GEOLOGINEN TUTKIMUSLAITOS

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THE STRUCTURE OF AN ARCHEAN AREA: ORIJÄRVI, FINLAND

BY
HEIKKI V. TUOMINEN

WITH 16 FIGURES IN TEXT AND 6 PLATES

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Helsinki 1957. Valtioneuvoston kirjapaino

CONTENTS

INTRODUCTION

The Orijärvi region in SW Finland forms a part of an Archean schist belt belonging to the Svecofennian orogeny. Thanks to the classic papers of Eskola (1914, 1915), it has been one of the key areas of Archean geology and the metamorphism of deep-seated rocks.

The area was investigated anew in the years 1945—1952 by Suomen Malmi Osakeyhtiö (The Finnish Ore Company). The purpose was to find new ores in this old mining region. The search resulted in the opening of two new mines, the Aijala copper mine and the Metsämonttu zinc mine.

For six years five full-time geologists and two geophysicists participated in the project. In the summer time they were assisted by some ten students. Only in 1945 and in 1952, the first and the last year of the investigation, was the number of workers smaller.

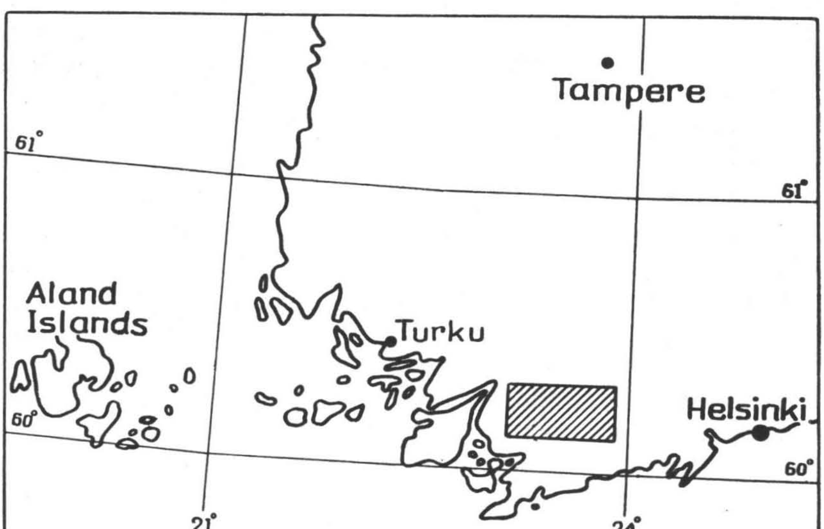

Fig. 1. Location of the Orijärvi region.

A detailed geologic and magnetic mapping, partly supplemented by electromagnetic measurements, was performed in an area of about 500 km². Besides, several reconnaisance surveys were made in the surrounding areas.

The author has compiled the original detail maps on a small scale in order to obtain a view of the dominating regional structures. These small-scale maps summarize a field material of records obtained from tens of thousands of outcrops and hundreds of drill holes, combined with about 500 000 magnetic and 200 000 electromagnetic observations. This material, if drawn up in tabular form and printed in small type, would fill at least 4 000 pages of the present journal.

The structural picture thus obtained differs sharply from the smooth-lined plastic regional structures shown by the recent maps of the Finnish Archean (Parras 1941, Hietanen 1943, 1947, and others).

The location of the area is shown in Fig. 1.

PREVIOUS WORK

At the beginning of the investigations very little was known about the tectonics of the Orijärvi region. Modern geologic maps, made by Erkki Mikkola (unpublished), were available only of the surroundings of Karjalohja and Lohjansaari. They form the easternmost part of the region.

The classic study of Eskola (1914) was made at a time when the concepts of structural analysis were little known. The paper reveals an interest mainly in petrology. According to Eskola, steep isoclinal folding is characteristic of the region. The axes of the folding, as seen from the small folds, always plunge to the east at angles varying from 10 to 70 degrees. The maps of Eskola are entitled »petrological maps» and do not give any clear idea about these structures.

In this respect the maps of Erkki Mikkola form a sharp contrast to those of Eskola. They show continuous beds folded into plastic anticlines and synclines, which are strikingly visualized in his maps. The fold axes and folds are relatively gentle as compared to the steep axes and isoclinal folds of Eskola (1914).

Later papers on the geology of the Orijärvi region follow the structural ideas of Erkki Mikkola or — those of Wegmann[1]) (Tuominen and T. Mikkola 1950, Tuominen 1951, T. Mikkola 1955, Salli 1955, Seitsaari 1955).

A technical report on the investigations discussed in the present paper was published by Tuominen, T. Mikkola and Simola (1956).

[1]) See Eskola (1941).

MORPHOLOGY

The relief of the area is low, like the relief of the Finnish Archean in general. The highest summits are about 100 meters above the sea level, and about 50 meters above the nearby lakes. The maximum relative height differences of the rock relief may be estimated at 100 meters.

There is a close relation between the tectonics and the topography. Valleys and ridges parallel to arched rock structures occur. They are, however, not very marked. The most prominent topographic features follow rectilinear fault systems characteristic of the Baltic shield. The valleys occur along the fault zones consisting of more or less broken rock. Small topographic differences in height between different blocks also exist. Further, the effects of faulting are also evident in the distribution and directions of the lakes and rivers, in the distribution and forms of the outcrops and in the distribution, pattern and fabric of the rocks.

SURVEY TECHNICS

COORDINATION OF MAPS

In order to coordinate the different surveys, they were tied to a picket line grid. At first separate grids were used for separate areas. As a rule these were parallel to the local average strike of the rocks as far as this was shown by the maps available.

Very soon, however, a general grid for the whole area was constructed. This followed the kilometric coordination of the official maps made in Transversal Mercator Projection.[1]) The distance between the picket lines was normally 0.5 km.

MAGNETIC SURVEY

The magnetic observations were made along parallel lines 40 meters, later 50 meters, apart, while the distance between observation points along the lines was normally 20 meters and very often only 10 meters. The survey lines were mostly in a N—S direction. However, in areas where the general strike deviates from north less than 45 degrees, the survey lines were turned W—E. The advance from one picket line to another took place pedometrically by the aid of a compass.

The instrument used was the Arvela magnetometer, adapted for the vertical intensity. The zero level, which is arbitrary, was chosen experimentally and corrected according to the geographic magnetic gradient. Thanks to this and some other corrections, the maximum error did not exceed $\pm$ 35 gammas. Observations made during magnetic storms were repeated. The results were presented in the form of contour maps 1 : 2 000.

[1]) These coordinates are indicated on all the maps included in the present paper.

ELECTROMAGNETIC SURVEY

The observation density was the same as in the magnetic survey. A dual-frame field ratio meter (»Turam») was used. The exciting cable was earthed at both ends and layed out parallel to the local average »strike». The current used had a frequency of 1 000 c/s. Profiles were run perpendicular to the cable. The results were compiled to maps 1 : 2 000.

During the first years the electromagnetic survey advanced side by side with the magnetic survey. Later it was restricted to areas critical from the point of view of possible ores.

GEOLOGIC SURVEY

At the beginning the geologic mapping was also based on the dense separate picket line grids. The maps were drawn to the scale 1 : 2 000. When these grids were replaced by the coarse general grid, the scale of the geologic mapping was reduced to 1 : 4 000. The outcrops and standard observations were then mapped on air photographs of this scale.

In some parts of the area only a general mapping was carried out. The scale was 1 : 10 000 or 1 : 20 000.

The areas mapped with the different accuracies are to be seen in Fig. 2.

REDUCTION AND COMPILATION OF FIELD MAPS

MAGNETIC MAPS

The many contours of the magnetic maps could not be presented in a small scale. However, it was found that the contours of +200 and +400

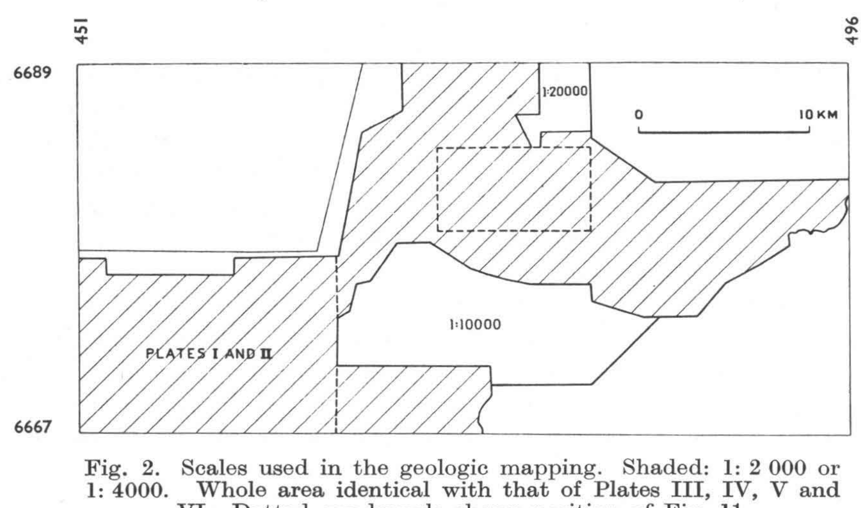

Fig. 2. Scales used in the geologic mapping. Shaded: 1: 2 000 or 1: 4000. Whole area identical with that of Plates III, IV, V and VI. Dotted quadrangle shows position of Fig. 11.

gammas reveal rather well the continuities and discontinuities in the structure of the area.

The reduction of the magnetic maps was done in the following way: The original contour maps 1 : 2 000 were photographically reduced to 1 : 10 000. On these maps the intervals of 200—400 gammas and more than 400 gammas were shaded in different ways. The maps thus obtained were photographically reduced to the scale 1 : 100 000 (Plate III).

The original contours were drawn without any consideration of geologic orientation. The only thing which might produce an erroneous orientation effect is the different density of the observation points in different directions. However, this hardly affects the orientation of the magnetic bands seen in the final map.

ELECTROMAGNETIC MAPS

The reduction of the electromagnetic maps was carried out, principally, in the same way as the reduction of magnetic maps. All the conductive zones of the 1 : 2 000 maps appear separately on the 1 : 100 000 map as well. From the different data of the original maps, however, only the following have been retained: Zones where the phase difference is more than 10 degrees per 20 meters, and those where it is less than this value have been marked in different ways.

In a physical sense [1]), the conductivities appearing in this area are low. Therefore, the phase differences are the most sensitive indicators of the conductivity differences and, accordingly, also of the differences in the physical character of the rocks. This is the reason why phase differences have been given in the maps. Our main interest is, however, in the origin, distribution and orientation of the conductive zones. The numerical values reveal relatively little in this connection.

If there are several closely spaced conductive zones, it is sometimes difficult to assertain their direction through the density of observation points used. In such cases the conductive zones have normally been drawn parallel to the local strike of rocks. An *en echelon* pattern of short conductive zones, as appears on the map, is possibly formed in this way and may, therefore, give a wrong picture. In these cases the trend of the *en echelon* pattern, as a whole, probably shows the trend of the conductive zones. Further, conductive zones parallel or nearly parallel to the survey lines (i. e., perpendicular to the cable) may have been left unobserved (Fig. 4), or their trend may come out incorrectly. Eventual errors of this kind have, however, very little effect on the general picture given by the electromagnetic map.

[1]) Personal communication by H. Jalander.

GEOLOGIC MAPS

The original outcrop maps 1 : 2 000 and 1 : 4 000 were photographically reduced to 1 : 10 000. In this scale the map was slightly generalized by combining the very close-lying outcrops. The outcrop areas were colored according to the character of the rocks. Then the map was reduced by means of color photography to the scale 1 : 50 000. The final map was drawn on the basis of this and the corresponding geophysical map. After this a reduction to 1 : 100 000 was performed photographically (Plate IV).

No tectonic symbols have been inserted in this map. The tectonic observations are represented separately in the form of structure diagrams (Plate V). Further, an interpretative tectonic map has been made (Plate VI).

In order to understand the structure diagrams in Plate V, the following definitions are given: Foliation is the planar orientation of minerals. This may be parallel to the layers and strata, or intersect them. Both types are common but can not always be distinguished in the field. — Lineation is the linear orientation (alinement) of mineral grains or grain aggregates. When the lineation and fold axis have been observed in the same place, and are parallel, the fold axis only is recorded. The fold axes are axes of small folds visible in single outcrops.

STRUCTURAL SIGNIFICANCE OF THE GEOPHYSICAL MAP

As is revealed by the foregoing discussion, the magnetic map is almost absolutely free of any geological interpretation and bias, and the electromagnetic map also meets high demands in this respect. Their geological meaning, however, is a matter of interpretation.

The magnetic »anomalies» are evidently caused by magnetic minerals, mainly magnetite and pyrrhotite, occurring in the rocks.

Characteristic of the magnetic map (Plate III) is that the separate areas of higher intensities form more or less broken bands. In the area north of Orijärvi these bands are distinctly parallel to the strata. Here the most consistent bands are caused by layers of diopside amphibolite, skarn and banded iron ore.

Equally high intensities are caused by the same rocks in other parts of the map area as well. However, the bands are usually not so continuous and sharp as on the northern side of Orijärvi. Particularly in the western parts of the area investigated, between Perniö and Kuovila, the magnetic bands themselves, as well as their geological meaning, are obscure. Obviously part of the bands, here, as also elsewhere, are brought about by mineralizations following secondary shear zones. In most cases it is impossible to separate them from bands lying parallel to the strata. At any rate, there exists no uniquely determined interpretation of the geologic significance of the magnetic bands.

The breaks occurring along the bands may be caused by several factors. For instance: 1. The amount of magnetic minerals may be smaller. 2. The rocks may be covered by sediments. 3. The rock cover above the magnetic rock may be thicker. 4. The magnetic layer may be partly or totally cut by other rocks, or 5. the layer may be cut by faulting. Several of these factors may be present simultaneously.

The breaks occur in most cases along the linear valleys characteristic of the area. They are repeated through several magnetic bands. The valleys are normally covered with Pleistocene deposits and, besides, often with water. Excavations and drill holes have shown that their bottom generally consists of brecciated rock and fault gouge. Very often these occur in conjunction with brick-red aphanitic mylonites (p. 20), to which disseminated hematite gives the color.

The rocks of this kind are characteristic of fault zones, and the dislocation is, in most cases, clearly indicated by the breaks of the magnetic bands (Fig. 3 and 4).

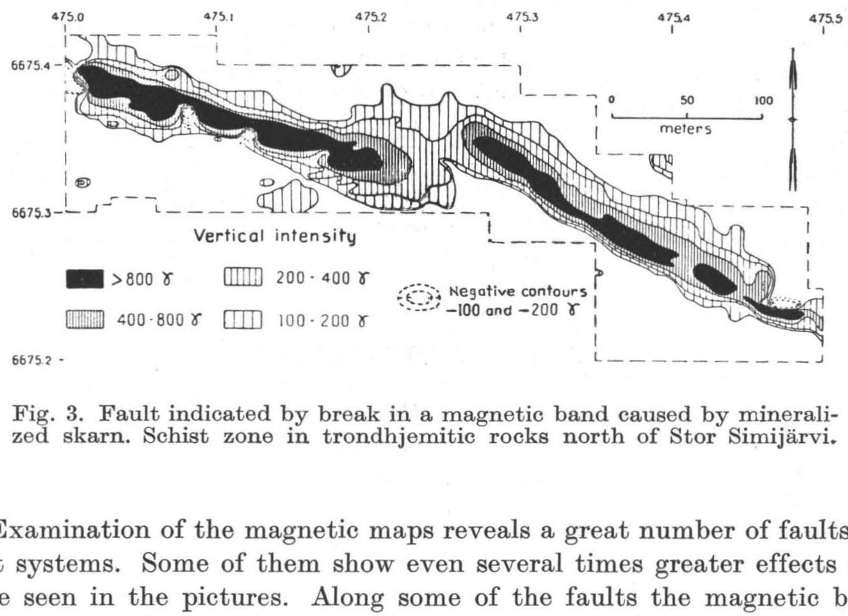

Fig. 3. Fault indicated by break in a magnetic band caused by mineralized skarn. Schist zone in trondhjemitic rocks north of Stor Simijärvi.

Examination of the magnetic maps reveals a great number of faults and fault systems. Some of them show even several times greater effects than those seen in the pictures. Along some of the faults the magnetic bands are bent. In other cases they are bent as well as broken, or there may be just a sharp break.[1])

[1]) In order to obtain a better idea of the important faults or fault systems, the transparent tectonic map of Plate VI may be superposed on the geophysical map (Plate III).

The conductive zones appearing on the map originate partly in conductivity in the rocks and partly in soil, particularly clay. When the topography of the rock surface is uneven and the valleys are filled with clay, relatively sharp anomalies may occur.

Generally, it is impossible to tell without special investigation the character of a conductive zone. Several factors may have produced the anomaly. Conductivity in the rocks is brought about either by conductive minerals or by electrolyte solutions, or both. Rocks containing conductive minerals normally form zones that are parallel to the strata or to secondary structures. The electrolyte solutions are characteristic especially of fault gouge or other zones of broken rock. They are further characteristic of zones of deep weathering, which is common in faults, broken rocks and rocks rich in sulphide minerals. On the other hand, however, the valleys filled with clay follow the very same zones. Hence, irrespective of whether the conductive zones observed are caused by rocks or by clay, they are in any case related to the structure of the rocks.

The geophysical map (Plate III) shows that some of the conductive zones run parallel to the magnetic bands. However, a considerable number of them follow strictly the lines intersecting the magnetic bands, i. e., the fault lines. Fig. 4 shows this fact in detail.

As a whole, the geophysical map gives a good picture of the structure of the area. Above all, the existence of the faults and their positions are indicated with accuracy. Secondly, conclusions about the relative movement along the faults may be drawn. This will be shown later in the paper. There are limitations to the validity of the map in showing the trend of strata in some parts of the area. However, it is not possible to trace them without the geophysical map.

ROCKS OF THE REGION

The map of Plate IV illustrates the main rock groups of the region. Petrographically, the classification is practically the same as that used by Eskola (1914). The rock names, however, are partly different. A short comparison of the names is given below.

Present paper	Eskola (1914)
Leptite	Even-grained leptite, cordierite-leptite and phyllite
Leptite gneiss	Leptitic gneiss
Leptite with insets of quartz	Blastoporphyritic leptite

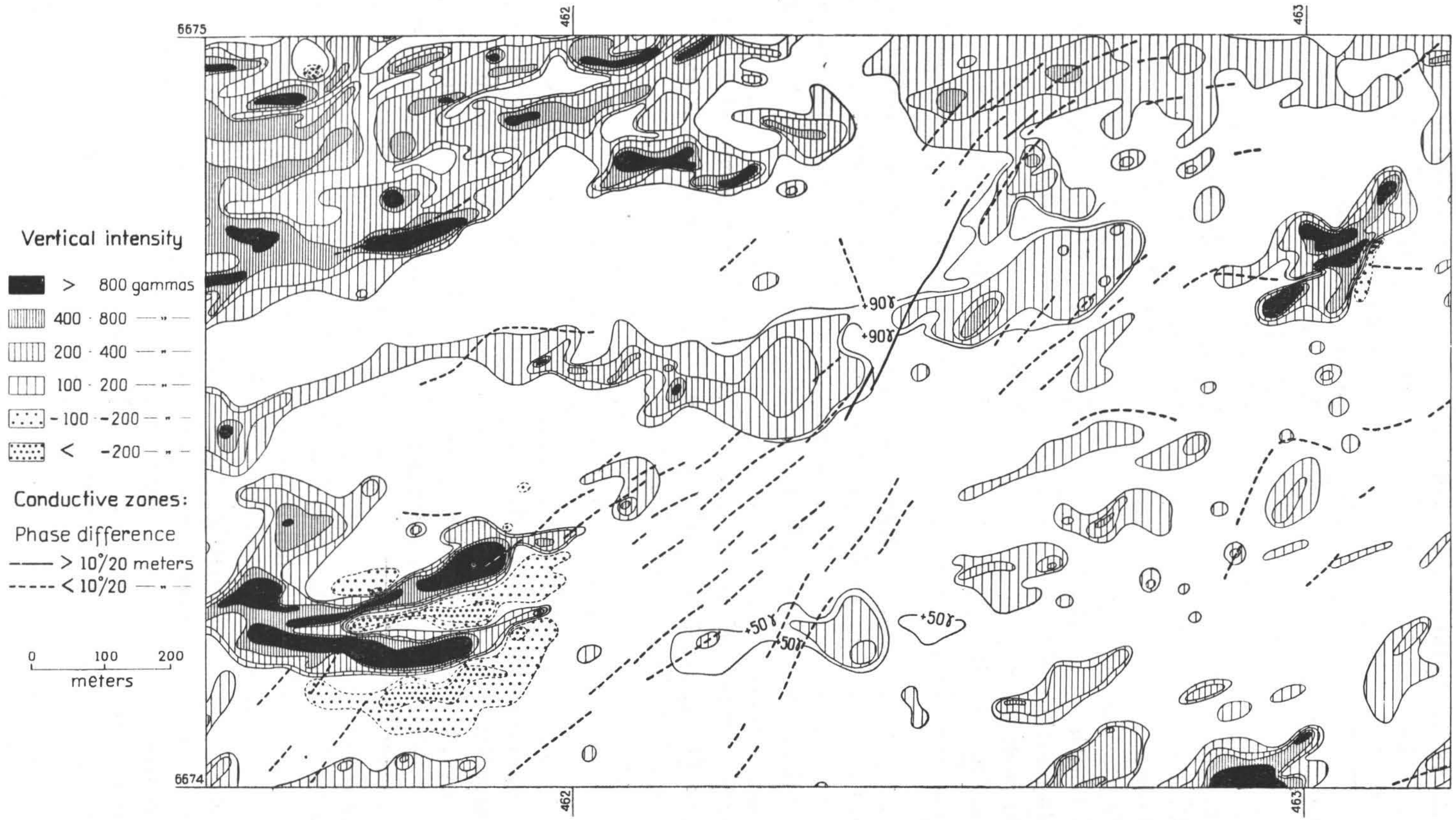

Fig. 4. Dislocations indicated by conductive zones, and breaks in magnetic bands. One of fault systems seen in magnetic survey strikes NNW and is parallel to measuring direction of electromagnetic survey. Therefore this fault system was not detected clearly enough electromagnetically. Drill cores across the solid line (phase difference > 10°/20 m) contain fault gouge and red mylonites.

Cordierite-anthophyllite rock and related rocks	Cordierite-anthophyllite rock, cordierite-anthophyllite-gneiss, quartz-cordierite-rock and cordierite-gneiss
Polymict conglomerate	Agglomerate
Marble	Limestone
Skarn	Skarn
Diopside amphibolite	Diopside-amphibolite
Peridotitic rock	Peridotite
Amphibolite	Amphibolite
Amphibolite gneiss	Diorite and gabbro
Quartz-dioritic, granodioritic and trondhjemitic rock	Quartz-diorite, granodiorite and oligoclase-granite
Granitic rock	Microcline-granite
Tectonic breccias (p. 20)	Agglomerate (in part)

Contrary to Eskola, genetical rock names are avoided except in some clear cases. Thus, names like granodioritic rock or peridotitic rock mean that the rock in question has, roughly, the petrographic appearance of granodiorite or peridotite. The name refers neither to a magmatic nor to a non-magmatic origin.

The petrography of the various rock types has been discussed thoroughly by Eskola (1914, 1915) and others. The rock groups seen on Plate IV are briefly described in the following.

LEPTITE AND LEPTITE GNEISS

The leptites are markedly layered, almost aphanitic gneisses as far as their groundmass is concerned. The composition of the different layers varies greatly. The coarser varieties, with their minerals visible to the unaided eye, are called leptite gneiss. These varieties are common in the area to the west of Koski, and in the surroundings of Karjalohja and Lohjansaari. Besides, they are common near the contacts of the granitic and trondhjemitic rocks into which they often grade.

Besides the predominant quartz and feldspar — potash feldspar or plagioclase, or both — the leptites and leptite gneisses always contain more or less mica. Almost everywhere there are layers with porphyroblasts of almandite, cordierite, sillimanite or andalusite. Some other layers are marked by hornblende or diopside, or both.

Small insets and inset-looking granular nodules of quartz and feldspar are common in the leptites and leptite gneisses. The distribution of the insets does not strictly follow the general layering of the rocks. In some cases, leptites of this type even seem to form dikes brecciating other rocks, as do the corresponding trondhjemitic rocks. It is remarkable, however, that the insets of quartz show the best crystal forms in zones of intensive mylonitization.

CORDIERITE-ANTHOPHYLLITE ROCK AND RELATED ROCKS

Fig. 5. Small open anticline situated in leptite gneiss with porphyroblasts of cordierite and almandite. Core filling of fold is cordierite-anthophyllite rock (lighter, above the knife). Fold is more open than apparent in picture. View from west. Eastern shore of Lake Makarlanjärvi, Perniö, west of western border of map. Photo Tuominen.

These rocks have been the most discussed rocks of the area (Eskola 1914, 1950, Tuominen and T. Mikkola 1950, Tuominen 1951). They are characterized by exceptionally large porphyroblasts of cordierite, which may be up to 30 cm in length. The most extreme member of this group is the cordierite-anthophyllite rock, consisting mainly of cordierite and anthophyllite. The other members form petrographically intermediate types between this and the common cordierite leptites and gneisses.

Normally the rocks in question occur as lenses in the cordierite leptites and gneisses. These are often phacolithic core fillings of small folds (Fig. 5). The map indicates merely the areas where these rocks are common, not the separate bodies.

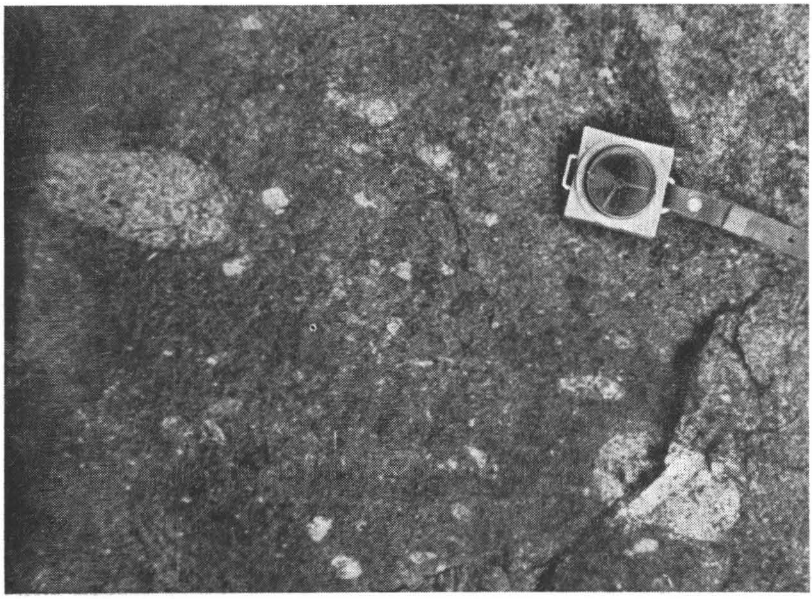

Fig. 6. Polymict conglomerate. Halfway between Kisko and Orijärvi mine. Photo T. Mikkola.

POLYMICT CONGLOMERATE

Layers of polymict conglomerate occur between Kisko and Jylynjärvi. The rock consists of round pebbles of granitoid rocks, amphibolite, acid fine-grained schists and quartz, embedded in an acid gneissose ground mass (Fig. 6). The diameter of the pebbles varies from about 20 cm down. The rock is interlayered with cordierite-andalusite leptites. The top of the strata, which is to the north, may be seen from the graded bedding.

MARBLE AND SKARN

Marble and the associated femic lime silicate rocks form in most cases thin layers intercalated with leptite, diopside amphibolite and amphibolite. Also the continuous zones of marble and skarn indicated on the map contain thin layers of other rocks. The thickness of the individual layers of marble or skarn is usually a few centimeters and seldom more. Thicker lenses of marble occur as a result of tectonic flow (Fig. 15).

The skarn rocks are usually rich in magnetite and often associated with layers of iron ore. Therefore they were easily traced in the magnetic survey. Also sulphide minerals are common in them, and the host rock of the sulphide ores is mostly skarn.

DIOPSIDE AMPHIBOLITE

The diopside amphibolites are dark and light densely layered rocks. The dark layers consist mainly of plagioclase and hornblende. The light layers contain abundant diopside but otherwise show greatly varying compositions. In some places olivine is met with. Thin layers of leptite and marble are common (T. Mikkola 1955).

PERIDOTITIC ROCK

A large area of peridotitic rocks occurs at the northern border of the region. Small bodies are spread over an area between this and Toija. These rocks have recently been discussed by T. Mikkola (1955).

According to him, they consist of large crystals of olivine and one or two of the following minerals: augite, diopside, biotite, anthophyllite, cummingtonite, set in a fine-grained ground mass of edenitic hornblende. Usually these rocks are associated with diopside amphibolites, rarely with other rocks rich in lime. Within the diopside amphibolites they form concordant, massive or more or less layered, beds or lenses. All mineralogically transitional forms occur, ranging from the peridotitic rocks to the common diopside amphibolites.

As T. Mikkola (1955) concludes, the relations between the peridotitic rocks and diopside amphibolites are similar to the relations occurring between cordierite-anthophyllite rocks and cordierite leptites.

AMPHIBOLITE

The amphibolites mainly consist of plagioclase and hornblende. In some cases, they may attain hornblenditic compositions. Massive as well as densely layered types occur. In addition, they form thin layers intercalated with leptite, marble and skarn.

When the amphibolite is densely intercalated with skarn, the rock may be called diopside amphibolite. Generally there were great difficulties in distinguishing systematically between amphibolites and diopside amphibolites. In most cases the beds of amphibolite contain layered parts, with some layers rich in diopside. Therefore, a part of the amphibolites given on the map, could obviously be classed as diopside amphibolites.

The amphibolites discussed seem to form conformable layers. Some narrow dikes also occur (Eskola 1914).

AMPHIBOLITE GNEISS

The amphibolites in the vicinity or within the trondhjemitic areas generally exhibit a coarser grain than other amphibolites. They are in most cases distinctly gneissose. Therefore, analogically to leptite gneisses, they are here called amphibolite gneisses.

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There are small patches of coarser rocks, gabbroic and dioritic, within the amphibolite gneisses. Therefore Eskola (1914) regarded them as strongly metamorphosed and deformed gabbros and diorites.

Such an interpretation is, however, hardly correct. The areas of trondhjemitic and related rocks contain small patches of leptite gneiss. Especially in the area south of Määrijärvi, there are several larger and smaller patches of leptite gneiss intercalating with amphibolite gneiss and skarn. Small deposits of magnetite are also common. With increasing grain size, the leptitic gneisses seem to grade over to trondhjemitic rocks. Simultaneously, the grain size of the amphibolites also increases. The same features occur throughout the large arch of amphibolite gneisses appearing in the middle of the map (Plate IV).

At any rate, irrespective of the origin of these rocks, the term amphibolite gneiss seems more descriptive of them than the names gabbro or diorite.

QUARTZ-DIORITIC, GRANODIORITIC AND TRONDHJEMITIC ROCK

The rocks of this group have in general a petrographic character, which may be called trondhjemitic. Also quartz-dioritic and granodioritic types occur. In places the rocks may attain granitic compositions (Eskola 1952 pp. 128—130). Because of the prevalence of the trondhjemitic rocks, however, just this name is used for the group elsewhere in the paper.

Generally the rocks considered are medium-grained and more or less gneissose. Besides, there are also fine-grained types characterized by insets or small nodules of quartz, and plagioclase.

The contacts towards the leptites are often very gradual [1]). Towards the amphibolites the change is, petrographically, rather sharp. Very commonly, however, there is a broad zone where the amphibolite is densely brecciated by the trondhjemite. Generally fragments of amphibolite — »dark inclusions» (Eskola 1914) — are common in this rock.

GRANITIC ROCK

This group includes all granitoid, migmatitic and pegmatitic rocks in which the potash feldspar generally exceeds the plagioclase.

The area in the NW-corner of the map consists mainly of red »Perniö granite», characterized by large crystals of microcline in a medium-grained ground mass. In this rock there are many relic structures indicating granitization.

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[1]) In cases of uncertainty whether a rock at the gradational contact should be included among the leptites or the trondhjemitic rocks, the older designation, if known, was applied.

The other granitic areas, in the southern and eastern parts of the map, are mainly migmatitic with remnants of all the rocks aforedescribed. The granitic parts are generally even-grained »Hangö granite».

Pegmatitic dikes are common, particularly in the easternmost parts of the area.

MIXED ROCKS

It appears from the descriptions in the foregoing that the layered rocks of the area — leptite, diopside amphibolite, amphibolite, marble and skarn — are often densely interlayered.

In these cases the ground color in the map represents the main rock, and the stripes the other rocks. In a few cases, however, there have been difficulties in deciding which of the rocks is in the majority. At the narrow leptite belt at Kuovila, for instance, the rock could almost as well have been described as diopside amphibolite with stripes of leptite and marble.

Further there are fine-grained rocks with granitic and trondhjemitic layers or dikes. On the other hand, inclusions and layers of fine-grained rocks occur in the trondhjemitic and granitic rocks.

ORIGIN OF THE ROCKS

Actually, all the rocks of the region are highly metamorphic, and even their bulk composition is more or less changed. As far as can be judged by their present appearance and geologic relations, they seem to have been formed in the following ways.

The leptites, diopside amphibolites, skarn and marble have been derived from argillites, marl and limestone. A part of the amphibolites has also come from marl. Other amphibolites originate from basaltic lavas and tuffs or near-surface intrusions.

The cordierite anthophyllite rock and related rocks have been formed mainly from argillites, in shear conditions, by removal of certain constituents, particularly, alkalis and lime (Tuominen and T. Mikkola 1950, Tuominen 1951). Similarly, the peridotitic rocks have been derived from the marls (T. Mikkola 1955).

The granitic rocks of the region are obvious products of diffuse granitization. Considering the trondhjemitic rocks there is evidence in favor of a similar interpretation. This conclusion is in part based on the fact that magnetic bands of the environment continue through the trondhjemitic areas. The question will be discussed in future papers. The leptites with insets of quartz will also be discussed later on.

Efforts have been made to clear up the sequence of the strata (T. Mikkola, see: Simonen 1953). Owing to the very complicated tectonics and variable metamorphic appearance of the rocks, this is, however, difficult.

TECTONIC BRECCIAS

Mylonites and breccias of different types and ages are common in the region. Together with very recent products of crushing there are healed breccias and mylonites.

In the mines of Aijala and Metsämonttu there are several faults accompanied by crushed rock and clay-like gouge. The rock fragments are coated with slickensides, and, sometimes, cemented together by carbonate or skarn. Similar gouge and crushed rocks underlie the valleys and gullies. Normally, there are all intermediate types from plastic gouge to fresh unaltered rocks.

In many places, parallel to the crushed zones, there are brick-red, very hard aphanitic mylonites and breccias. These are seen, for instance, in several outcrops bordering the valley of Lake Kiskon Kirkkojärvi. The red color comes from very fine divided hematite. In other cases, the mylonites and breccias are greenish. Then they consist of small rock fragments in an aphanitic matrix of quartz and epidote.

The densely layered rocks form many kinds of tectonic breccias. The competent layers are broken into pieces surrounded by the incompetent ones (Fig. 7). In other cases thin layers, whether competent or not, are broken and form fragments within the thicker layers. The layered character

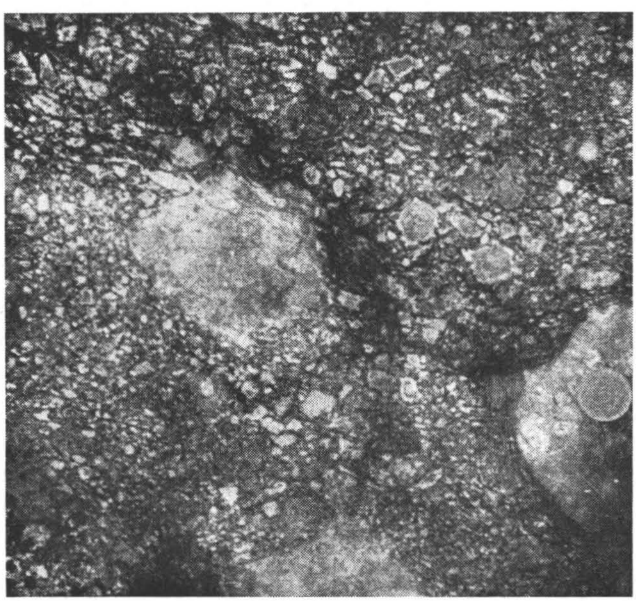

Fig. 7. Fault breccia in layered cordierite leptite. 3 km ENE from Aijala mine, east side of road. Photo Tuominen.

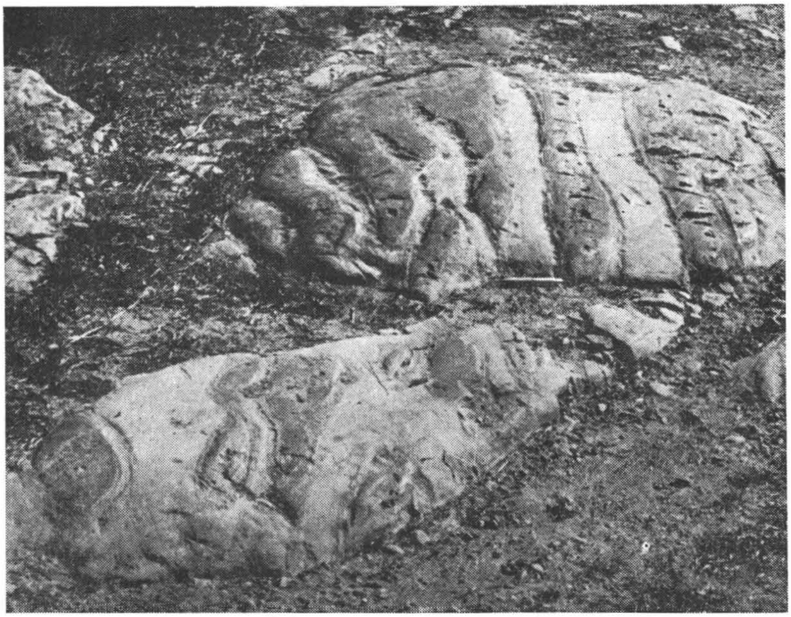

Fig. 8. *Boudinage* in layered amphibolite, Kisko. Photo T. Mikkola.

of the rock is generally destroyed, but may be still traceable in some places. The fragments may be angular or more or less rounded.

Breccias of this kind are common in association with almost all the fault zones. Besides, there are other breccias in the region, that are products of *boudinage* phenomena (Fig. 8).

FOLDING

The trend of the main axis of the folding is roughly W—E, i. e., parallel to the schist zone. As deduced from small folds, it generally plunges to the east (p. 30).

The various rocks have been folded differently. The unlayered or slightly layered beds of amphibolite and leptite form open folds (Fig. 5). These are generally slightly asymmetric, with their southern limb steeper than the northern limb (Fig. 9).

On the other hand, the densely layered leptites, amphibolites and diopside amphibolites form often close, in some places almost isoclinal folds. All types between these and very open folds are common.

Isoclinal folding is particularly characteristic of marble. Thin intercalating layers of other rocks have in places folded with the marble. In other places they have broken into pieces. In a way the breccias so formed resemble intrusive breccias. Generally, the marble has yielded plastically

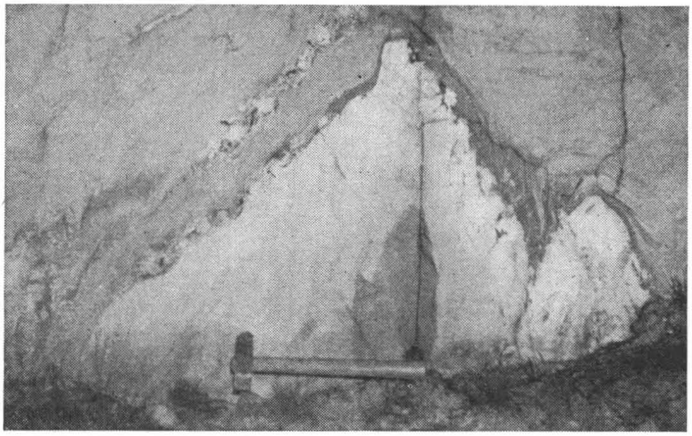

Fig. 9. Asymmetric fold in leptite gneiss with insets of quartz. The fold has gained more height owing to slipping parallel to fracture cleavage. View from west. Perniö, west of western border of map. Photo J. Tuura.

to all deformation (Metzger 1947). For instance, when faults intersect the beds of marble, this has often been squeezed into them.

In many cases, the banded iron ores (Fig. 10) as well as the cordierite-anthophyllite rock and the rocks related to it show a plastic past similar to that of marble.

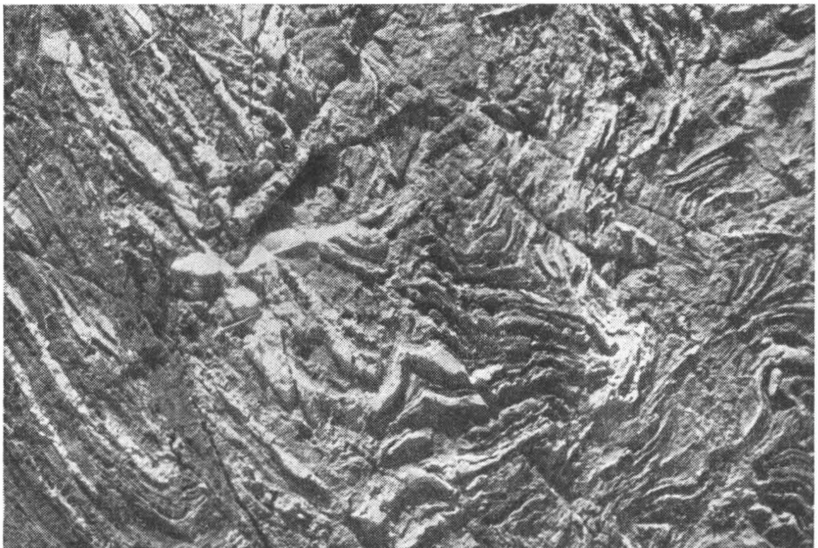

Fig. 10. Banded iron ore in skarn. West of Kuovila. Photo M. Tavela.

The height of the close and isoclinal folds is small, one meter or less. In a larger scale the layers show an open folding like that of the competent beds. Marble and the other highly plastic rocks are commonly squeezed out of the limbs and concentrated along the hinges of folds. This is observed in small folds the breadth of which is just a few meters. It is possible, however, that a similar concentration occurs in the thick piles of incompetent sediments along the hinges of the large regional folds.

Apart from a few clear cases, it is difficult to trace the large anticlines and synclines on the basis of the standard structural observations alone. This follows, partly, from the fact that no key horizon distinct enough is known.

The crest of the apparently largest anticline — or anticlinorium — of the region runs along the eastern branch of Lake Määrijärvi, seen in the center of the map (Plates IV and VI).

At the northern shore of this lake, the dragged beds of leptite gneiss dip gently, 0—40 degrees, to the north under the trondhjemitic rocks. At the southern shore the dip is 40—70 degrees to the south. Thus this anticline is asymmetric and leans slightly to the south similarly to the smaller anticlines mentioned.

Apart from the subordinate folds, north of this anticline the beds dip generally to the north. Northward from the Orijärvi mine, the dip decreases gradually. The trough of the syncline is in the vicinity of Kurkelanjärvi or still more north. Here, however, the conjunction of two or three broad fault zones completely disturbs the folded structures.

The other anticlines and synclines seen in Plate VI are deduced from the distribution of the rocks and the trend of the magnetic bands. Generally, this can be done only roughly. The location of the great syncline to the south of Stor Simijärvi (south of the center of the map) is, however, quite evident. The ratio between the lengths of the northern and the southern limb of the Määrijärvi anticlinorium is an additional example of the asymmetric character of the folding.

There are also numerous other folds deviating from the general folding. These folds are associated with faulting.

FAULTING[1)]

Small faults are visible in every outcrop (Fig. 9, 10 and 12). Larger ones generally run along the small gullies separating the different outcrops. An example is given in Fig. 13.

Similar conditions in a larger scale are seen in Fig. 11, which shows the outcrops north of Lake Orijärvi in the scale 1 : 50 000. The position of the area appears from Fig. 2. The amphibolites and diopside amphibolites

[1)] For previous works on Baltic shield see Edelman (1949) and Sederholm (1932).

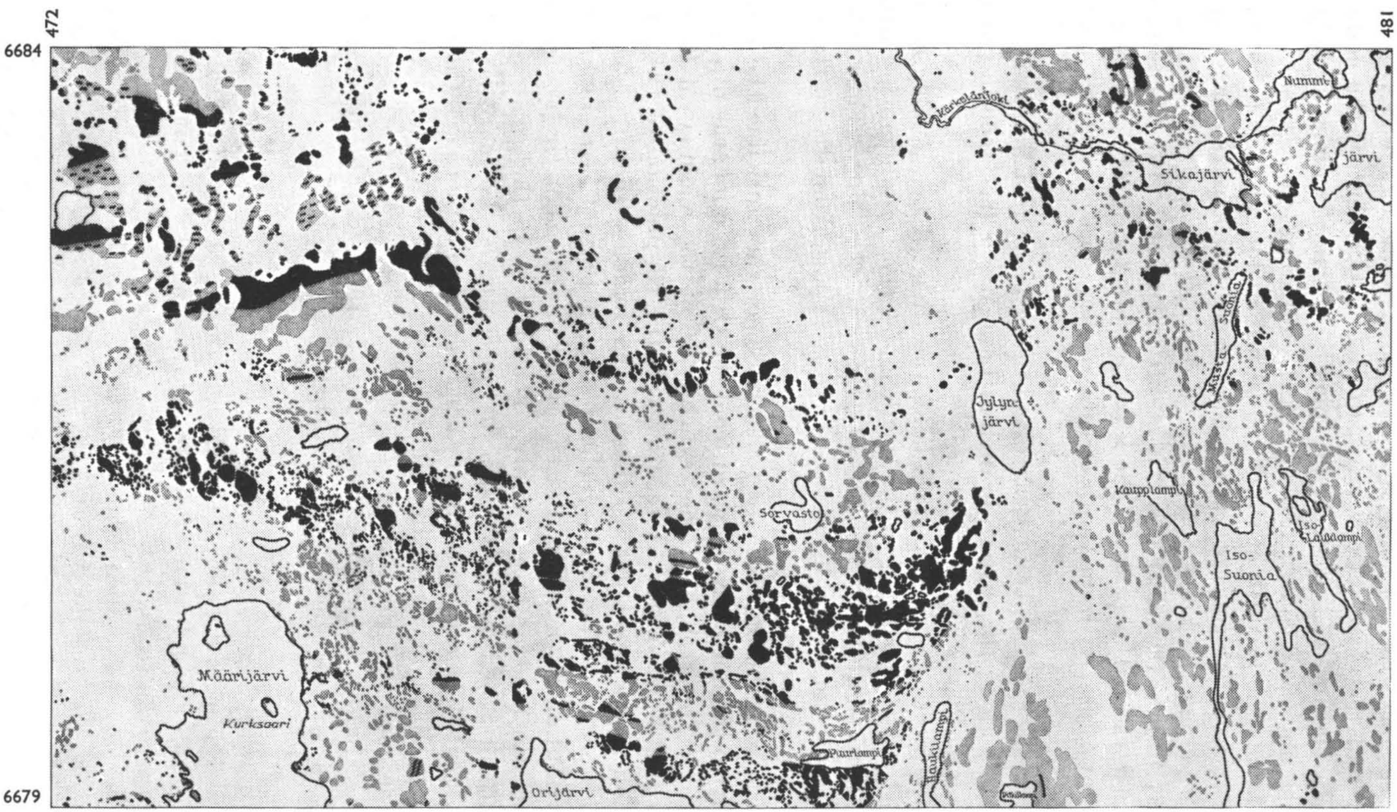

Fig. 11. Map of outcrops north of Lake Orijärvi, 1: 50 000. Black: amphibolite and diopside amphibolite. Gray: other rocks. Rectilinear interstices between outcrops are faults. Mapped by V. Hyppönen, A. Varma and T. Mikkola, with assistants. Position of area is seen in Fig. 2.

are shaded black while all the other rocks are gray. The interstices between the outcrops correspond to small gullies. These form several rectilinear systems along which dislocations have taken place.

The broad arch of the black-shaded patches consists of diopside amphibolite. At the east end this arch seems to be bent north towards the southern end of Lake Jylynjärvi. East of the valley of this lake the same rock is seen again at the northern side of the lake. The valley indicates a large fault along which the eastern block has been lifted up relative to the block at the western side of the valley. This fault is very clearly seen in the geophysical map (Plate III) as well.

To the north and NE of Lake Orijärvi there are some sharp gullies trending NE. Small dislocations along them are clearly visible in the layers shaded black. The eastern blocks appear to have been moved NE relative to the western ones. An obvious interpretation of the phenomenon, remembering the northern dip of the layers (p. 23), is: The eastern blocks have been lifted up relative to the western ones. Owing to faults of this kind the black-shaded layers have finally been completely cut off. This latter fault trends from the east end of Puurlampi to the south end of Jylynjärvi.

This means that the apparent bending of the amphibolite layers toward the north has been created by repeated faults. The character of other obvious fault systems seen on the map (Fig. 11) is a matter for future study.

Drag folds, connected with the faults, give some information about the relative movement along the faults. An example is seen in Fig. 14. The recumbent monocline seen in the photograph belongs to a fault zone forming the valley of Lake Seljänala, east of the center of the map. This fault is parallel to the fault of Puurlampi-Jylynjärvi. The crest of the monocline pointing WNW clearly indicates an overthrust in this direction.

The valley of Lake Kiskon Kirkkojärvi, west of Kisko, is a great fault zone, as indicated by the geophysical map. In the vicinity of Kisko, the W—E trending magnetic bands make a sudden turn to SW, parallel to the fault. So do the beds as well. When trending W—E, the beds generally dip to the north. After the turn the dip is to the SE at an angle varying from 40 to 90 degrees. Close to the northern border of the map a broad magnetic band indicates a similar turn along the same fault zone. The phenomenon is probably similar to that seen in Fig. 14.

Folds with steep axes occur along a fault zone following the NW branch of the Lake Määrijärvi. This zone forms the western border of the trondhjemitic area south of the Orijärvi mine. The dislocation is clearly visible in the magnetic bands. The axes of small folds seen on the islands and shores of the lake plunge steeply SSE (Fig. 15).

The same orientation is also seen on the small island of Kurksaari, famous for its big crystals of cordierite (Eskola 1914, pp. 203—208). This

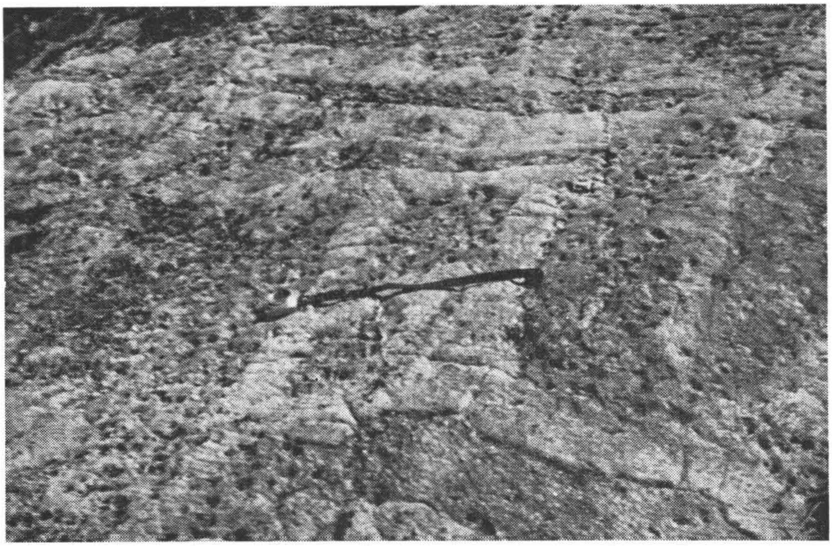

Fig. 12. Chessboard structure caused by two systems of shear zones crossing each other in cordierite gneiss. Nygruva, 0.5 km from Orijärvi mine. Photo T. Mikkola.

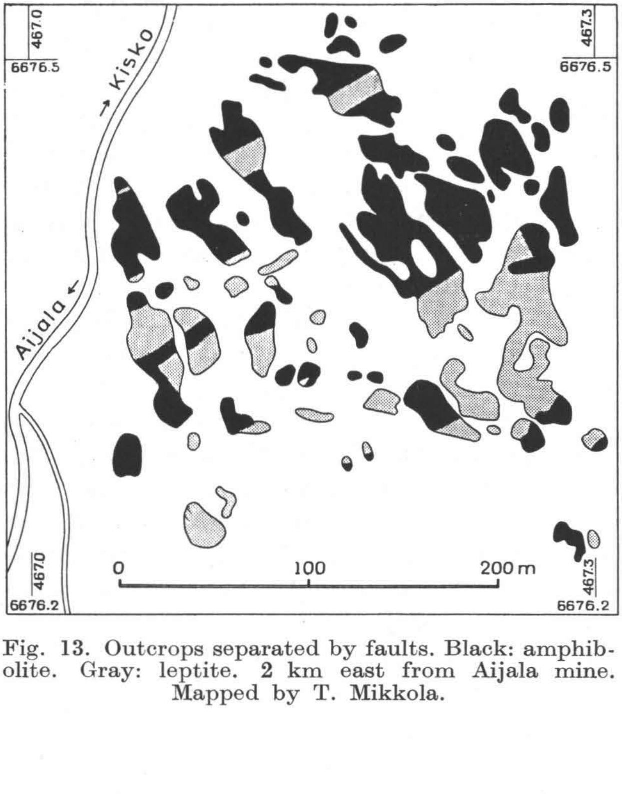

Fig. 13. Outcrops separated by faults. Black: amphibolite. Gray: leptite. 2 km east from Aijala mine. Mapped by T. Mikkola.

Fig. 14. Monocline in overthrust zone of Lake Seljänala. View from south. Rock is amphibolite gneiss. Head of largest cape on eastern shore of Lake Seljänala. Photo T. Mikkola.

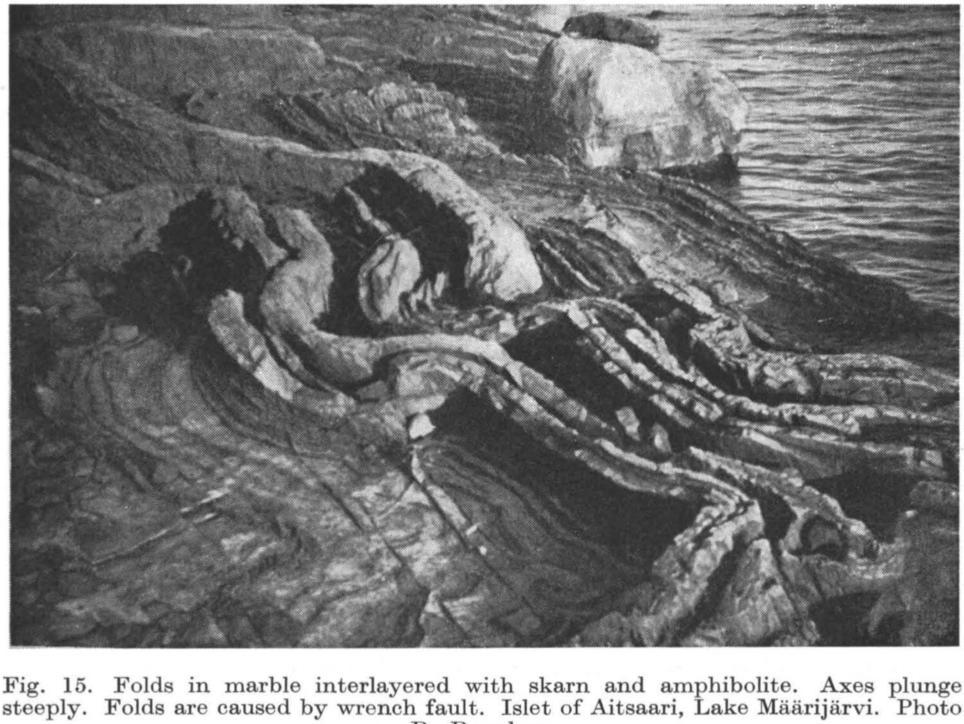

Fig. 15. Folds in marble interlayered with skarn and amphibolite. Axes plunge steeply. Folds are caused by wrench fault. Islet of Aitsaari, Lake Määrijärvi. Photo R. Rancken.

island is situated strictly at the line of the strongest dislocation. The cordierite-anthophyllite gneiss contains sharp-edged fragments of leptite and may thus be regarded as metamorphosed fault breccia. This fault zone is indicated on the map (Plate VI) as a wrench fault. A vertical movement may, however, also have taken place.

The geophysical map gives an impression that the syncline of Stor Simijärvi has been intersected along the line Aitsaari—Myllyjärvi trending N—S. East of this line the syncline is narrower than west of the line. The anticline of Määrijärvi is intersected at the east end of the lake. East of this line the anticline is broader than west of it. The phenomena indicate a relative uplift of the eastern block. Parallel to the latter fault, there are strong shear zones dipping about 40 degrees to the east. It is obvious, therefore, that the uplift of the eastern block is a thrust to the west.

Several smaller thrust faults are visible in the mines of Metsämonttu and Aijala. One of them dips 15 degrees to the south and shows a net slip of 300 meters. Another one dips about 60 degrees to the north. »Horses» of ore are dragged along the fault. The amount of the dislocation is unknown [1]).

Some of the most important fault zones of the region are shown in Plate VI. The dip and the relative movement are indicated if known. It is remarkable that all the faults whose character has been determined are thrust faults and thus indicate a lateral compression.

STRUCTURE DIAGRAMS

It appears from the foregoing that there are shear zones parallel to the faults. This fact is seen in Plates I and II. They are maps (1 : 50 000) representing the westernmost part of the region (Fig. 2).

Plate I shows the outcrops of this area. The trondhjemitic and granitic rocks are shaded black and all the other rocks gray.

Observations of foliation, fold axis and lineation made in the area are represented in the transparent Plate II, which can be superposed on the outcrop map. The plunge of the axes and lineations are given in degrees. The numerical value of the dip of the foliation is not given. Generally it varies between 70 and 90 degrees. Gentler dips, from 30 to 50 degrees to the east, are observed in two N—S striking zones only. These zones are at the east and west borders of the trondhjemitic area, left of the center of the map. Several long gaps between the outcrops in Plate I are faults. NW of Saarijärvi, there is a line with a sudden change in the size of the outcrops shaded black. It is a fault, the effect of which is seen in the topography: The southern block is moved down relative to the northern block.

[1]) Personal communications by Arno Varma and Aimo Mikkola.

Plate II shows that there are several systems of foliation crossing each other parallel to the faults. The fold axes and lineations also seem to be parallel to these. Which of these tectonic features are connected with the Svecofennian folding, can not be deduced from the map.

In order to study the problem, a great number of tectonic observations were plotted on the Schmidt net and drawn into contour diagrams. The result is seen in Plate V. The diagrams represent different areas of the Orijärvi region. Corresponding observations from the Mustio area, made by Härme (1954), were treated in the same way and the diagrams were included in Plate V. The Mustio area is indicated by the number VIII.

As the observation density is not the same throughout the areas covered by single diagrams, these have only a qualitative value. In addition, some of the maxima seen in the diagrams may contain several maxima lying close to each other.

The following features become evident on the basis of the diagrams: The most common strike of foliation is parallel to the schist zone. Foliations

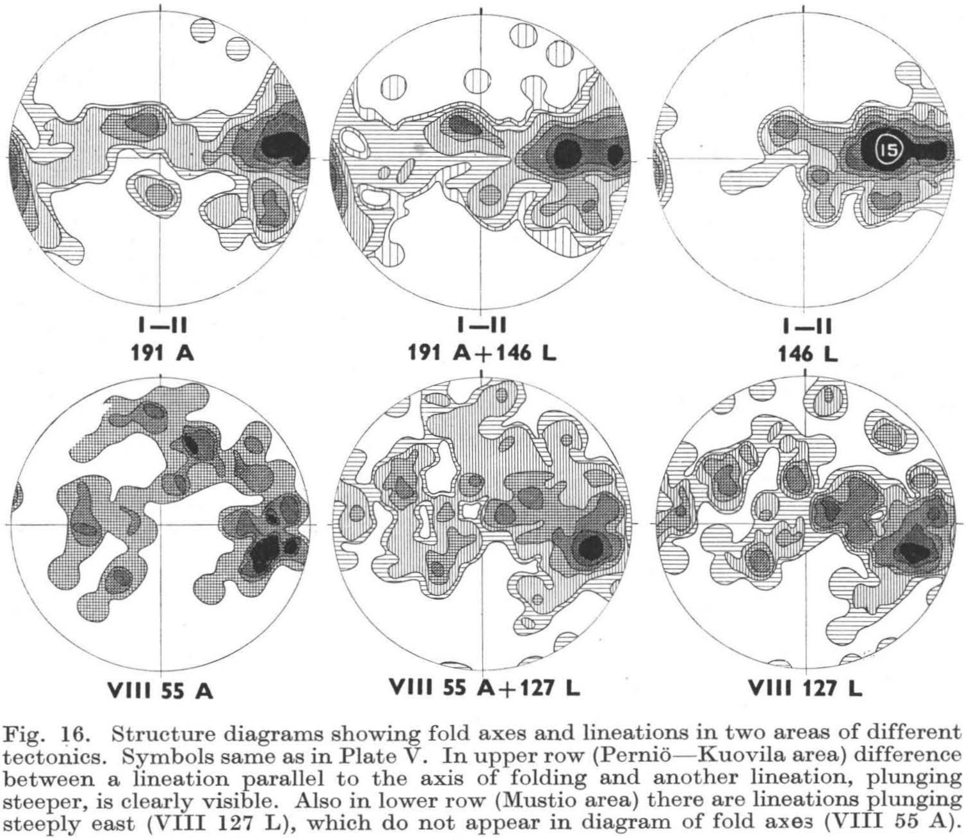

Fig. 16. Structure diagrams showing fold axes and lineations in two areas of different tectonics. Symbols same as in Plate V. In upper row (Perniö—Kuovila area) difference between a lineation parallel to the axis of folding and another lineation, plunging steeper, is clearly visible. Also in lower row (Mustio area) there are lineations plunging steeply east (VIII 127 L), which do not appear in diagram of fold axes (VIII 55 A).

showing a dip to the east are frequent, but foliations dipping to the west very rare. The diagrams combining all of the fold axes (I—VIII, 531 A) show a maximum plunge which is gentle to the east. It is obvious that this maximum gives the general attitude of the folding. The same maximum is seen also in the lineation diagram (I—VIII, 379 L). However, the lineation diagram shows another maximum close by, which is not seen in the fold diagram. Additional data are seen in Fig. 16.

This means that there are two general systems of lineation. One of them is parallel to the axis of folding, and plunges on the average 15—20 degrees to the east. The other one, plunging on the average 45 degrees to the east, is very probably connected with the overthrusting to the west (p. 25). Differences in petrofabrics are not known.

The diagrams of Plate V show considerable differences between the structural character of the eastern and the western part. In the east, gentle foliation parallel to the strata is common. The asymmetric character of the folds appears from the fact that gentle dips to the north are more frequent than gentle dips to the south (p. 21). In the western part (areas I and II), no gentle foliations are found.

The axis of folding in the Mustio area (VIII) deviates from the direction of the foliation. There is a possibility that the folds of the Mustio area do not belong to the general system.

Many of the features seen in the structure diagrams become understandable when compared with Plate VI.

STRUCTURAL POSITION OF THE TRONDHJEMITIC ROCKS

In all the papers on the tectonics of the Orijärvi region the mode of occurrence of the trondhjemitic rocks (oligoclase granite) has been a central object of interest (Wahl 1936, Eskola 1949, Tuominen and T. Mikkola 1950, Tuominen 1951, Saksela 1953). The opinions expressed differ. However, in all these papers the rocks are considered as synkinematic or synorogenic Svecofennian »granites».

As appears from Plate IV, a part of the trondhjemitic rocks are connected with brecciated fault zones. In these cases the direction of the foliation and lineation is that of the faults and not of the general folding. Therefore it is doubtful whether even the term Svecofennian can be attributed to all these rocks.

CONCLUSIONS

It may be concluded that the rocks of the Orijärvi region are folded over a general fold axis plunging on the whole gently to the east. Generally, the folds are open and slightly asymmetric, leaning to the south.

The folding has been accompanied and followed by intensive faulting and brecciation. Faults occur parallel to the folds, as well as in directions crossing the folds. The most important faults show a roughly eastern dip, and are connected with a general overthrust to the west. Most of the faults have caused a foliation, lineation and small folds parallel to them.

The two most frequent lineations plunge to the east. The gentler of them is parallel to the b-axis of the general folding. The steeper one is in the direction of the overthrust towards the west.

The largest folds can be traced in the geologic map. However, the distribution of the rocks in the actual surface section is primarily determined by faulting.

It has been a general belief that a high plasticity of deformation is characteristic of the Finnish Archean and other »plutonic» areas (Read 1955). It is true that minor plastic features are visible almost everywhere in the Finnish Archean. However, on the basis of what is seen in Orijärvi, it seems that the significance of this plasticity has been exaggerated.

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Suomen Malmi Osakeyhtiö, May 1957.

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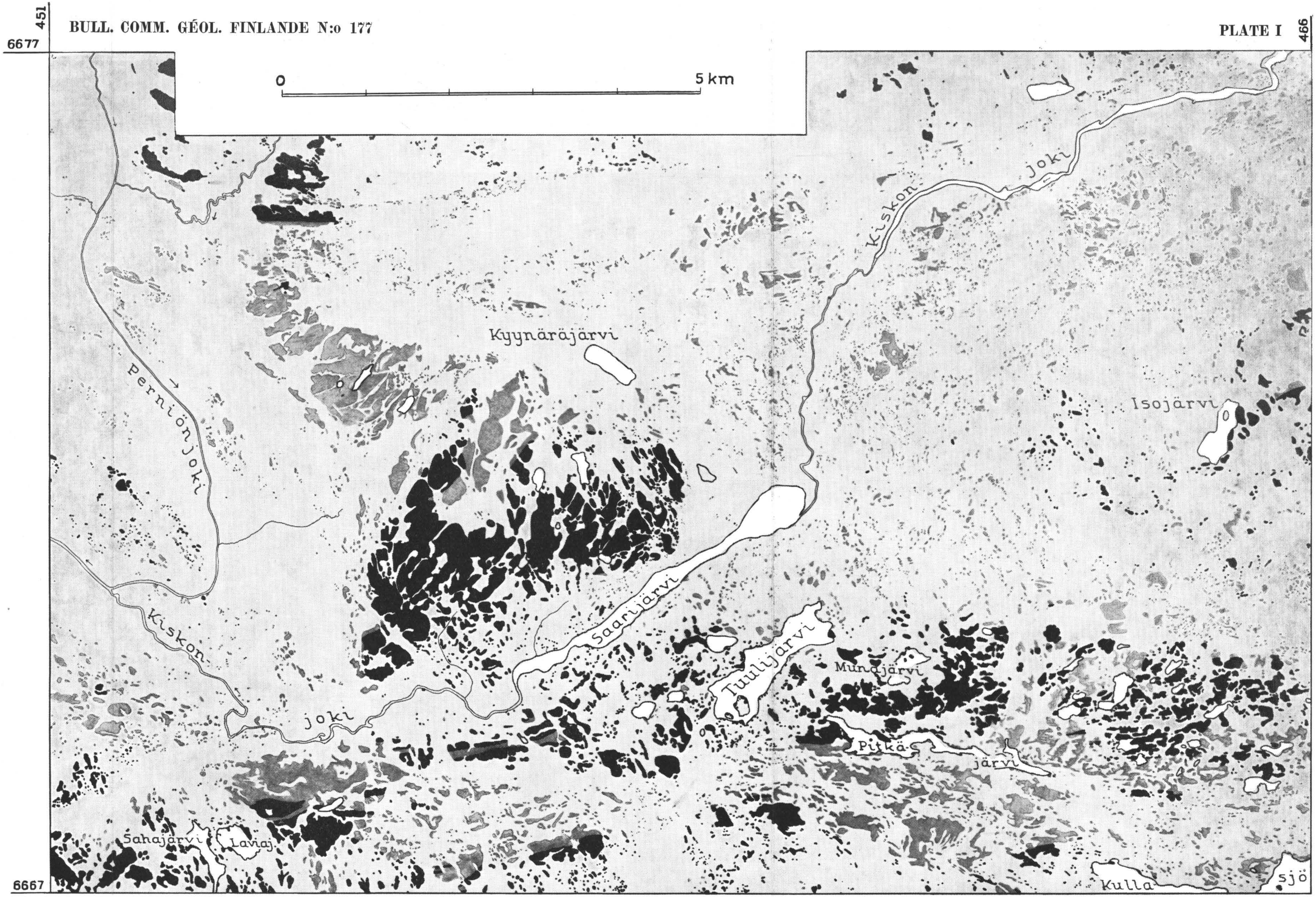
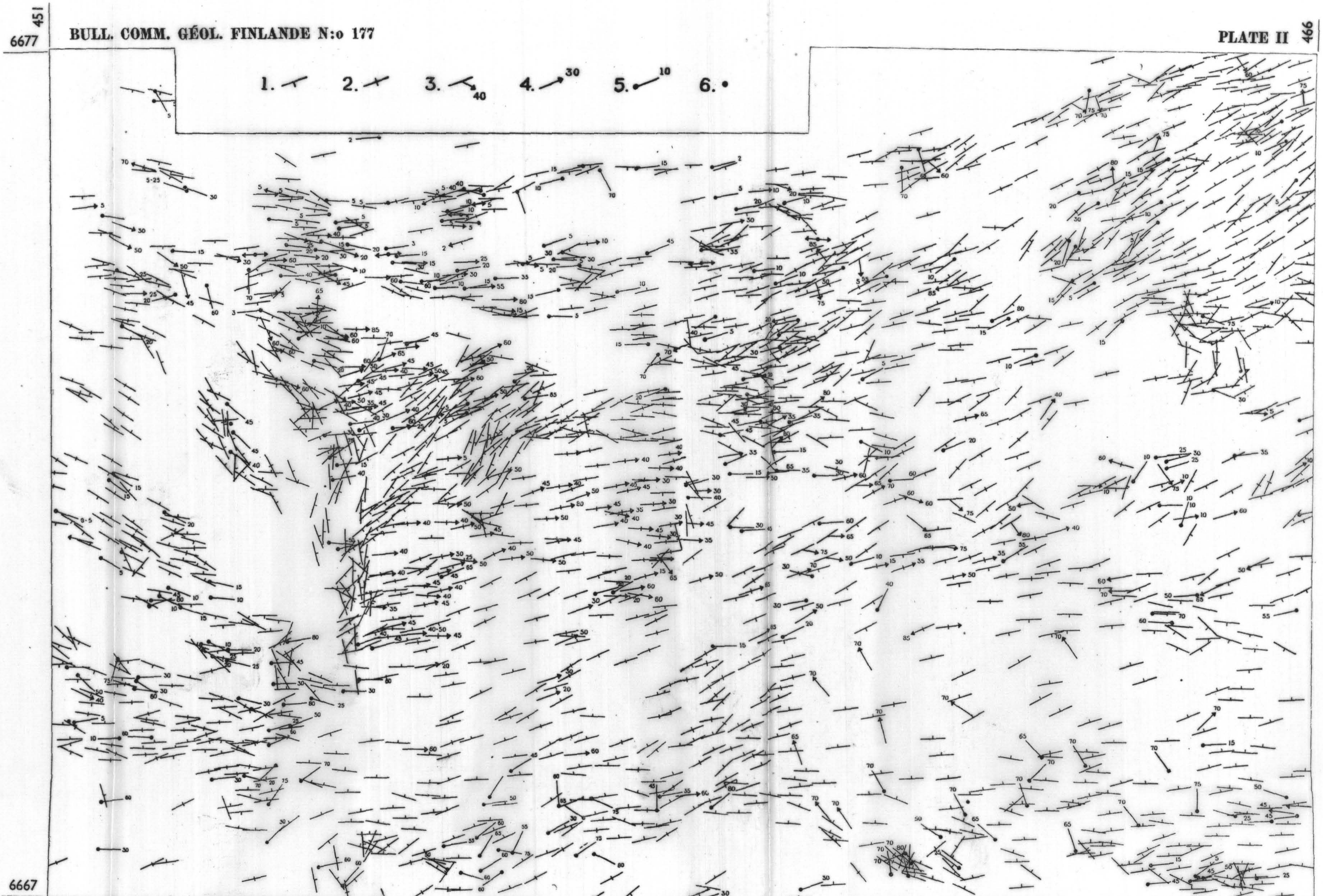
N:o 159. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XXVI. .... 400: —

N:o 160.	Simonen, Ahti. Stratigraphy and Sedimentation of the Svecofennidic Early Archean Supracrustal Rocks in Southwestern Finland. P. 1—64. 17 fig. 8 tabl. 2 maps. 1953	200: —
N:o 161.	Disler, Jürg. Die Kupferkieslagerstätte von Outokumpu, Finnland. (Ihre Lage, ihre Struktur und ihre Form.) S. 1—114. 39 Fig. 9 Diagr. 4 Taf. 1953	400: —
N:o 162.	Kaitaro, Simo. Geologic Structure of the Late Pre-Cambrian Intrusives in the Åva Area, Åland Islands. P. 1—71. 37 fig. 6 tabl. 1 map. 1953	200: —
N:o 163.	Vaasjoki, Oke. On Migmatites and Ore Mineralizations in the Pernaja District, Southern Finland. P. 1—62. 24 fig. 3 tabl. 1 plate 1 map. 1953	200: —
N:o 164.	Vähätalo, Veikko O. On the Geology of the Outokumpu Ore Deposit in Finland P. 1—99. 9 fig. 13 tabl. 19 plates and 3 maps. 1953	650: —
N:o 165.	Wiik, H. B. Composition and origin of Soapstone. P. 1—57. 11 fig. 6 tabl. 1953	150: —
N:o 166.	Suomen Geologisen Seuran julkaisuja. — Meddelanden från Geologiska Sällskapet i Finland. — Comptes Rendus de la Société géologique de Finlande XXVII. P. 1—106. 16 tabl. 43 fig. 1954 ..	350: —
N:o 167.	Hyyppä, Esa. On the Pleistocene Geology of Southeastern New England. P. 155—225. 33 fig. 1955	200: —
N:o 168.	Suomen Geologisen Seuran julkaisuja. — Meddelanden från Geologiska Sällskapet i Finland. — Comptes Rendus de la Société géologique de Finlande XXVIII. P. 1—141. 63 fig. 34 tabl. 1955 ..	450: —
N:o 169.	Salmi, Martti. Prospecting for Bog-Covered Ore by Means of Peat Investigations. P. 1—34. 6 fig. 8 tabl. 1955	150: —
N:o 170.	Okko, Veikko. Glacial Drift in Iceland, its Origin and Morphology. P. 1—133. 35 fig. and. one table in text. 32 fig. in plates I—XVI. 1955	400: —
N:o 171.	Pääkkönen, Veikko. Otanmäki, the Ilmenite-Magnetite Ore Field in Finland. P. 1—71. 41 fig. 19 tabl. 2 plates and 3 maps. 1956	300: —
N:o 172.	Suomen Geologisen Seuran julkaisuja. — Meddelanden från Geologiska Sällskapet i Finland. — Comptes Rendus de la Société géologique de Finlande XXIX. P. 1—100. 24 fig. 30 tabl. 1956	350: —
N:o 173.	Ramdohr, Paul. Die Beziehungen von Fe-Ti-Erzen aus magmatischen Gesteinen. S. 1—19. 2 Diagr. 25 Taf. 1956	400: —
N:o 174.	Savolahti, Antti. The Ahvenisto Massif in Finland. The Age of the Surrounding Gabbro-anorthosite Complex and the Crystallization of Rapakivi. P. 1—96. 22 fig. 11 tabl. and 1 map 1956	350: —
N:o 175.	Salmi, Martti. Peat and Bog Plants as Indicators of Ore Minerals in Vihanti Ore Field in Western Finland. P. 1—22. 6 fig. 1 tabl. 1956	100: —
N:o 176.	Marmo, Vladi. Geology of the Nokia region, Southwest Finland. P. 1—38. 16 figs. 1957	150: —
N:o 177.	Tuominen, Heikki. The Structure of an Archaean Area: Orijärvi, Finland. P. 1—32. 16 figs. 6 plates. 1957	—
N:o 178.	Mölder, K., Valovirta, V. und Virkkala, K. Über Spätglazialzeit in Südfinnland. (painossa — in print)	—
N:o 179.	Repo, R. Untersuchungen über die Bewegungen des Inlandeises in Nordkarelien. S. 1—178. 114 Abbild. 1 Taf. 1 Karte. 1957	—



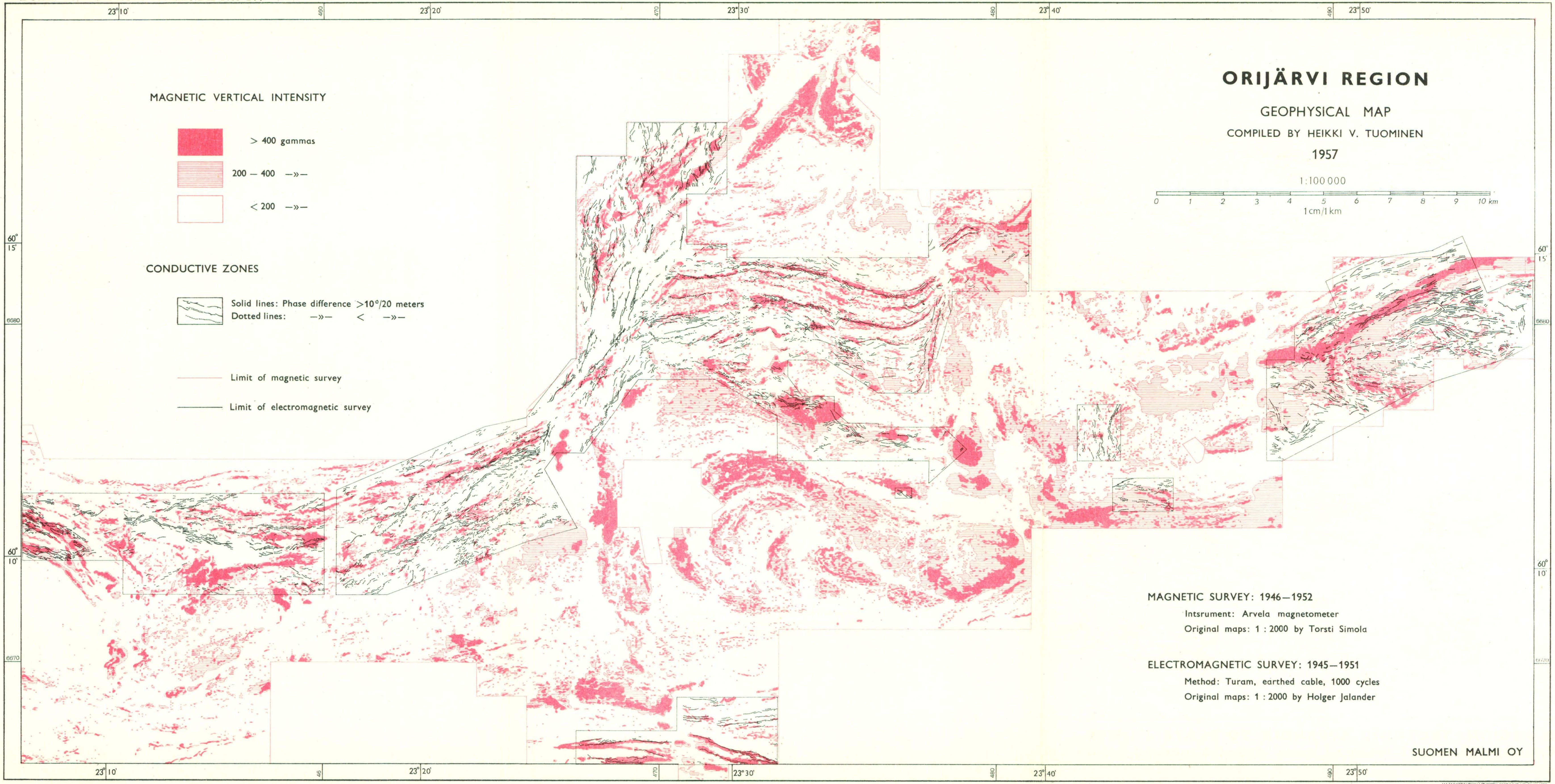
ORIJÄRVI REGION: OUTCROPS OF THE PERNIÖ—KUOVILA AREA 1:50000

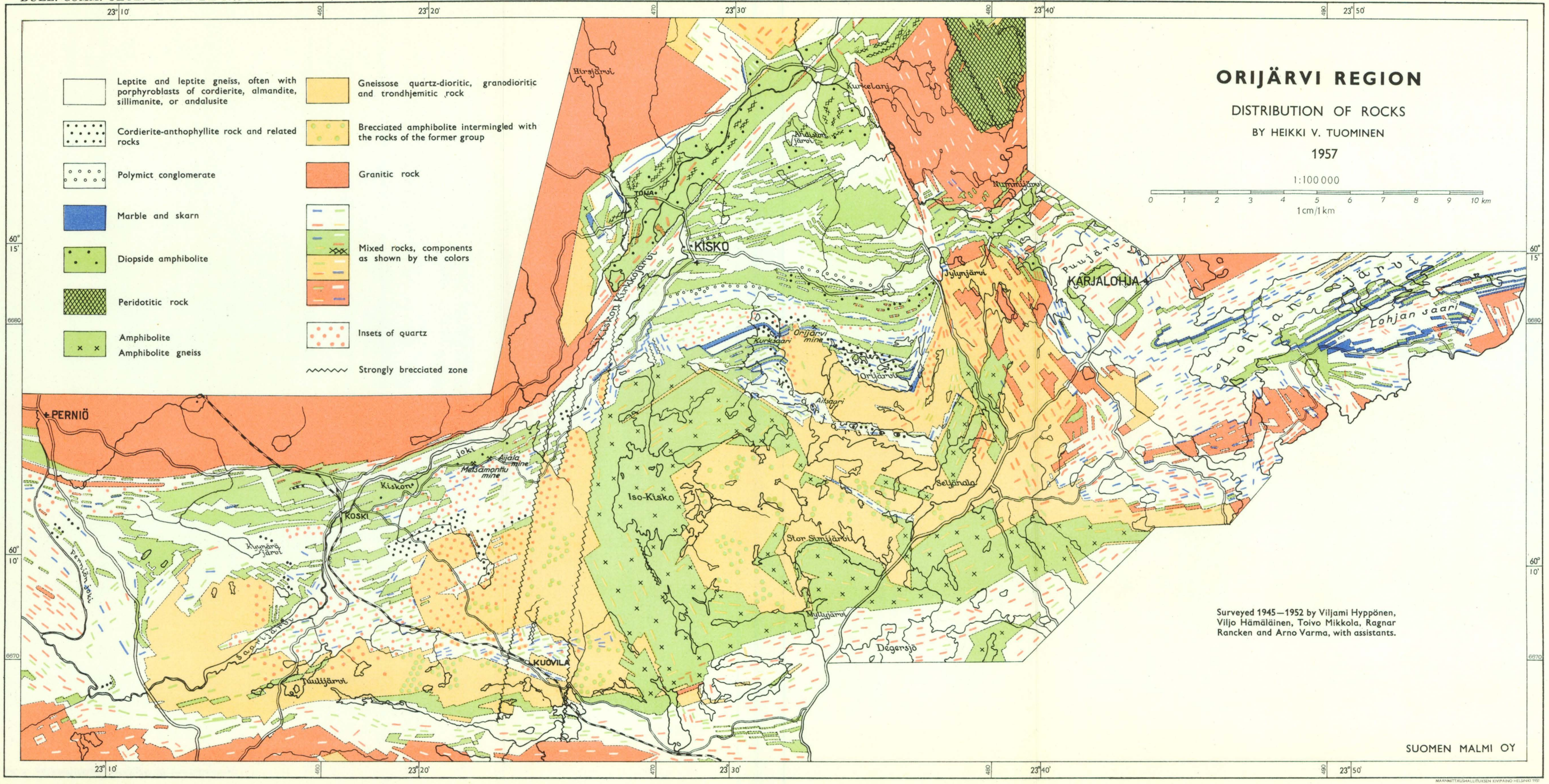
Black: Trondhjemitic and granitic rocks. Gray: Other rocks

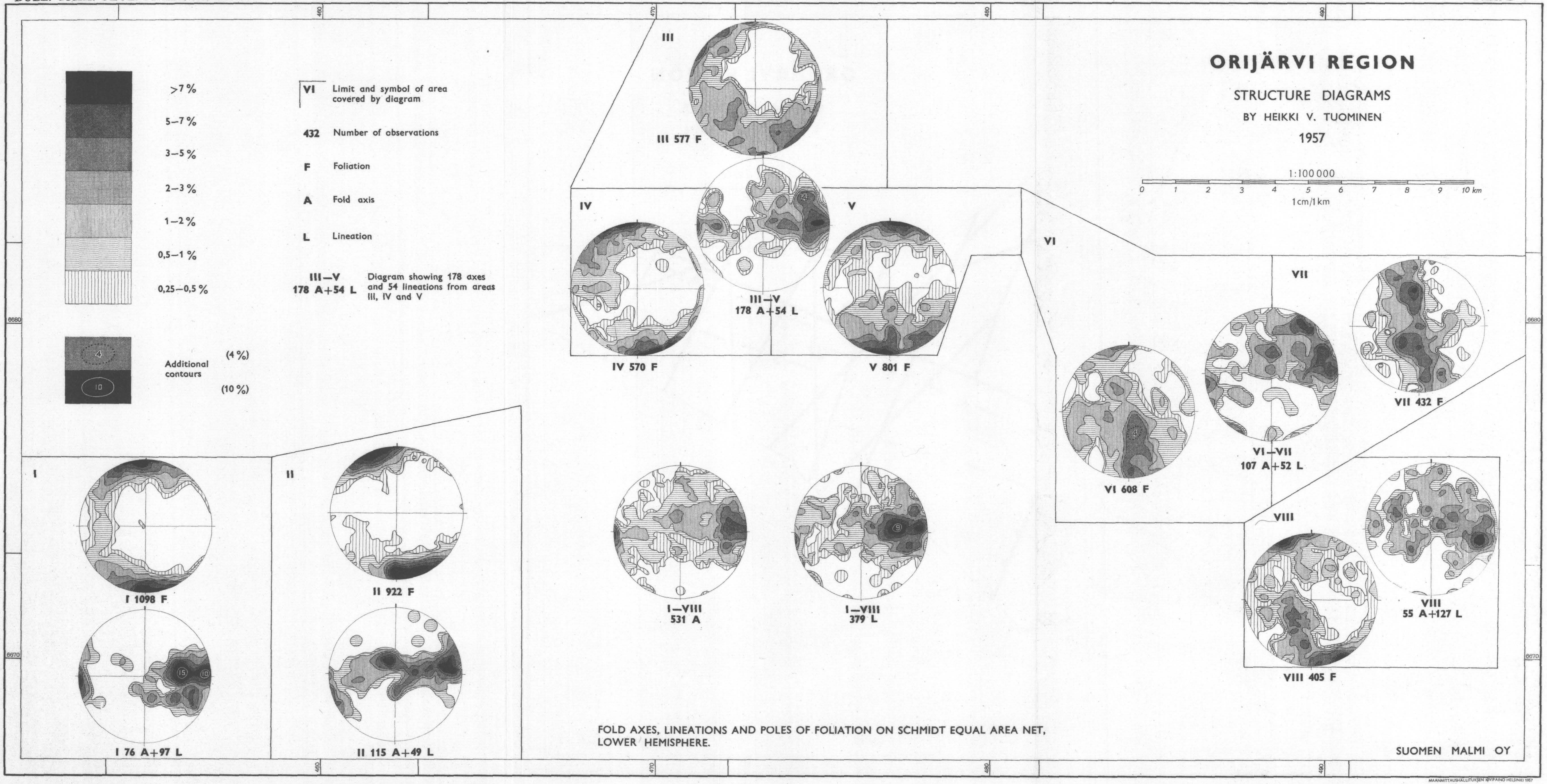


ORIJÄRVI REGION: TECTONIC APPENDIX TO PLATE I 1:50000

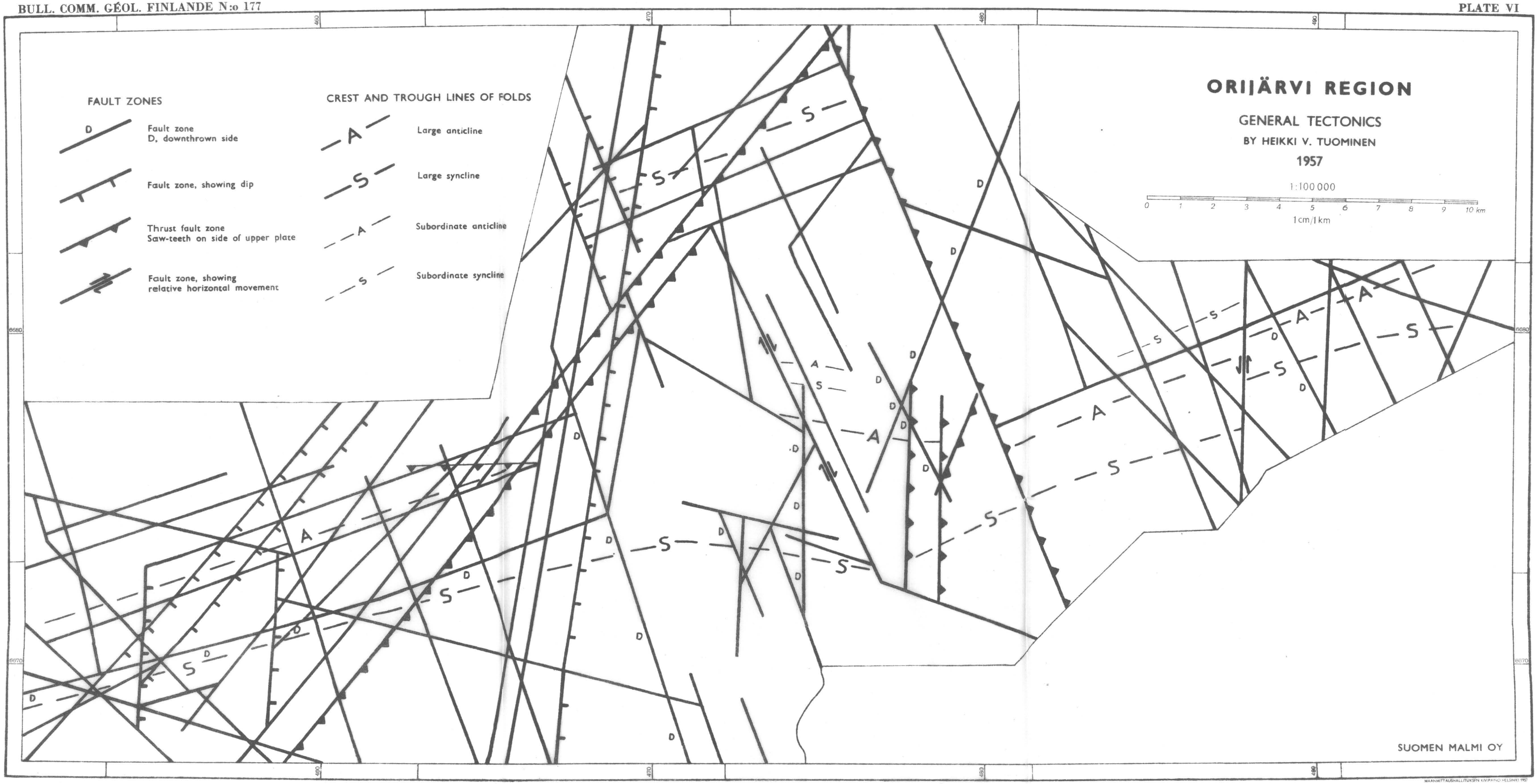
1. Foliation 2. Foliation where vertical 3. Foliation and lineation combined 4. Lineation 5. Fold axis 6. Fold axis where vertical


ORIJÄRVI REGION
GEOPHYSICAL MAP
COMPILED BY HEIKKI V. TUOMINEN
1957
1:100 000
0 1 2 3 4 5 6 7 8 9 10 km
1 cm/1 km
MAGNETIC VERTICAL INTENSITY
> 400 gammas
200 — 400 —»—
< 200 —»—
CONDUCTIVE ZONES
Solid lines: Phase difference >10°/20 meters
Dotted lines: —»— < —»—
Limit of magnetic survey
Limit of electromagnetic survey
MAGNETIC SURVEY: 1946—1952
Intsrument: Arvela magnetometer
Original maps: 1 : 2000 by Torsti Simola
ELECTROMAGNETIC SURVEY: 1945—1951
Method: Turam, earthed cable, 1000 cycles
Original maps: 1 : 2000 by Holger Jalander
SUOMEN MALMI OY
23°10'
23°20'
23°30'
23°40'
23°50'
60° 15'
60° 10'
6680
6670
460
470
480
490


ORIJÄRVI REGION
DISTRIBUTION OF ROCKS
BY HEIKKI V. TUOMINEN
1957
1:100 000
0 1 2 3 4 5 6 7 8 9 10 km
1 cm/1 km
Leptite and leptite gneiss, often with porphyroblasts of cordierite, almandite, sillimanite, or andalusite
Cordierite-anthophyllite rock and related rocks
Polymict conglomerate
Marble and skarn
Diopside amphibolite
Peridotitic rock
Amphibolite
Amphibolite gneiss
Gneissose quartz-dioritic, granodioritic and trondhjemitic rock
Brecciated amphibolite intermingled with the rocks of the former group
Granitic rock
Mixed rocks, components as shown by the colors
Insets of quartz
Strongly brecciated zone
Surveyed 1945—1952 by Viljami Hyppönen, Viljo Hämäläinen, Toivo Mikkola, Ragnar Rancken and Arno Varma, with assistants.
SUOMEN MALMI OY
23° 10'
23° 20'
23° 30'
23° 40'
23° 50'
460
470
480
490
60° 15'
60° 10'
6680
6670
Hirsjärvi
Kurkelanj.
Ahdistonjärvi
Toija
Kisko
Nummijärvi
Jylynjärvi
Puujärvi
Karjalohja
Lohjanjärvi
Lohjan saari
Kurksaari
Orijärvi mine
Orijärvi
Aitsaari
Perniö
Aijala mine
Metsämonttu mine
Kiskonjoki
Koski
Kuuma järvi
Perniönjoki
Iso-Kisko
Stor Simijärvi
Seljanala
Myllyjärvi
Degersjö
Kuovila
Saarijärvi
Tuulijärvi



MAANMITTAUSHALLITUKSEN KIVIPAINO HELSINKI 1957


ORIJÄRVI REGION
GENERAL TECTONICS
BY HEIKKI V. TUOMINEN
1957
1:100 000
0 1 2 3 4 5 6 7 8 9 10 km
1 cm/1 km
FAULT ZONES
Fault zone
D, downthrown side
Fault zone, showing dip
Thrust fault zone
Saw-teeth on side of upper plate
Fault zone, showing
relative horizontal movement
CREST AND TROUGH LINES OF FOLDS
Large anticline
Large syncline
Subordinate anticline
Subordinate syncline
SUOMEN MALMI OY