. 20 fig. 8 plates. 3 maps. 1938 .... 200: —

N:o 123. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XII. P. 1—107. 20 fig. 3 planches. 1938 .... 200: —

N:o 124. Väyrynen, Heikki. On the Geology and Tectonics of the Outokumpu Ore Field and Region. P. 1—91. 11 fig. 2 maps. 1939 .... 200: —

N:o 125. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XIII. P. 1—119. 45 fig. 1 planche. 1939 .. 120: —

N:o 126. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XIV. P. 1—140. 60 fig. 4 planches. 1941 .... 150: —

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N:o 128. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XV. P. 1—183. 43 fig. 2 planches. 1943 .. 200: —

N:o 129. Lokka, Lauri. Beiträge zur Kenntnis des Chemismus der finnischen Minerale. Glimmer, Pyroxene, Granate, Epidote u. a. Silikatminerale sowie melnikowitähnliches Produkt und Shungit. S. 1—72. 48 Tab. 1943 .... 150: —

*N:o 130. Hietanen, Anna. Über das Grundgebirge des Kalantigebietes im südwestlichen Finnland. S. 1—105. 55 Fig. 8 Tafeln. 1 Karte. 1943 .... 250: —

N:o 131. Okko, V. Moränenuntersuchungen im westlichen Nordfinnland. S. 1—46. 12 Abb. 4 Tab. 1944 .... 90: —

N:o 132. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XVI. P. 1—196. 41 diagr. 9 tabl. 3 cartes. 3 fig. 1944 .... 200: —

N:o 133. Rankama, Kalervo. On the Geochemistry of Tantalum. P. 1—78. 1 fig. 8 tabl. 1944 .... 150: —

N:o 134. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XVII. P. 1—91. 59 fig. 1 carte. 1944 .... 150: —

N:o 135. Sahama, Th. G. Spurenelemente der Gesteine im südlichen Finnisch-Lappland. S. 1—86. 12 Fig. 29 Tab. 1945 .... 150: —

N:o 136. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XVIII. P. I—XXXVIII; 1—67. 3 diagr. 11 tabl. 2 cartes. 11 fig. 2 planches. 1945 .... 200: —

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N:o 138. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géolo-

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