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ON THE GEOLOGY AND TECTONICS OF THE OUTOKUMPU ORE FIELD AND REGION

BY

HEIKKI VÄYRYNEN

WITH 11 FIGURES IN THE TEXT AND 2 MAPS

HELSINKI
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CONTENTS.

PREFACE 5

THE DISCOVERY AND INVESTIGATION OF OUTOKUMPU AND THE DEVELOPMENT OF ITS OUTPUT 7

THE SPREADING OF GLACIAL BOULDERS. MINOR OCCURRENCES OF SULPHIDE ORES 8

EARLIER GEOLOGICAL RESEARCHES 10

THE MAIN GEOLOGICAL FEATURES AND ROCK SERIES OF THE REGION 12

THE FAULT AND JOINTING TECTONICS OF THE REGION 14

- THE KOLVANANUURO—NUNNANLAHTI FAULT-LINE 14
- THE OUTOKUMPU—LUIKONLAHTI FAULT-LINE 15
- OTHER FISSURES AND JOINTING DIRECTIONS 17
- THE ORIGIN OF CRACKS AND FAULTS 17

THE FOLDING TECTONICS 18

- AXIAL DIRECTIONS AND THE TECTONIC DIVISION 18
- THE JATULIAN AREA 20
- THE SYNCLINE OF THE HÖYTIÄINEN BASIN 21
- THE ANTICLINAL ZONE 23
- THE AREA OF SERPENTINE INTRUSIONS 24
    - The geological structure of the zone 24
    - The rôle of the nappes 26
    - The extent of the overthrusts 27
    - The relation of the intrusive magma to the overthrust movements 29
- THE PISA AREA 29
    - The Pisa—Keyritty—Kinahmi area 29
    - Movements of the Iisalmi segment 31
- THE SAVO AREA OF SCHISTS 33

GEOLOGICAL DESCRIPTION OF THE STRATIGRAPHIC ROCK GROUPS 35

- THE BASAL COMPLEX 35
    - Pre-Jatulian schists 35
    - Gneissose granites 36
- THE AUTOCHTONOUS KARELIAN SERIES 37
    - The Jatulian conglomerates 37
        - Conglomerates with pebbles of quartz 37
        - Conglomerates with pebbles of granite 38
    - The Jatulian quartzites 39
    - The Kalevian conglomerates 40
        - The relation of the Kalevian series of rocks to the Jatulian 40
        - The conglomerates containing pebbles of quartzite 41
        - Conglomerates with pebbles of granite 41
        - The nature of the Kalevian conglomerates 42
        - The distribution of the conglomerates 43
    - The Kalevian quartzites 43
    - The Kalevian phyllites 45

5674—38

ALLOCHTONOUS ROCK SERIES 46
The structure and composition of the series 46
The blebbed gneisses 48
The origin of allochtonous series 50
ALLOCHTONOUS ZONES IN THE PHYLLITE AREA OF NORTH KARELIA 52
The Outokumpu ore field 52
Map and sections of the Outokumpu ore field 52
The rocks of the ore field 55
The relation of the dolomites to the serpentine 57
The Kuusjärvi—Juojärvi zones 59
The Outokumpu—Ruhvo zone 60
The Kokonvaara—Ruhvo zone 61
The Huutokoski—Viitalampi zone 62
The zone of Kylylahti 64
The Solankylä and Revonkangas areas 64
The Saarivaara—Miihkalinjärvi zone 65
The Hanhivaara blebbed gneisses 66
The Kaavi and Säyneinen zones 67
The Palolampi area 67
The Kortteinen zone 70
The Niinivaara, Poskijärvi and Suuri Säyneinen areas 70
The Vehkalahti—Säyneinen zone 72
POST-JATULIAN IGNEOUS ROCKS 73
GABBROID INTRUSIVES 73
SERPENTINES 75
YOUNGER GRANITES AND PEGMATITES 80
ORE DEPOSITS 83
THE OUTOKUMPU ORE BODY 83
THE PALOLAMPI ORE 87
OTHER PYRITE OCCURRENCES 87
REFERENCES 88

PREFACE.

The present investigation has been carried on since 1922 for the purpose of publishing a description of the Outokumpu ore field on behalf of the Geological Survey. As the investigation of the immediate vicinity of Outokumpu does not suffice to explain all the problems bearing upon the geological development of the area, the understanding of which is, however, essential in order to obtain an idea of the origin of the ore body itself, I have been obliged to extend my investigations to the whole area now under treatment. Owing to prospecting work having been my chief task, however, I was only able to devote a few weeks every summer to carrying out these researches and even in this manner only during the summers of 1922—24, 1926 and 1929—30. When the Petsamo investigations became a more urgent task for the Geological Survey, I was unable to find any time for these researches. Having recently published a description of the Petsamo nickel ore field, I decided to publish the part of my work that concerns my observations of the general geology and tectonics, as a thorough investigation into the petrography will still take some time. I hope, however, that I shall be able to publish its results in the near future.

The following geologists have drawn detailed maps of the area dealt with: Dr W. W. Wilkman (1901, Juuanvaarat), Mag. Phil. A. Talvia (1910, the Pisa area), Mr J. N. Soikero (1912, 1915, Saarivaara—Ukonvaara), Dr E. Mäkinen (1916, Polvijärvi), Prof. E. H. Kranck (1916, Polvijärvi), Mag. Phil. Alb. Näätänen (1923, Nunnanlahti), Engineer Hugo Törnqvist (1923, Polvijärvi, Niinivaara, Halivaara), Dr A. Talvitie (1923—24, Säyneinen, Martonvaara—Pihlajavaara), Dr P. Haapala (1929—30, Kortteinen—Säyneinen) and the students Messrs A. Simonen, M. Lehijärvi, Y. Väisänen, A. Enkovaara, V. Kuosmala (1938, Kaavi—Juuka). I take this opportunity of thanking them for their conscientious work.

I am especially grateful to Dr Eero Mäkinen, managing director of the Outokumpu Company Ltd., for the generosity and hospitality I always enjoyed during my work on the ore field. My thanks are

also due to Mr Kauko Järvinen, mining engineer, and the other officials of the company for their assistance.

The English translation has been made by Mr Edward Birse, to whom I am greatly indebted for his careful work. Besides I have to thank Dr Erkki Mikkola, of the Geological Survey, for his valuable suggestions in respect to the geological expressions and designations in English and for reading the proofs. The maps are the work of Miss Thyra Åberg, whose meritorious work is well-known.

Helsinki, December 1938.

Heikki Väyrynen.

THE DISCOVERY AND INVESTIGATION OF OUTOKUMPU AND THE DEVELOPMENT OF ITS OUTPUT.

The discovery of the Outokumpu ore reawakened the hopes that had already expired in Finland of establishing a mining industry and of succeeding in finding ores. It has therefore been described very often in print and referred to even in a foreign language (Sauramo 1924), so that it would be superfluous to go into the subject thoroughly on this occasion. The Outokumpu ore was discovered by means of the systematic prospecting that was carried out under the guidance of the mining engineer O. Trüstedt, owing to the fact that a block of copper ore sized about 5 cub. ms., containing 3.75 % Cu, was found in the parish of Rääkkylä, 55 kms. SSE of Outokumpu, in digging the Kivisalmi canal. Investigations were directed towards the Outokumpu district for the reason that the block of ore contained quartzite impregnated with ore and among it blocks of serpentine were also found in the moraine, Outokumpu being the nearest outcrop of these rocks against the advance of the land-ice. As other ore blocks were found in the Outokumpu district and in addition to them a magnetic disturbing field was encountered, a number of mining claims were soon secured, diamond drilling was started and, in March 1910, two years after the search was begun, ore was discovered in the third drill hole.

This early success led to energetic prospecting work which was extended to the whole region described here. All the occurrences of serpentine were mapped geologically in detail and investigated magnetometrically.

The diamond drilling and trenching were continued at Outokumpu with such success that in 1913 it was estimated that there were at least 7—8 million tons of ore with a copper content of about 4 %, and copper works were built for refining it, only capable, it is true, of dealing with about 10,000 ore-tons for experimental purposes, as it was decided to use a new method invented by the Norwegian engineer V. Hybinette, of which sufficient experience had not yet been gained.

However, this experimental period lasted a long time, as the output did not prove satisfactory until 1928. The delay was due partly to the incompleteness of the method, partly to political conditions and partly to the absence of railways. Mining was carried on during this period first by the owners, the Finnish State and the company of Hackman & Co., later by a company working on a lease. The production of the mine amounted to 15,500 tons of ore annually on an average, but the production of copper only to 223 tons on an average, because the greater part of the ore, 130,000 tons, was used as sulphur ore, while only 87,000 tons or an annual average of 6,200 tons were used in producing copper. It was only after the Finnish State had become the sole owner of the mine in 1924, a railway had been built to Outokumpu in 1927 and the mining was extended and the erection of a concentrating plant was finished in 1928, in which in the present state since 1932 two concentrates are prepared from the ore, a copper concentrate (22—25 % Cu) and a sulphur concentrate (43—46 % S), that the Outokumpu mine embarked upon a stage actual development. The output, which was planned to amount to 100,000 tons of ore annually, has since increased by degrees and has in some years even exceeded 350,000 tons. The sulphur concentrate has been consumed entirely within the country, but the copper concentrate was at first sold abroad until a copper works was completed in 1936 on the river Vuoksi in the neighbourhood of the Imatra power station, from which power is obtained for smelting. Finally the roasting cinder from the sulphur concentrate was used for manufacturing iron, when the Vuoksenniska Company began to produce purple ore from it in 1936 and to smelt iron in its electric smelting furnace in 1937. The technical development of the mine and of the plant have recently been described by Mäkinen (1938).

THE SPREADING OF GLACIAL BOULDERS. MINOR OCCURRENCES OF SULPHIDE ORES.

The fortunate and rapid discovery of the Outokumpu ore deposit gave rise to further investigations in the sedimentary area of North Karelia, in which attention was devoted mainly to observing the spreading of the glacial boulders. In the neighbourhood of Outokumpu itself the spreading of the boulders was limited to a small area, seeing that the Jaamankangas plain, an extensive sandy tract formed during a delay in the recession of the Glacial ice-sheet, simultaneously with the great terminal moraines, the Salpausselkäs, begins a little to the south of Outokumpu, covering all the morainic deposits as well as all exposures of Archaean rocks. To the east and north-east of Outokumpu, where the nearest outcrop of Archaean is at a distance of about 6 kms. from Outokumpu, the conditions are the same. Owing to this the investigation of the immediate neighbourhood of Outokumpu in this direction was rendered difficult.

To the south-west and west, however, the morainic accumulations offer more opportunity for the study of boulders, and about 8 kms. SW of Outokumpu, in the vicinity of the village of Kuusjärvi, blocks of ore were found, which led to investigations with the aid of diamond drilling in this neighbourhood, though they did not result in the discovery of any considerable ore deposit.

Magnetic surveys showed that the sulphide impregnations continued in a NE direction from Outokumpu in the form of a belt of a few kms. in width up to the NW side of Lake Viinijärvi, where there were morainic deposits as well as outcrops of Archaean rock. Here, too, occurrences of iron pyrites were discovered, especially in the neighbourhood of the river Sukkulajoki, about 14 kms. from Outokumpu, but the loose boulders starting from these tracts were concealed on the bottom of Lake Viinijärvi. The zone impregnated by the iron pyrites continues about 7 kms. NE of the river Sukkulajoki to the neighbourhood the village of Haapovaara, but no considerable sulphide occurrences nor blocks have been discovered there.

Sulphide impregnations have also been found especially on the eastern shore of Lake Viinijärvi and on the islands of it, in the vicinity of the church of Polvijärvi and in the vicinity of Huutokoski, 6 kms. NE of it. It is difficult, however, to trace the spreading of the blocks deriving from these districts, owing to the fact that there are very few local blocks in general and the greater part of the boulders consists of granites and gneisses found in place at a distance of a least 20 kms. to the NW. This is probably due to the local very flat topography, as it is generally in schist areas, which showed no protrusions to be attached by the moving land ice, and the loosened material has apparently mostly travelled a long distance.

Blocks that obviously derived from this district, have been discovered far outside it (Väyrynen 1935). Mention has already been made of the block found at Rääkkylä, which led to the discovery of the Outokumpu deposit and, according to microscopic examination, seems to have come from the Outokumpu ore. Two other blocks were found about 22 kms. E of Joensuu in the village of Selkie and one 7 kms. SE of the latter place in the village of Röksä. The two blocks found at the former place are of a different type from the Outokumpu ore and point rather to the deposits of iron pyrites of the Polvijärvi district. The block found at the latter place differs from both these types of ore.

In addition to these places considerable sulphide impregnations have been found in the phyllite area of North Karelia in the Revonkangas district, about 16 kms. N of Polvijärvi, and at the N end of the region in the Petrovaara district NW and NE of Lake Saarijärvi. A block of pyrite found at Ahmovaara, in the NE corner of the phyllite area, apparently also comes from the same area.

Iron pyrites also occur in the small phyllite areas NW of the large phyllite terrain. The most considerable is the Palolampi occurrence, which the author discovered in 1929. There are others of less value in the villages of Niinivaara, Kortteinen and Säyneinen.

The spreading of the boulders often occurred at a wide angle in the region described. The cause of this is apparently that the striae of the land ice on the ledges go in two main directions. The one direction of the striae, principally in the NE part of the area, runs on an average S 25°—30° E and the other direction, principally in the SW district, is S 50°—60° E almost due E. The latter direction of the striae is, however, also found to some extent on the same area as the former up to Polvijärvi under the lee of the former direction. Thus the blocks of the rocks of the Polvijärvi and Höytiäinen district spread both due east and almost due south.

EARLIER GEOLOGICAL RESEARCHES.

Disconnected observations of the occurrence of minerals in the region were published in Holmberg's works in 1855—58. The first geological views on the geologic structure of this district were expressed by Wiik in 1874, which explains the origin of the „primitive formations'' in accordance with Werner's neptunistic conceptions prevailing at the time. A modern point of view while discussing the area in question was first adopted by Tigerstedt (1892) and Sederholm (1893, 1897), the former dealing with the district E of Höytiäinen, situated E of our map, and considering the conglomerate-quartzite-phyllite series occurring there as an original succession of deposits, while the latter expressed the opinion that has prevailed since, according to which the quartzites on the E edge of the phyllite terrain, which he called Jatulian in 1897, are younger than the phyllites and the schists connected with them and intruded by the granites, but the latter have been overthrust above the former by tectonic movements. This point of view was adopted in their detailed descriptions of the district by

Frosterus and Wilkman in 1902, 1916 and 1920. They differ from the opinion expressed by Sederholm only in the particular that, while Sederholm considered the phyllites to belong to the L a d o g a n system intruded by p o s t - B o t h n i a n granites (on the shore of Lake Ladoga), Frosterus separated their less altered parts as being younger than these granites, but older than the Jatulian quartzites. In collaboration with Ramsay he gave to this part the name of the K a l e v i a n system. At first the opinion prevailed that there were no granites intruding the Kalevian and Jatulian rocks in the region, so that these did not belong to the actual type of Archaean rocks. Later, however, many phyllites intruded by granites were included in the Kalevian system, especially in the Outokumpu district. The Jatulian quartzites were, nevertheless, still considered to be younger than these p o s t - K a l e v i a n granite intrusions. Thus the age division of the rock groups of the region had developed in the following manner:

1. The oldest schists (Ladogan),
2. Gneissose granites and post-Bothnian granites,
3. Kalevian quartzites and phyllites,
4. Kalevian metadiabases (''metabasites''),
5. Post-Kalevian granites,
6. Jatulian quartzites,
7. Jatulian uralite-diabases.

Owing particularly to the fact that, besides quartzites, also dolomites and phyllites belong to the Jatulian series both in the Onega region and at Suojärvi (Metzger 1924) and Soanlahti, Eskola reverted in 1925 to Tigerstedt's view, already referred to, that the Kalevian phyllites formed a continuous sedimentary sequence with the Jatulian quartzites, being less metamorphic in the east (Jatulian) and most altered under the influence of the granites in the west (Ladogan). He called this whole succession the Karelian system.

In his investigations both in the Kainuu region (1927) and in the North Karelian sedimentary area (1933) Väyrynen also came to the conclusion that the quartzites that were called Jatulian were older than the Kalevian phyllites, but did not form a continuous series of deposits. In some places the phyllites with their basal conglomerates containing pebbles of quartzite have been laid down on top of the Jatulian quartzites, in others with conglomerates containing pebbles of granite directly above the granites. Both these series are thus unconformable.

The tectonics of the region were dealt with by Wegmann (1928—29), who expressed the opinion that the Karelian sediments have been brought from the west in the form of overthrust nappes, and the basal granite massifs between these, such as the Petronvaara massifs, in the same way. The North Karelian area of schists represents an axial depression and the terrain of gneissose granites to the north an axial culmination. The granite massifs of Vaivio between Höytiäinen and Viinijärvi as well as the Liperinsalo and Oravisalo massifs further south represent an upfold of axes, in which the welt [1] corresponding to the Petronvaara massif has been exposed and rows of serpentine occurrences especially indicate zones of movement that have been followed by ophiolitic intrusions.

The structure of serpentines in particular was investigated by Haapala (1936) and the mineral paragenesis of ore deposits by Väyrynen (1935).

THE MAIN GEOLOGICAL FEATURES AND ROCK SERIES OF THE REGION.

The greater part of the investigated district is underlain by sedimentary rocks constituting the North Karelian phyllite arc. In addition there are similar phyllites in small areas to the west and north-west of this region. The principal phyllite terrain is bordered on the NW, N and E by quartzite ranges. In the NW these differ geologically from those in the E in the respect that the former are connected with dolomitic limestones, tremolite schists, and dark phyllites, which are lacking in the E, and also owing to the fact that at the contacts of the eastern quartzite ranges with the underlying gneissose granites very frequently there are distinct basal conglomerates. The last-mentioned quartzites are therefore to be regarded as autochtonous, whereas conglomerates are always absent between the quartzites in the NW and the gneissose granites. In their place ''eyed'' gneisses and other tectonitic features appear which show that these quartzite sheets are allochtonous.

In the W and SW the phyllites, in the direction of their strike, become coarser and pass over to mica schists, then to gneisses and finally to arterites. The granites intruding these latter are either

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[1] The term ''welt'' has been adopted by the author from Bucher's work (1933), which is one of the most many-sided, serviceable, and elucidative recently published text-books of moderate size on tectonic geology.

pegmatitic, aplitic, or small-grained grey biotite granites. This latter type of granite occurs in a large body in the neighbourhood of Maarianvaara village, the Maarianvaara granite, and in smaller intrusions in the neighbourhood of the church of Kaavi and in the village of Kortteinen.

We can therefore distinguish the following rock divisions:

1. The oldest schists (Pre-Jatulian, Ipatti schists). There is only a very small field of these in this region, occurring in the NE corner of the map I, SW of Nunnanlahti.

2. Gneissose granites (''granite gneisses''). They occur in the northern part of the region, on the islands of Lake Pielinen and in the Vaivio massif between Lakes Höytiäinen and Viinijärvi. The gneissose granites exhibit very varied features, most of them are grey. They are, however, connected in places with reddish and homophanous granites.

3. Jatulian quartzites. Two types of rock series belong to these in the North Karelian sedimentary area: a) the Sariolan facies, and b) the Kainuuan facies. The former contains conglomerates with pebbles of granite, and arkose quartzites, the latter conglomerates with pebbles of quartz embedded in a cement rich in sericite, and quartzites with or without sericite. The former type occurs principally in the Latvajärvi neighbourhood. Only the latter type occurs in the district investigated. It includes the point of the Koli area in the NE corner of the map on the shore of Lake Pielinen, further the quartzite area, shaped like a horseshoe, SW from the former, and the small Venepohja quartzite.

4. Jatulian metadiabases (''metabasites''). These are small- or medium-grained amphibole diabases and amphibole gabbros intruding Jatulian quartzites. Formerly they were divided into Jatulian and Kalevian. As they never occur in the phyllite area, they all belong together. Petrographically, too, they all belong to the same group.

5. Kalevian basal conglomerates and quartzites. Of the rock occurrences belonging to this group in the district dealt with the most considerable ones, lying immediately on the granite, are the Timonvaara quartzite, the Heinävaara conglomerate, the Sotkuma breccia and the Kuorinkajärvi conglomerate. A little conglomerate is found, too, lying on top of the Jatulian quartzite to the E of Lake Kuhnustanjärvi.

6. Kalevian phyllites, gneisses, and arterites. The main area of phyllites is divided into two parts, the eastern in the environment of Lake Höytiäinen and the western in the Viinijärvi —Juojärvi district. The phyllites of the eastern area are of much more

varied composition than those of the western, including: fine, dark phyllites rich in mica, grey stratified and grey unbedded phyllites, grey stratified quartzitic, and dark unstratified quartzitic rocks. The western district consists for the greater part of grey phyllites with or without a visible bedding. Other types only occur on the eastern edge of the region.

7. This division, as well as the small phyllite areas, is characterised by zones containing serpentines, composed, besides the serpentines, of fine-grained pure quartzites, carbonaceous phyllites, ''Garbenschiefer'', tremolite and diopside-tremolite rocks, and dolomites. These belts very often also contain iron pyrites.

8. Allochtonous quartzite-phyllite-dolomite series. These types of rocks show their characteristic development especially in the Pisa area, but also at the ridges of Juuanvaarat on the NW edge of the principal phyllite area.

THE FAULT AND JOINTING TECTONICS OF THE REGION.

THE KOLVANANUURO—NUNNANLAHTI FAULT-LINE.

Frosterus and Wilkman noted a large number of faults in the eastern quartzite terrain in the E of the area of phyllites. Several of them also intersect the area under consideration (Fig. 1). One of these, the most pronounced and largest of all, is the fault-line passing through the rocky valley of Kolvananuuro, which proceeds along the boundary of the parishes of Kontiolahti and Eno and reaches the phyllite area at the N end of Lake Hautajärvi, causing a considerable deflection in the junction of both rocks. The fault-line follows an almost uninterrupted narrow cleft or ravine with abrupt slopes, along which rivers flow along the whole distance at times to the NW, at others to the SE, forming long and narrow lakes between, like Lake Kaianjärvi, which is about 3.5 kms. long, but only 50—100 ms. wide. In some places in the area of schists breccias have been found in the abrupt rock walls of this cleft, but not elsewhere. *E.g.*, about 0.5 km. NW of Lake Hauanjärvi there is ''a rock mass full of splintered schists, some of which are joined together by a hornstone-like cement'' (Frosterus and Wilkman, 1916). There is also at Ahmovaara a portion of schists in the Möhkyrinkallio ledge, situated on the same line, which is intensely brecciated and in the vicinity porous schist breccia appears in the form of loose boulders, from which the carbonate cement has apparently been dissolved. The fault continues clearly further to the NW, forming from Lake Mölönjärvi to Nunnanlahti the boundary between the areas of granite and blebbed schists in the W and the phyllites in the E (Fig. 1, 1—2), as Wilkman has described in greater detail (1915). At Nunnanlahti the granite is brecciated close to the schist contact, full of cracks filled with calcite. On the very boundary the sheet-like pieces of granite and schist have become mixed and the matrix is often pure quartz. The direction of the fault in the quartzite area is N 25° W and in the phyllite area N 40° W, dipping steeply to the W for the whole distance of about 50 kms., and both at Hautajärvi and in the Mölönjärvi and Nunnanlahti districts the western side has been raised in relation to the eastern part.

THE OUTOKUMPU—LUIKONLAHTI FAULT-LINE.

In the west, too, there are evidently, judging by the straight courses of the rivers and the shore contours, plenty of similar fault-lines (Fig. 1), the direction of which is N 35°—45° W. There is certain evidence of these, however, only in the Outokumpu mining field, in which such a fault is visible in the shaft Kumpu B itself, where it cuts across the ore. Here at the point, where the fault occurs, there is a loose, water-permeating breccia, in which crushed pieces of granite dyke are found in a very fine-grained, clayey and in some places chloritic substance. The fault runs from NW to SE and dips about 70° to the SW. The striation of the slickensides shows that the upward movement of the western side occurred in a NW direction, at 60° angles from the horizontal plane.

Several such faults appear to intersect the rocks of the Outokumpu ore-field. In most of them, as in those referred to, the western part seems to be lifted.

Their exact direction cannot be determined in the mining field. The direction of the above-mentioned fault discovered in the mine appears to be about N 20° W, but, as more faults were discovered in mapping the area, it is a case of a whole faulting zone. To the NW of Outokumpu, towards the parish of Kaavi, such an obvious lineal arrangement can be observed in the contours of Lakes Rikkavesi and Luikonlahti that they can be considered to have been controlled by numerous fault-lines. Especially Lake Luikonlahti, over 10 kms. in length, but for the greater part only 300—500 ms. wide, the longitudinal direction of which intersects the Outokumpu ore-field, seems to lie on the continuation of the faulting zone referred to (Fig. 1, 3—4). The direction of the fault-lines would therefore be N 40° W here, too.

By means of the same movements the open fissures may have occurred, which intersect the Outokumpu ore and other rocks and in which there is only a clayey filling mass containing here and there

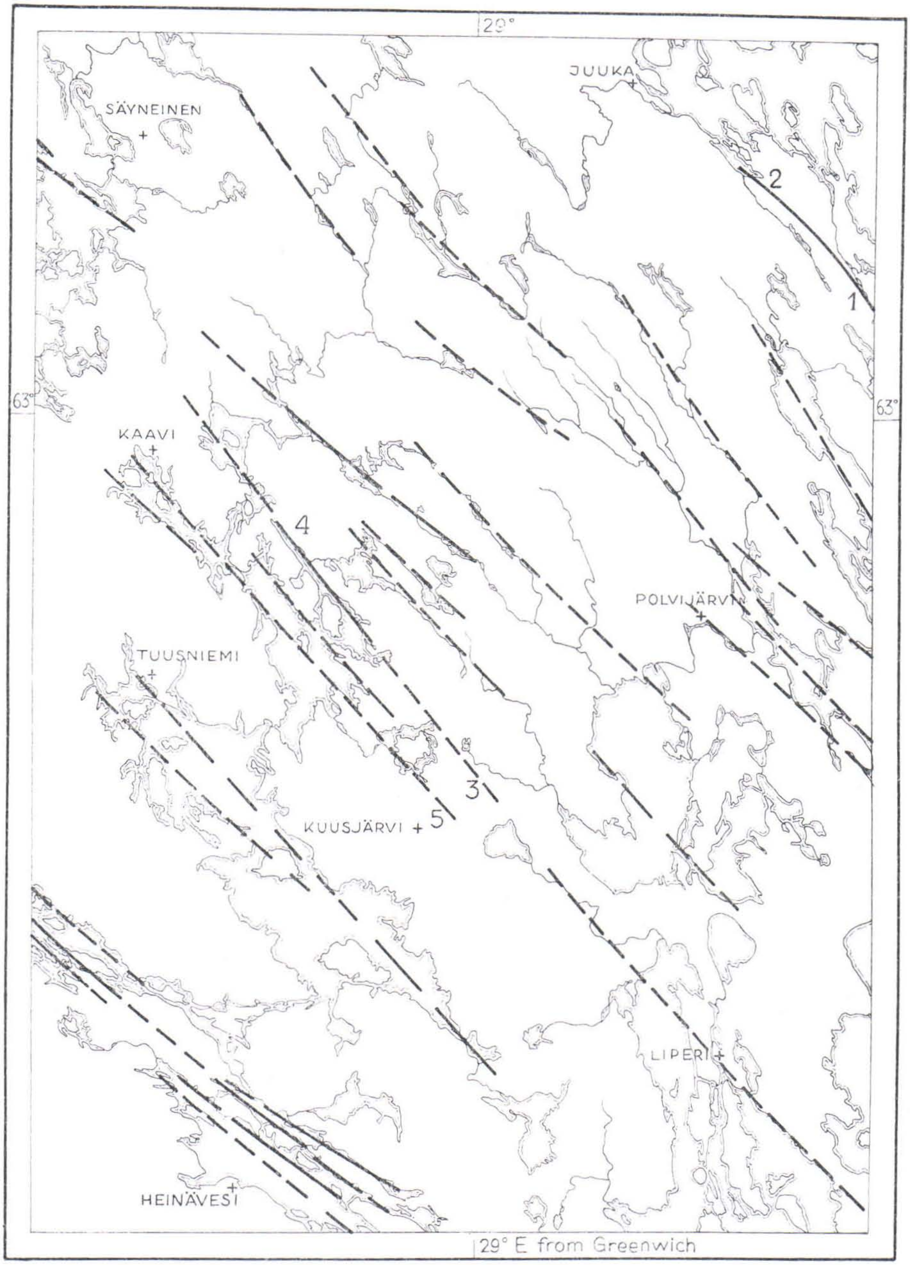


Fig. 1. The most pronounced fault-lines of North Karelia. Scale 1:600,000.

dark, hard pieces of serpentine material, two opposite surfaces forming shiny slickensides.

In the outcrops, however, there seem to be no joints running in this direction.

OTHER FISSURES AND JOINTING DIRECTIONS.

Other cracks can be observed fairly generally in the rocks, also directed fairly uniformly, varying in the SE part of the area between N 60°—80° W, the mean being N 70° W, thus intersecting the former at an angle of 20°—40°. In the NW part their direction is almost NW—SE. These fissures differ from the former in character in that they do not appear in the topography of the landscape, nor are crushing zones ever connected with them, nor have they caused any dislocations of layers worth mentioning. On the other hand, dykes of quartz occur, running in their direction, in some places up to 5 ms. in thickness. Metasomatic changes have also occurred in the mica schists along these cracks. The dip of these fissures is, as a rule, about 70° to the NE, thus the reverse of the former. It is a remarkable fact that both in their strike and dip they are perpendicular to the folding axis.

These facts, the position of the fissure lines, but also their exceptionally smooth surfaces, determine these cracks as transversal fissures, which Cloos described by the letter Q in his granite tectonics.

In addition, there are in some places, especially in the quartzites, two sets of cracks almost perpendicular to each other, which form an angle of about 45° to the former. The displacements in these correspond to the pressure exerted in the direction of the former cross joints.

THE ORIGIN OF CRACKS AND FAULTS.

The transversal fissures, being perpendicular not only to the strike of the schists, but also to the folding axis and tension (pitch), and thus going in the same direction as the greates compression, are caused, according to George F. Becker, by the inhomogeneity of the material. The two directions of cracks, that are perpendicular to each other, on the other hand, represent the master joints, the circular sections of the strain ellipsoid, in which the shearing strain ''Scherspannung'' attains its maximum. This is proved by the fact that no displacements worth mentioning have occurred in the direction of the former cracks, though they have taken place in connection with the latter. Filling dykes, again, occur in the former, but not in the latter. Either of these two sets of cracks therefore originated during the period of orogenetic deformation.

On the other hand the movements belonging to the category of the Kolvananuuro and Outokumpu faults are fairly late, younger than the orogenetic period, as the faults intersect the dykes of pegmatite and are still open and filled with fairly loose material, to which their great importance in the topographic respect is due. They originated at the earliest in the radial movements caused by isostatic readjustment as the response to the wearing down of the Karelidic mountain chain. This manner of origin is indicated, among other things, by the fact that the western part has, as a rule, been lifted in regard to the eastern part. They might, of course, be considered still younger, but they do not correspond to the direction of the Caledonian mountain chain, nor is there sufficient reason to assume that such late dislocations were so closely-spaced.

THE FOLDING TECTONICS.

AXIAL DIRECTIONS AND THE TECTONIC DIVISION.

Wegmann has made an ambitious effort to explain the folding kinetics of the Karelidic orogeny. To vindicate it by a tectonic analysis, however, he was obliged to base himself to a large extent on assumptions, as there was not yet sufficient material at that time for making a tectonic analysis based on actual observations, nor is there even now in the whole orogenic zone. *E.g.*, the structure sections of the North Karelian area of schists are obviously drawn on the assumption that the folding axis in the whole of this area pitches due S. Instead, already partly at the hills of Juuanvaara and Timonvaara, but especially to the west of them up to the village of Säyneinen, another direction of the axis prevails exclusively, plunging in mean 25° due S 50° W according to numerous determinations that correspond very well (Fig. 2), thus almost at right angles to the axial direction in the Nunnanlahti district and the one found in the whole Höytiäinen basin, the mean for which is 30° S 20° E. The view expressed by Wegmann therefore requires appreciable correction at any rate in this respect.

Judging by the fact that the axial directions in these contrasted parts of the investigated area differ so greatly and that the areas of different axial directions are bounded so sharply against each other as has been observed on the Juuanvaara—Timonvaara line, both the areas have apparently a kinetic development of their own. They cannot be treated on such a uniform basis as Wegmann has attempted to do. Nevertheless, in regard to Wegmann's treatment it must be acknowledged that by showing analogies between the Karelidic orogeny and the Alps it contains very many ideas worth considering, although it has not always proved rigt in details.

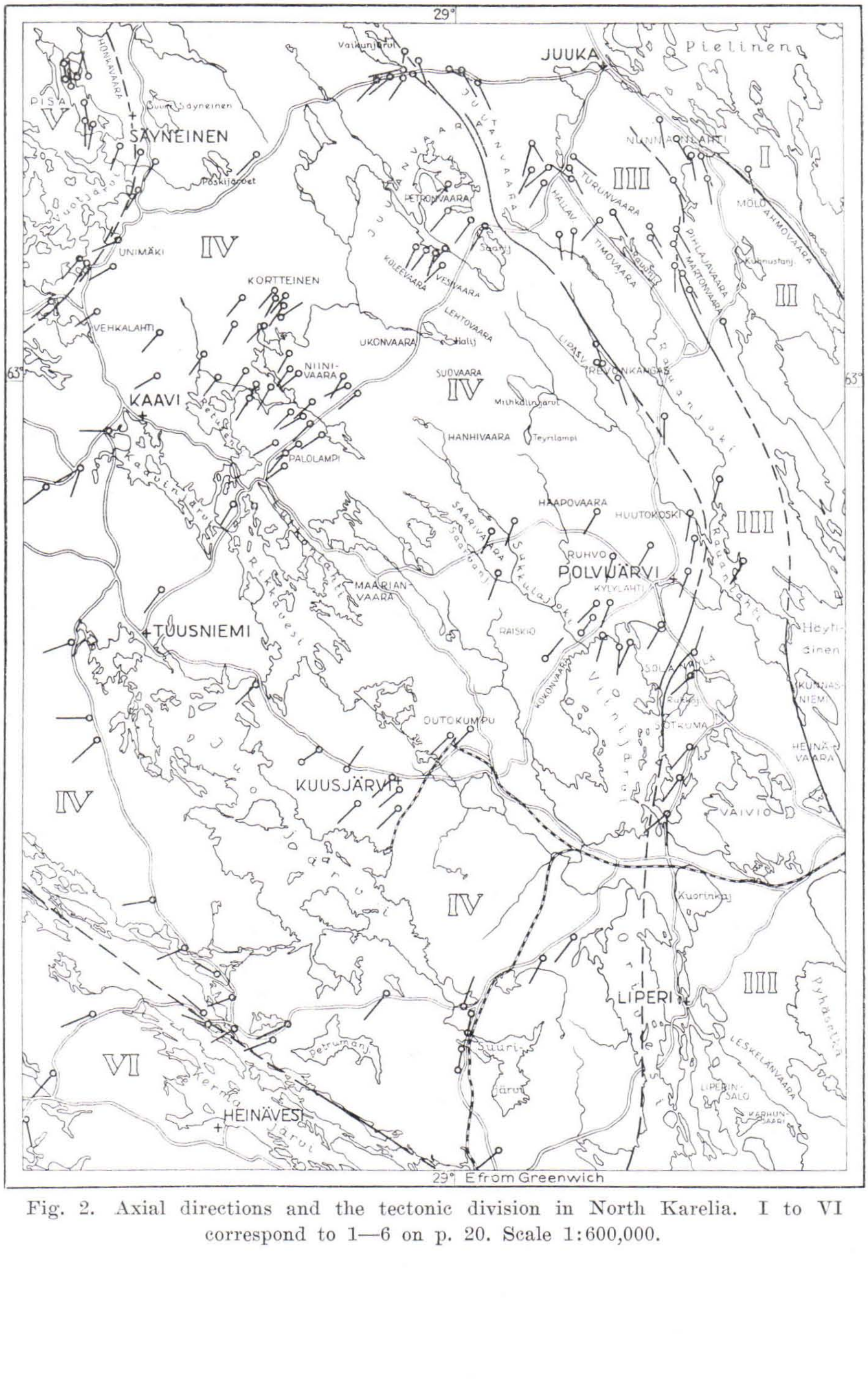


Fig. 2. Axial directions and the tectonic division in North Karelia. I to VI correspond to 1—6 on p. 20. Scale 1:600,000.

With regard to the tectonics we can divide the investigated area into the following zones:

1. The Jatulian area in the NE corner of the map (Fig. 2), also embracing an old basal complex and a narrow belt of Kalevian phyllite up to the fault-line of Mölönjärvi—Kolvananuuro.

2. The syncline of the Höytiäinen basin, bounded in the W by the prominent tectonic line formed by the southern part of the granite massif of the church of Juuka being thrust over the Pihlajavaara quartzite. This line follows the eastern slope of Martonvaara quartzite ridge towards the S, and it apparently continues as the eastern limit of the Vaivio granite massif and further through the town of Joensuu and the gabbro body of Onkamo to the Tohmajärvi gabbro area (Fig. 4, p. 32).

3. Besides it seems correct to distinguish a narrow anticline zone, which is bounded on the W by the E limit of the Petronvaara granitic massif and continues thence SE in a more or less straight line to the bay of Rauanlahti, the westernmost branch of Lake Höytiäinen, and thence past the church of Polvijärvi and along the E shore of Lake Viinijärvi and southward to the granite massif of Liperinsalo lying beyond the mapped area.

4. The greater part of the region dealt with is what might be called the area of serpentine intrusions. In this area the strikes of the schists form concentric curves arched towards the SE. The pitch of the folding axis is, however, in the whole area almost constantly S 40°—50° W.

5. The Pisa area, in the NW corner of the map, in the centre of the above-mentioned curvature.

6. The area of Savo schists, in the SW corner of the map, to which the serpentine intrusions do not extend, and which is separated from the belt of serpentine-intrusions by a pronounced zone of shearing.

THE JATULIAN AREA.

In the NE corner of the area dealt with a narrow belt of quartzite appears and below it in the NE its old basement of deposition and above it a narrow phyllite strip (Map I).

The quartzite belt is a branch of the extensive Jatulian quartzite area of Koli—Kaltimo. This part of the quartzite division dipping to the W at an angle of 50°—60°, is uniform and continuous and does not appear to have moved much on its basement, but the complex as a whole is much more broken up in the Koli—Kaltimo area than is shown on the general geological map, sheet D 3, Joensuu. It is very closely cut up into sheets which overlap each other and also show slices of their basement in between, which consist either of gneissose granites or schists or of gabbroid rocks. Occasionally also intrusive gabbros are met with between the sheets.

On the Koli peninsula jutting out into Lake Pielinen another northern branch of the quartzite zone has been forced like a finger into the older schists, so that their mullion structure at the point of the finger pitches vertically.

In the W the Jatulian area is limited by the tectonic boundary line of Nunnanlahti—Kolvananuuro, referred to above (p. 14) as a fault-line, which can be followed for a distance of over 50 kms. It runs in the same direction as the other fault-lines referred to above and has the same characteristics being clearly visible in the landscape. In its southern part it disregards all the older geological structures, but in the northern, at Nunnanlahti, it has apparently followed an earlier, much more pronounced zone of tectonic movement (Wegmann 1928). It should be noted, however, that the rocks looked upon by Wegmann as ophiolites have not intruded in connection with this movement, but are pre-Jatulian tuffitic amphibole schists and phyllites connected with them, fine-grained leptitic acid rocks, and serpentines that have intruded them, also pre-Jatulian, connected with the zone extending along the N shore of the Koli peninsula and the shore of Lake Pielisjärvi in the mapped district (Väyrynen 1933, p. 61).

THE SYNCLINE OF THE HÖYTIÄINEN BASIN.

The schists of the Höytiäinen district form, generally speaking, one large syncline. They are slightly metamorphic phyllites, below which at the bottom of the syncline a quartzite stratum is visible at its northern point, but on the eastern side at Kontiolahti the schists have been deposited, beginning with a conglomerate with quartzitic and granitic pebbles, partly on the top of the Jatulian quartzites and S of Lake Latvajärvi directly on the granite basement.

Regarding the relation of these phyllites to the Jatulian quartzite zone of the Koli—Kaltimo area there has always been a difference of opinion. Tigerstedt (1892) assumed, as already stated, that the phyllites lay above the quartzites in their original position, but already earlier, for his theoretical reasons, Wiik had presumed that the North Karelian phyllite series was older than the Koli—Kaltimo quartzite area to the E of it and assumed that their present order was due to later inversion (1876, p. 64). Sederholm was the first to present the more modern view of overthrusting (1897, p. 211). This opinion has been adopted by most of the geologists who have dealt with the subject since. This opinion has been vindicated by the fact that schists, often strongly crumpled and partly crowded with veins and lenses of quartz, occur along the contact zone of the area of phyllite, as photographed by Wilkman in the ledges close to the Pörönvaara farm. Frosterus and Wilkman have also described a number of brecciation phenomena which they consider to have originated in connection with the overthrust referred to. Some of these breccias merge, however, into distinct conglomerates and the majority are most probably similar features.

It cannot be denied, however, that an overthrusting of the phyllites occurred above the quartzites. I would not, however, consider the abundance of the quartz veins in the schists as proof of this, but in my opinion the microscopic structure of the phyllites elucidates the matter best. The phyllites are often megascopically very neatly finely laminated close to the quartzite contact, although the lamination does not seem very regular. Microscopically, however, it is seen at once that this is not at all a case of actual regular bedding, but of sliding surfaces that can go in transverse directions (Fig. 3). Evidently

Fig. 3. Gliding surfaces in a strongly sheared phyllite NW of Lake Latvajärvi, parish Kontiolahti. Magnified 30 diameters.

differential movements have occurred here, but there is nothing to prove that they have attained such proportions as has been assumed.

On the contrary, conglomerates have been recently found in some places (Väyrynen 1933), which prove unquestionably that these phyllites were originally deposited unconformably on the Jatulian quartzite. This syncline should therefore be considered essentially autochtonous, as a series folded to a comparatively gently-shaped syncline.

THE ANTICLINAL ZONE.

At the northern end of the syncline referred to a basal granite massif extending southward from the neigbourhood of the church of Juuka has overthrust it along the W limb of the quartzite zone at its base. This tectonic limit is best visible at the hills of Ahvenmäki and in the cliff opposite it in the W on the other side of a little river. Here steeply dipping theets of granite, quartzite, conglomerate, and basic rocks alternate.

Further south this overthrust plane turns in a SE direction passing the Martonvaara quartzite ridge and continues obviously as the E limit of the Vaivio granitic massif, which has along this line overridden the phyllites outcropping at Kunnasniemi, on the W edge of Lake Höytiäinen, belonging to the syncline of the Höytiäinen basin, as the shearing and brecciation phenomena at Heinävaara described by Frosterus and Wilkman indicate. Here, too, conglomerates with granite pebbles are present on this line, but their significance in connection with such an overthrust is uncertain, as will be seen later.

On the W edge of the same granite massif there are, however, at the village of Sotkuma conglomerates, which show that the phyllite series was deposited directly on the granite basement. On the southern edge of the massif a small quartzite strip exists N of Lake Kuorinkajärvi and above it towards the phyllites a conglomerate, which, however, contains granite pebbles.

At the northern end of this anticline zone the Timonvaara ridge of quartzite is situated, on the E slope of which a zone of conglomerate extends for a long distance between the quartzite and the underlying gneissose granite. It is often very intensely sheared, but in some places there is a well preserved, perfectly distinct basal conglomerate with granite pebbles in it. In such circumstances the Timonvaara quartzite would seem to have moved comparatively little on its original basement.

There is, however, no considerable quartzite horizon below the phyllites situated in the basin of Lake Rauanjärvi on the SE side of

Timonvaara, but they seem to lie on the granites, although the junction between them and the granite may also be a tectonic one. No exposures of this boundary have been found.

In this intervening zone the phyllites were thus mainly deposited immediately on the basement of granite, while on the contrary the phyllites of the Höytiäinen basin in the trough of the syncline rest on a thick quartzite deposit. Consequently the welt, represented by the granite massif of this intervening zone, should have been raised at any rate above the syncline of the Höytiäinen basin already at the time of the transgression of the phyllite series, but this welt seems to have remained in its embryonic state and has not thrust over the Höytiäinen syncline any further.

The phyllites in this zone are most like the schists of the Höytiäinen syncline, and their slightly metamorphic condition indicates that, even though far-reaching overthrust may have passed over this ridge, no ophiolitic intrusions seem to have extended there between the nappes.

At any rate further south at the islands of Liperinsalo and Oravisalo the nappe, as Wegmann, too, points out, seems to have moved over the corresponding granite massifs, as the peculiar breccia-like rocks found at Leskelänvaara, Niinikkosaari and Karhunsaari E of the Liperinsalo massif can be better explained, in my opinion, as tectonitic features that accumulated on the leeward side of the massif than as conglomerates, as Frosterus, Wilkman (1916, 1920), and Saksela (1933) have explained them. Besides the basement rock called basal granite is actually a flat-lying banded gneiss, which it is also easier to interpret as tectonitic product.

Here the ophiolitoid intrusion has reached above this gneiss massif and it is also accompanied by stronger metamorphism and mineralisation (Väyrynen 1935).

THE AREA OF SERPENTINE INTRUSIONS.

The geological structure of the zone.

The zone which we have called the area of serpentine intrusions, is the most important part of our area of investigation, not only because it represents the largest part of our region, but also because one of its more important features, the serpentine intrusions, is connected with such a considerable ore deposit as the Outokumpu copper ore, the explanation of the formation of which depends on an understanding of the geology and tectonics of the whole of this area.

This zone is also the most interesting on account of its being the most difficult to comprehend.

The difficulty of comprehending both the tectonics and geology of this zone is due to several circumstances. In the first place, as regards the tectonics, the curved shape of this area which differs from the direction of the former zones; secondly, the exceptional directions of the folding axes of this area; and lastly, the occurrence of serpentine intrusions in belts and the special features connected with them.

With regard to the geological problems it should be mentioned that there are two types of sedimentary series in our area: a phyllite division, grading over to gneisses and arterites, which could be called the Kalevian flysch, and a quartzite-dolomite-phyllite succession which could be called the Pisa series. In addition it should be noted that, although the gneissose granites occurring in the north are considered to belong to the basal complex, no basal conglomerates have been discovered in the area, on the basis of which the mutual relations of these rock groups could be established, as above, *e. g.*, the mutual relation between the Jatulian and Kalevian divisions, or at any rate their original order of deposition. Conglomerates have, indeed, been found in a couple of places in the neighbourhood of Halivaara though not at the base of the series lying immediately on the granite, but tectonically enclosed. It is therefore natural that both the rock complexes have been thoroughly moved and that different opinions may arise as to their mutual relationship. Frosterus at first (1902) coordinated the phyllites of the Pisa series to the Kalevian phyllites, and as the quartzites of the former series are usually situated above the phyllites, he considered them as a higher horizon in the Kalevian. Wilkman, on the other hand, coordinated these quartzites in question to other "Kalevian" quartzites and interpreted the transitional rocks between the quartzite and gneissose granites, *i. e.* the gneisses and blebbed gneisses as basal formations, as *in situ* deposits of disintegration gravel in metamorphic habit. Others again have emphasised the fact that the quartzite-dolomite-phyllite series in question is the same as in the Suojärvi Jatulian, and consider this to prove that they belong together and that the Karelian system represents a continuous sequence from the Jatulian to the Ladogan.

In my opinion the following facts should be taken into consideration in dealing with the mutual relationship of these sedimentary series:

1. The Pisa series still occurs in a typical development at Juuanvaara, but to the east there is not even a trace of it. Timonvaara,

which is connected with it almost due SE, is of an entirely different type.

2. Both these types of rock complexes, the Pisa series and the Kalevian flysch alternate between Juuanvaara and Pisa, though each clearly preserves its typical character. It therefore seems to be difficult to consider that they belong to the same series.

3. Below the Pisa series towards the gneissose granite no basal conglomerates have ever been found, which would prove that it was situated on its original floor, but gneisses and augen gneisses, which rather afford proof of the allochtonous character of these rock complexes.

4. The rock division now in question is usually connected with ophiolitic serpentine intrusions, which also prove that it has been greatly displaced horizontally.

For these reasons the facies of Pisa series should be considered foreign to the whole area we are dealing with. Its generally thoroughly moved state is also proved by the fact that it forms a synclinal basin in the Pisa area, in which intensely folded phyllites are situated in the middle, but in the Juuanvaarat area the phyllites and limestones have been closely folded together in front of the eastern edge of the quartzite sheets sloping to the west.

It is, indeed, true that no basal conglomerates have been found either underlying the flysch series towards the gneissose granites in the zone we are dealing with, but usually the same kind of gneisses and "eyed" gneisses as below the Pisa series. It is therefore evident that the phyllites have also been thrust on their basement, but they are by no means foreign to this area, being connected with the autochtonous deposits lying due E. Their greatly metamorphic state and granite intrusions and even the fairly large granite bodies prove, however, that the area was pressed down during the orogenic period to a great depth which increased to the west, and thick overthrust masses were translated upon it from the west. By the pressure of these the phyllites, too, were deformed so violently that all the conglomerate beds were rolled out and became unrecognisable.

The rôle of the nappes.

The best proof of the overlapping of the area by a continuous nappe is afforded, however, by the curved strike of the phyllite area already referred to, the northern end of the curve pointing almost NW and the southern end in the Juojärvi district almost W, and the very regular pitch of the folding axis, in general slightly SW (25° S 50° W).

This shows that a push from the NW, differing entirely from the general direction of the Karelidic deformation and caused by some solid mass, was acting towards this area and forced the phyllite zone into an arcuate shape. As the schists very often show fairly or slightly inclined positions in large areas, this curved shape is not due to the compression of the crystalline substructure, of the whole basement, because in such a case the dip of the schists would be steeper, but rather to an overthrusting of a solid sheet above the phyllites.

The serpentine intrusions also point in the same direction. These serpentines seem sometimes to occur, as in the Kaavi district, as almost horizontal sheets or as flat bowls in or above the schists, but mostly, as in the Outokumpu—Ruhvo and Saarivaara—Miihkali zones, they dip to the SE, to the convex side of the curve.

If these serpentines had been forced up by pressure coming from the NW and along shear planes upwards from the depth, it would be inexplicable, why they should have risen up along cracks sloping to the SE. Thus there is no other possibility than that the serpentines must have originated from moving magma under a flat-lying cover. In that case their position on the leeward side of the bow-formed downfolds is at once clear.

Then the rocks of the zones containing serpentine intrusions can also provide an explanation as to the composition of the nappe that overthrust our area in connection with the *mise-en-place* of the ultrabasics. The quartzites, dolomites and carbonaceous phyllites building up the Outokumpu area and the occurrence of the same sequence of rocks in other serpentine zones clearly indicate that it is a case of a complex identical with the Pisa series.

In these circumstances many facts point decidedly in the direction that the Pisa series, which is so widely spread, besides the above place in the allochtonous formations of the Juuanvaarat hills (Juuanvaara, Petronvaara, Vesivaara, Koleevaara) and south of them at Lehtovaara, extended, as a continuous sheet, over the phyllites that contain serpentine intrusions up to the bay of Rauanlahti, the westermost branch of Lake Höytiäinen, and the eastern shore of Lake Viinijärvi, *i. e.* as far as the Vaivio basal granite massif. We might call this overthrust sheet the Outokumpu nappe.

The extent of the overthrusts.

The width of the Outokumpu nappe, measured in the direction of the radius of the curvature, *i. e.* from the margin of the Pisa area to the eastern shore of Viinijärvi and the margin of the Vaivio massif is exactly 60 kms. It is evident that this sheet once actually covered the whole of this area, as there are remnants of it all the way as ''klippen'' in the downfolds. It is, however, not so clear that the nappe was thrust uniformly over the whole of this area. In the Kaavi district the crystalline substructure has been broken into sheets that overlap each other, and parts of the thrust mass have been wedged between them (the Kortteinen—Luikonlahti zone). In this case, therefore, it is possible to adopt a view of an imbricate structure similar to the one, by which Holtedahl avoided the assumption of very extensive nappes in the Caledonian mountain zone (1921). Above the phyllite area, however, it had to be transported from Maarianvaara to the Vaivio massif, *i. e.* as a continuous sheet of about 25 kms.

An important fact has, however, not been mentioned. The Juuanvaara range, which clearly belongs to the Pisa series, dips much more abruptly than the other parts of the Outokumpu nappe in these districts, up to 50°—60° SW. It should be noted, besides, that this quartzite has neither moved to the SE nor folded at any rate as intensively as the areas SW of it, because it clearly retains a folding axis pitching in a SSE—S direction. In the Pisa area, on the other hand, the pitch is almost to the S. Therefore it seems possible to draw the conclusion that this nappe was formed at first by overthrusting in an ENE or E direction, but later, when a push from the NW was directed towards it, it yielded to that. Then, however, Juuanvaara was torn away from the overthrust sheet, wedged between rigid masses of granite and pressed into a steep position. By this means, of course, the width of the overthrust was reduced and evidently it extended originally still further east, as the blebbed gneisses of Turunvaara indicate. The width of the nappe in this direction must in every case originally have been over 30 kms.

Further south much higher figures are obtained for the width of the overthrust, measured in the same direction, from the western margin of the serpentines W of Tuusniemi to Rauanlahti 55 kms, as in any case this complex of rocks must have come from beyond the flysch-area.

On the other hand, it might be assumed that the schists of the Kaavi and Tuusniemi district with their overthrust masses have been carried from farther away in the NW with the stress from this direction. Such a movement, to which we will refer later, is indicated by the wedge-like shapes of the Niinivaara and Säyneinen phyllite areas and by the fact that it can be concluded on the basis of the structure of the folds that the schists were folded in some places, such as Luikonlahti and the neighbourhood of the church of Kaavi, towards the SW. Besides, it must undoubtedly be presumed that the phyllites even in the large phyllite area were compressed in the direction of their strike, because otherwise its deformation into a bow would have caused appreciable tension and rifts, which again would have resulted in magma intrusions. Owing to this compression the area of schists has widened out to the west from its original breadth. If we calculate the minimum width of the zone from Maarianvaara to Rauanlahti, we obtain at least 25—30 kms.

The relation of the intrusive magma to the overthrust movements.

Below the nappe considerable masses of magma have evidently moved, reducing its friction against its basement, it might even be said carrying it forward. Their quantity cannot be estimated on the basis of the quantity of serpentines, for it is probable that the magmas were not peridotitic in composition, but much more acid, as, *e. g.,* I have shown in the Petsamontunturit area (1938 c), so that only local accumulations of olivine crystals were formed at the bottom which by continued cooling down resulted in serpentine bodies, while the vastly greater part of the magma was squeezed further and was able to extrude to the earth's surface, apparently in front of the anticlinal zone.

From these intrusions the pyrite ore magmas and other solutions containing sulphides, from which the Outokumpu ore and other copper and iron pyrite deposits generally situated close to the serpentines originated, were separated and kept to their track here, as in Petsamo.

The formation of serpentines probably occurred already at the time of the eastward movement of the overthrust, as the serpentines extend farther, especially in the south, than the movement proceeded to the SE.

The intrusion of the granites, which is confined principally to the Kaavi and Tuusniemi districts and to the west of them, is evidently the consequence of the movement from the NW to the SE and is apparently associated with the latest tectonic disturbances in the area. Subsequently only the fault movements referred to in the beginning occurred.

THE PISA AREA.

The Pisa—Keyritty—Kinahmi area.

The Pisa district constitutes the SE point of the oblong area, consisting chiefly of gneissose granites and gneisses, which extends from the Pisa district to the NW up to the Vieremä phyllite area past the town of Iisalmi. This area is, on geological maps, considered as corresponding to the resistance area of East Finland, the foreland of the Karelian orogeny (Fig. 4).

Coarse blebbed (augen) and other gneisses predominate in the Pisa area and a sedimentary series is situated on top of them. Two quartzite ridges exist in the W, of which the W one comprises the following hills from S to N: Kiiskimäki, Suuri (Great) Pisa and Pieni (Little) Pisa, in which the quartzite beds dip abruptly (70°—75°) to the W. To the E of this chain, separated from the former by the narrow Lake Valkeinen and by a wedge of blebbed gneisses both in the N and in the S, lies the Mustikkamäki quartzite range, which shows folding with two synclines and an anticline between them. The narrow tail of this zone, is directed to the SE, dips slightly to the NE below the phyllites and is wedged between the blebbed gneisses.

To the E of Mustikkamäki, close to the quartzites in the Siikajärvi basin, first dolomitic limestones and phyllites are met with intercalated with quartzite, and further E phyllites, in which there are very intensely folded bands of grey quartzite. The phyllite horizon exhibits a distinct synclinal form and two axial depressions, both in the N and in the S, and in the N quartzite is found in the downfold and dolomite occurring in connection with it.

The gneisses and blebbed gneisses in the E of the area have been thrust over the quartzites and phyllites of the Säyneinen phyllite area, to the E of them, the thrust plane sloping at an angle of about 45°, and a thin sheet of granite having been intruded along it. The serpentines are lacking here, but appear at Vehkalahti, in the S end of the zone.

It seems quite evident that the Pisa area constituted a part of the huge rigid sheet, which deformed the phyllite area as described above, because the first bow of quartzite, the Unimäki—Honkavaara belt, directly adjoins the margin of the Pisa area. The pitch is quite different in the Pisa area than in the area of bows, and the gneisses of the former area have overthrust the latter belt of quartzite, that dips to the W and NW and is associated with the first serpentine intrusions, as we have seen. One would therefore expect the seam, from which the Outokumpu nappe started moving, to be in this zone. This cannot be the case, however, for the Pisa sedimentary series is allochtonous as well and has been riding away from further in the W. This is indicated by the blebbed gneisses. The case seems to be the same in regard to the Keyritynmäki quartzite ridge that lies 13 kms. further N and is 17 kms. long. It is only the Kinahmi quartzite ridge 15 kms further W, to the W of the church of Nilsiä, which seems to represent the zone of departure of the Outokumpu nappe, in other words, the zone of roots. In that case the seam of the geosyncline should be at this zone and the Pisa—Keyritty area should be soldered to the Iisalmi resistance segment after squeezing out of the nappes from this geosyncline. This is also made probable by the fact that conglomerates with pebbles of granite have again been found W of Kinahmi, in an autochtonous position.

Movements of the Iisalmi segment.

The question arises, whence the pusch of the Iisalmi block in a SE direction was caused. NW of the Vieremä area there is no such active mass that could have forced the Iisalmi block to the SE, there being a late-Karelidic granite intrusion here (see Sederholms's map, Ancient rocks, 1930). On the other hand, however, a strongly sheared zone of gneiss occurs W of the Vieremä area, to the W of Lake Näläntöjärvi, and the vertical position of these gneisses squeezed in against the Iisalmi block shows that the western Archaean crustal segment has not been able to ride above the Iisalmi block here, but has been pressed against it. This later again has evidently not been able to be thrust over the East Finnish resistance area in the E, and it has therefore had to deviate southward. This oblong block, which now lies almost parallel to the Karelidic mountain chain, was evidently situated formerly in a more transverse position and was deflected owing to the pressure into its present position, when the E end of the block was displaced to the SE, all the phenomena described having been due to it. The granitic body S of Kajaani would have intruded into the opening that was made.

More probably, however, the Iisalmi block was originally wider and its NE corner was thrust to the E into the Paltamo district, but the SE corner was not able to ride over in the same way, the block having to make a turn. This supposition explains at the same time the overthrusting phenomena established in the Kiehimä district (Wegmann 1928). The intrusion of the granite, too, under the overthrust mass is as natural as in the former case. In either case the result is a deflection and the protrusion of the SE corner of the block towards the SE. Possibly a deformation that occurred in the block and the rock complex dammed up in front of the block from Rautavaara to Kaavi transmitted this movement still further, possibly contributing to the rise of the Vaivio and other massifs in front of the protrusion.

The gradual wedging out of the Sotkamo quartzite—phyllite area in its southern end and the sharply different aspect of the area

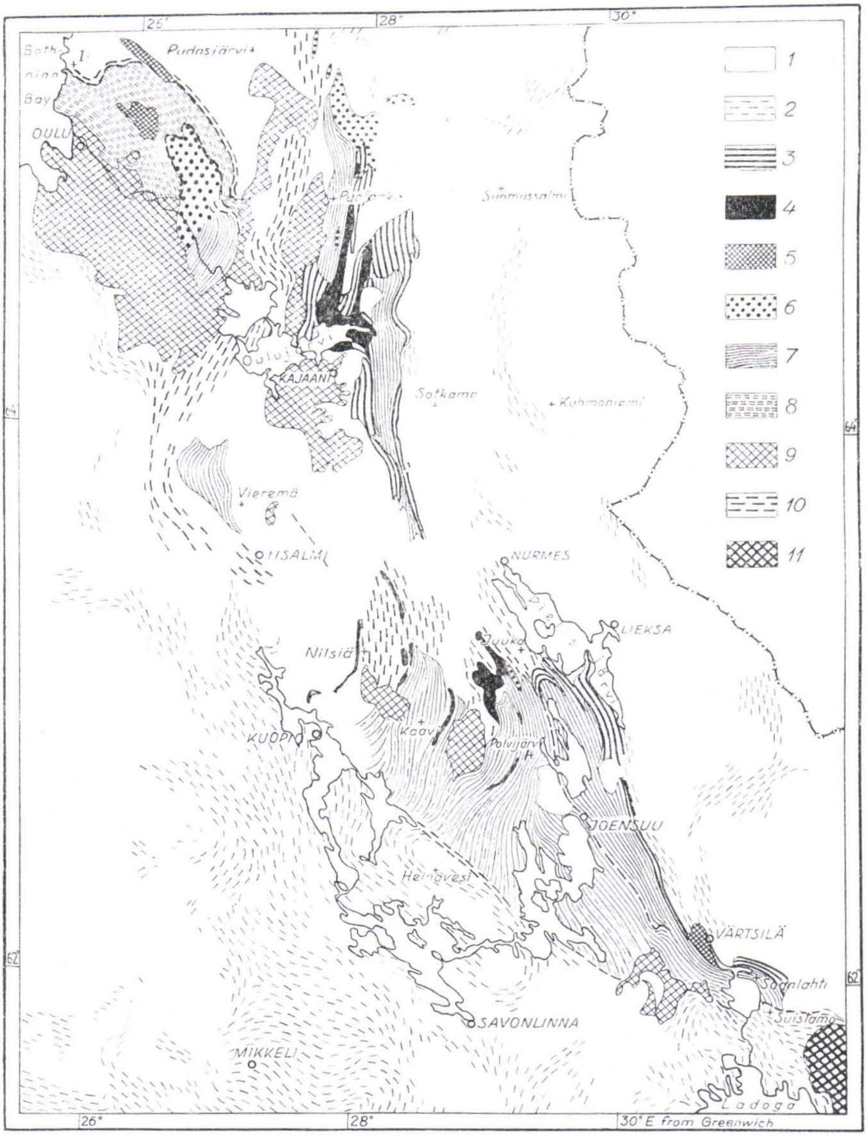


Fig. 4. Karelian rocks in the areas of Karelia and Kainuu.

1 pre-Jatulian granites
2 pre-Jatulian schists
3 autochtonous Jatulian
4 allochtonous Jatulian
5 post-Jatulian basic rocks
6 Kalevian quartzites and conglomerates
7 Kalevian phyllites
8 schists belonging to Kemides
9 post-Kalevian granites
10 tectonitic gneisses
11 rapakivi

SW of the church of Juuka, where several overthrust masses have been piled up above each other, may also be partly explained in this way, as well as perhaps also the finger-like projection pointing NE from the Koli area and the fact that the Pisa facies has disappeared entirely from this intervening area, between Kajaani and Juuanvaarat, but appears again in the Kajaani district (the Paltamo and Puolanka dolomites). Originally the blocks of Iisalmi and Ii may have been connected, but, when the northern end of this block also met with obstruction, it had to bend in the middle and was broken. In this case the push to the SE could have been caused by the rigid masses in Lapland (the folding of the Kemijoki area).

THE SAVO AREA OF SCHISTS.

The zone of serpentine intrusions is bounded in the SW in an entirely different manner. Here the Savo area of schists intersects this zone transversely to its strike, even transversely to the direction of the folding axes. On the margin there is a very pronounced zone of shearing a few kms. in width, along which all the lake contours are strictly orientated in its NW—SE direction, as seen from the maps. It extends through Lakes Suvasvesi and Kemijärvi. In many parts serpentine intrusions extend right up to this zone, but in no part beyond it. I have drawn attention to this circumstance on a previous occasion (1933).

Such a shear zone can be traced for a distance of about 90 kms. from the church of Savonranta to the church of Vehmersalmi near Kuopio. In the Kuopio district the zone is hidden for a distance of about 50 kms. under Lake Kallavesi. Between it and the W margin of the Vieremä area in the NW (about 70 kms.) as well as from Savonranta to Lake Jänisjärvi in the SE (about 80 kms.) the trend of the zone has not been investigated in detail.

The general views of Sederholm and others concerning the chronological divisions of the Karelian system were referred to on pages 10—11. The classical area of the Ladogan series was situated between Lake Jänisjärvi and the N shore of Ladoga, although also all the other phyllites dealt with here were assigned by Sederholm to the same, still as late as in 1910, on his map of ancient rocks in the second edition of the Atlas of Finland. Later, however, Frosterus and Wilkman (1917, 1920, and 1923) separated almost all the schists we are dealing with from Ladogan schists into Kalevian and Sederholm also adopted this division in his general map last published (1930). He reckoned among the Ladogan schists, besides the original Ladogan area, certain small areas of Savo schists. Eskola (1925), however, preferred to unite the Ladogan schists, though not defining to what extent, with the Kalevian and Jatulian as the Karelian system. Hackman (1931) also considers both in his rock map sheet, D 2, Savonlinna and in its explanation as a continuous Kalevian—Ladogan sequence.

Moreover, Väyrynen (1929) stated that the phyllites at Soanlahti, looked upon by Sederholm as Ladogan and therefore older than Jatulian, are, according to the Partanen conglomerate occurrence, also later than Jatulian and assigned them later (1933) to the Kalevian flysch-facies. He also showed, on the other hand, that the Ladogan rocks occurring on the shore of Lake Ladoga in the Pitkäranta, Sortavala, and Ruskeala districts were entirely facies-strangers in regard to the flysch deposits, but were reminiscent of the Savo schists of the Savonlinna and Kerimäki districts to such an extent that they should be considered to belong to the same division as the latter.

Nowhere in the area of Savo schists, indeed, have any signs of unconformity been found, similar to those in the Karelian series. The unconformity described by Wilkman in the Kuopio district cannot be considered to be an original one, but rather tectonic, the Kuopio quartzites being connected to the Kinahmi zone of roots. They can therefore also not be looked upon as a particular facies belonging to the Karelian system. They can be correlated better with the schists intruded by gneissose granites that occur in the great East Karelian resistance block, because the Ladogan amphibole schists in particular fully correspond to these amphibole schists. The metamorphism in the W parts of the Kalevian flysch deposits and in the Savo schists, however, is so completely similar that they could not have been distinguished from each other at all, unless the margin of the serpentine intrusions occurred so clearly. When, therefore, the serpentine intrusions disappear in the Savonranta district and the strike of both schists is the same, the boundary in question can no longer be discerned further to the SE. It seems probable, however, that the Kitee body of pegmatitic granite that also penetrates the Karelian schists has found its access along an overthrust plane, and this margin therefore passes through it and along the S shore of Lake Jänisjärvi to Suistamo, seeing that in Ruskeala and 10 kms. S of Suistamo, at Kokkoselkä, typical Ladogan rocks predominate.

GEOLOGICAL DESCRIPTION OF THE STRATIGRAPHIC ROCK GROUPS.

THE BASAL COMPLEX.

Pre-Jatulian schists.

The oldest components in this complex are some patches of schists, consisting of thinly-bedded, occasionally also agglomeratic amphibole schists and phyllites and in addition to them here and there of fairly acid, fine-grained leptitic rocks. In three places quartz-banded iron ores have been discovered in connection with the amphibole schists.

The author detected schists belonging to this category in the Koli area E of the Jatulian quartzite on the E slope of the Ipatti hill (1933), and they continue to the NE point of this area, which projects in the form of a peninsula into Lake Pielisjärvi. Here the author stated the presence of these schists at the foot of the NE slope of Rintasenvaara hill underlying the Jatulian basal conglomerate. The base of the Jatulian conglomerate clearly intersects them unconformably, and there are many pebbles of similar schists in the conglomerate. In the N point of the peninsula at the bay of Niinilahti these schists are intruded by granite and continue along the NW shore of the peninsula to Savilahti. On this shore they are connected with basic intrusives ranging from diorites in a continuous series up to gabbros and serpentines. From the bay of Savilahti this zone turns NW and can be followed in the NE corner of our map, mainly as occurrences of basic rocks more or less continuously along the capes and islands of the shore of Pielisjärvi to about 6 kms. SE of the church of Juuka, where serpentine appears as many large blocks close to the highroad, but is not visible in ledges. Here the zone again turns suddenly backwards to the SW being traceable up to Nunnanlahti and Mölönjärvi. Judging by the loose boulders the serpentines, too, continue uninterruptedly from the sharp bend mentioned above. In the Nunnanlahti district the zone widens again to an extensive area of amphibole schists and phyllites. The pre-Jatulian age of these rocks is proved also by the frequent occurrence of amphibolite pebbles in the Sariolan conglomerates of the Mölö district. The association of the banded leptitic rocks with the series of schists also proves the same. In his rock map sheet, D 3, Joensuu, however, Wilkman has coloured the SE part of this area, between Nunnanlahti and Mölönjärvi, as Karelian metabasites, and Wegmann has interpreted them as ophiolitic intrusions. The author, however, considers them in this district, too, to be at least partly effusive or sedimentogenous rocks similar to the above-mentioned, being a ramification of the larger areas in the NW.

The other gneisses in the area of our map, marked by Wilkman as pre-Karelian, are, in the opinion of the present writer, either tectonitic (in the north) or otherwise more strongly metamorphic parts of the phyllites (Kaavi—Tuusniemi).

The present writer has already drawn attention earlier (1938 a) to the fact that these pre-Jatulian schists only occur in a narrow zone in the vicinity of Karelian areas. Further off they are only met with in a few zones. This would seem to indicate that these schists occurred in the pre-Jatulian denudation surface more abundanly than at present, but did not reach deep. The later erosion, going deeper, has removed them except where the pre-Jatulian surface of levelling has remained close to the present one, either in the vicinity of the Karelian zone or in some zones going in the same direction as the Karelidic chain. In these a warping down of the earth's crust has evidently occurred in connection with the Karelidic orogeny (Kuhmoniemi zone) (Fig. 4).

The Savo schists are also pre-Jatulian, though they do not belong to the basal complex proper, but overthrust the Karelian schists from the W. The amphibole schists are fully similar in both of the old complexes, but these differ from each other in that the Savo schists are connected with numerous limestones, of which only small traces have been found in the schists of the basal complex referred to, and in that the main part of the Savo schists consists of phyllites, which are much less distributed in the schists belonging to the basal complex.

Gneissose granites.

The granitic rocks belonging to the basal complex are very varied both in their composition, structure, and texture, and apparently they also differ in age. In some places they are foliated and streaky or banded, in others homophanous, even-grained or porphyric. Some of them are rich in plagioclase, others in microcline. The massive granites often clearly penetrate the streaky and gneissose types. All these variations are also found in the rocks in question inside the region dealt with.

In the Vaivio massif the rock is for the greater part a normal granite, though in parts migmatitic in different degrees. In the SE part of the massif it contains more micaceous gneiss material, in the NW less. The granitic component is a medium- or fine-grained rock, which does not appear to the unaided eye to be at all deformed or crushed, but under the microscope both crushing phenomena and especially the formation of fine cracks filled with sericite can be observed in it.

The gneissose granites in the N part of our area in the parishes of Juuka, Kaavi, and Säyneinen are of quite a different nature. In this area there are in general very few granites with normal structure, but very strongly sheared types varying between porphyry granites, augen gneisses, and gneisses. Such gneisses mostly contain larger grains of feldspar, which are rarely rectangular in shape, but mostly lenticular or granulated and often drawn out into narrow seams. The mica is arranged between them in continuous strips. Thus the rock frequently grades over into a typical blebbed gneiss, even into highly crushed cataclasite. Besides, the rock is often mixed with pegmatitic material generally in the form of veins going parallel to the schistosity. In some places the pegmatite, too, is heavily crushed and schistose. Such a deformation is most pronounced in the village of Kortteinen in the parish of Kaavi, where a grey, small-grained, entirely homophanous granite, the Maarianvaara granite, has intruded into the gneisses in the form of narrow, long sills. However, the shearing is almost as strong in the Vaikonjärvi district, where some quartzite lenses are wedged between these gneisses. But even as far east as the neighbourhood of the church of Juuka the deformation is very pronounced and the pegmatite intrusions are very common. Nor is this strong deformation limited to the vicinity of the Karelian sedimentary areas, but extends to the N up to Nurmes (Fig. 4).

Consequently, it does not seem likely to the author that the axial culmination of Nurmes was due to the circumstance, that the basement, upon which the Karelian sediments were laid down, was more resistant here to the orogenetic forces than elsewhere. Rather was it the Iisalmi block that stood firm against the tremendous test of strength, instead of the segment in front of it having greatly thickened and bulged upwards so as to raise the sediments lying above to such a height that they were entirely worn off by the levelling of the old mountain chain.

THE AUTOCHTONOUS KARELIAN SERIES.

The Jatulian conglomerates.

Conglomerates with pebbles of quartz. The basal contact of the Jatulian quartzites towards the gneissose granites is seldom exposed in the area of our map. Mostly a narrow depression runs along this junction,with either a river or a fen in it. Close to the contact the quartzite usually contains sericite, and where the bottom horizon is best visible, soft sericite schists usually occur, frequently associated with a conglomerate bed of several metres or at least several decimetres in thickness, where mostly angular quartz grains of 1—2 cms. in diameter have been embedded in the soft mass of sericite.

Movements have often occurred along this contact, the quartz grains having drawn out into lenticular shapes, and the rock appears like a mylonite schist. But often, too, the quartz grains are quite undeformed, and in those cases the true clastic origin of the rock cannot be denied. Both forms can be seen in plenty in the Koli area, where on the steep eastern slope of the Koli hills even the contact zone itself outcrops fairly well. In the area of our map the basal contact of the branch of quartzite projecting from the Koli area towards Nunnanlahti is not visible, but on the N margin of the curved quartzite zone that occurs W of it there are a couple of exposures, as well as on the edge of the eastern branch in the Mölönjärvi district, although here, owing to tectonic movements, there are recurrences, too, in the boundary zone in like manner as in the Latvajärvi district in the parish of Kontiolahti, off the map, which has become famous through the researches of Frosterus and Wilkman.

The basal formations of Jatulian quartzite are therefore similar here to the basal modifications of the Kainuuan (Jatulian) quartzites that I have described earlier (1928). As kaolin deposits have already been found in many places associated with the sericite schists occurring in these bottom strata, but nowhere else, I still consider that my previous explanation of the origin of these sericite schists (1924, 1928, and 1929) is the only possible one.

According to it the pure quartz sand, the primary material of the Jatulian quartzites, was formed as a result of long chemical weathering, owing to which the other minerals were decomposed, forming deposits of kaolin. The origin of these, without exception fine-grained quartzites must be that of wind-deposited sediments, the formation of which on the earth's surface devoid of vegetation is easily comprehensible even in a humid climate. Then the rainwater washed away kaolin that had been produced as a result of chemical weathering, between and on top of the coarser residual sediments uncovered between the sand-dunes. This opinion is confirmed by the subsequent discoveries of kaolin.

C o n g l o m e r a t e s w i t h p e b b l e s o f g r a n i t e. In some places, however, conglomerates formed of chemically unweathered material are found on the bottom of these Jatulian quartzite beds, but they never occur in large areas as continuous strata. Where they occur, they may even form thick deposits, but their horizontal extent is small, and they always pass over upwards into sericite schists similar to those already referred to. These accumulations that have escaped chemical weathering, were apparently formed originally in local depressions, and have remained below the ground-water plane.

Such formations are possibly represented in the area on our map by the zones of conglomerates of the Mölö and Särkkälä farms and of the hills of Portinkallio, Käkivaara and Koposenvaara in the area of Mölönjärvi. Frosterus and Wilkman have given a detailed description of these (1902, 1917, 1920).

These deposits, including, *e. g.*, the Koposenvaara conglomerate which is very reminiscent of tillite (Frosterus, Wilkman 1920, Fig. 27), were apparently formed during an earlier phase of the pre-Jatulian erosion, when the sub-Jatulian peneplain had not yet reached its final stage and when the weathering was principally mechanical. At that time such formations were apparently much larger in extent. Quite similar deposits adjoining Jatulian quartzites still occur in the Onega region (Väyrynen 1938). The author has therefore described them under the name of the Sariolan facies of the Jatulian system (1933).

The Sariolan deposits had apparently not yet undergone diagenesis before the wearing down of the relief had proceeded to such a stage that the mechanical disintegration abated and the chemical weathering gained the upper hand. This is indicated by the fact that conglomerates occur in the Latvajärvi area, in which the sericitic (originally kaoliniferous) cement has run between the entirely unweathered pebbles of granite. It cannot be established, whether the general difference in climate during an orogenic epoch, and, on the other hand, during the phase of peneplanation (Ramsay 1924) had an influence upon this change of conditions. Chemical weathering was able, at all events, easily to affect the loose deposits, and produced the large quantities of pure quartz sand as residual sediments, from which the Jatulian quartzites were formed, and of the Sariolan facies only remnants were left in the largest depressions.

The Jatulian quartzites.

The quartzites belonging to this category are only represented on our map by two zones: a branch projecting from the Koli area into the NW corner of the map and a curved zone that occurs W of it, in the northern end of the syncline of the Höytiäinen basin. These rocks are white or slightly reddish, fine-grained, pure quartzites, exceedingly uniform in appearance in every respect. The bedding is often visible and the individual layers are always thin and even. Ripple-marks are only rarely met with. Cross-bedding and coarser layers between the finer ones have never been discovered. As to their composition the grains of these quartzites are pure quartz, feldspar and other minerals being exceedingly rare. Only a few small tiny flakes of sericite occur between the grains. The sericite increases gradually towards the bottom, occurring at first principally on the bedding planes and then becoming the principal constituent in the sericite schists, a rock that also occurs as the cement in the conglomerates with quartz pebbles.

These quartzites therefore make up another Jatulian facies laid down when the chemical weathering gained the upper hand over the mechanical. The present author suggested in a previous paper that they should be called the Kainuuan facies (1933). These strata of pure, fine-grained quartz sand, which are devoid of both coarser and clayey intermediate layers, could not have originated otherwise than as wind-deposited sediments.

In the area dealt with no marine Jatulian, the third facies group of the Jatulian sequence, which occurs in South Karelia (Metzger 1924 and Hausen 1930) and in the Onega region (Ramsay 1906), has been found anywhere in the autochtonous Jatulian series.

The Kalevian conglomerates.

The relation of the Kalevian series of rocks to the Jatulian. Both on the E and W of the Vaivio massif conglomerates occur on the contact of phyllite series towards the granites of this massif. Thus the phyllites were deposited here immediately on top of the pre-Jatulian granites. According to what has been stated above in regard to the Jatulian quartzites, they cannot by any means be looked upon as deposits of a limited extent only. The Kainuuan facies also occurs everywhere in Kainuu and Karelia and even in the Onega region so similary that it must be considered originally to have been spread fairly continuously over a very wide area. Consequently the position of the Kalevian phyllites directly above the pre-Jatulian basement signifies an appreciable unconformity between the Kalevian phyllites and the Jatulian. The author has emphasised this fact previously both in the Kainuu area (1928) and in Karelia (1933). This unconformity is also proved by the conglomerates, which occur on the bottom of the phyllite series, even when this is deposited on top of the Jatulian quartzite series, as is the case N and E of the syncline of the Höytiäinen basin. The present author has previously reported 7 different occurrences of such conglomerates in this area (1933). Thus even before the transgression of the phyllite series to this area furrows and welts in the form of synclines and anticlines were formed here, and from the latter the Jatulian rocks were removed by erosion, but remained in the former. The syncline of the Höytiäinen basin and its W anticline were thus already initiated at that time. From the W the Jatulian appears to have been removed by erosion from the whole phyllite area, while in the E it appears to have been preserved over a large area, possibly in a depression which was subsequently compressed, and divided into sheets which were thrust over each other (Koli—Kaltimo area). Apparently this folding also explains the absence of marine Jatulian in this area and perhaps its transgression southward was also caused by these movements. But even if this were the case, the period of erosion must have lasted so long that the phyllites, which were deposited for the greater part on top of the pre-Jatulian granites, cannot be considered contemporaneus with the marine Jatulian.

The conglomerates containing pebbles of quartzite are all situated outside our area in the E except one. This one is interesting in this respect, however, that it is situated on the contact of the phyllites of the Höytiäinen basin towards the underlying quartzites, thus inside the Jatulian quarzite syncline. This conglomerate, situated E of Lake Kuhnustanjärvi, near Lake Pitkälampi, contains many rolled pebbles of quartz, quartzite, and granite in a dark, micaceous cement. This conglomerate is important, because it is these very phyllites of the Höytiäinen basin that have moved least, and also because the granite pebbles contained in this conglomerate prove that the granite outcropped at that time at no great distance from this place.

Conglomerates with pebbles of granite. The E boundary of the Vaivio massif is tectonic, being an overthrust front, and this fact also affects the significance of the occurrence of conglomerates which has been discovered in this zone at Heinävaara. A zone of shearing and breccias separates the occurrence of the conglomerates referred to from the granite massif itself, and the breccia-like nature of the conglomerate itself, which Frosterus and Wilkman have described (1902, 1917 and 1920), points to the fact that the conglomerate is not necessarily a basal conglomerate in character, but may have originated later during the period of overthrusting from an exposed granite front as a marginal conglomerate. The conglomerate is associated, however, with a deposit of bluish-grey quartzite, intercalated with phyllite, as mentioned further on.

On the other hand the conglomerates that occur W of the Vaivio massif in the village of Sotkuma should be considered to be actual basal conglomerates. Thanks to the abundance of outcrops of Archaean rocks the village of Sotkuma offers a good opportunity of investigating particularly the basal parts of the phyllite series.

Close to Lake Rukkojärvi the granite floor is seen only at a distance of a few dozen metres from the phyllite ledges. The granite is, indeed, schistose, but its granitic nature is obvious. The phyllite is fine, highly micaceous and clearly stratified. Near the bottom there is rusty, feldspathic quartzite. — Further south on the margin first thicker layers of quartzite appear, and still further onwards the upper part of these quartzites is associated with diopside-tremolite rock. Finally, in the vicinity of the highroad, there are thick strata of more or less feldspathiferous quartzites containing diopside and tremolite in some places and distinct pieces of granite in others. Sometimes the granitic fragments are separated from each other by a pure diopside-tremolite mixture (the Sotkuma breccia). Above them rusty tremolite and actinolite schists are also visible in a couple of localities.

West of the village of Sotkuma a bluish-grey, glassy quartzite occurs above these macroclastic sediments, alternating with a phyllite schist. At Pöhönniemi, however, a breccia follows above this composed of granite fragments and diopside-tremolite cement, apparently being due to overthrusting, and above it again a bluish-grey quartzite alternating with phyllite.

There seems to be no reason to doubt that this Sotkuma conglomerate is a basal conglomerate of the phyllite division and was deposited immediately on top of the granite.

The nature of the Kalevian conglomerates. At the bottom of the phyllite series macroclastic deposits, breccias and conglomerates have thus been found, in which the fragments and rounded pebbles are, in addition to dyke quartz, mostly pre-Jatulian granitic rocks and quartzites of the Jatulian type, occasionally amphibolite, and to a very small extent schists. The variety of the pebbles of the conglomerates keeps within very narrow limits, to say nothing of the breccias. The pebbles consist generally of a single kind of rock only, the same type of granite, the same quartzite, or amphibolite. There is very little foreign material. This shows that the transport of coarse matter occurred on a very small scale, when these accumulations were formed.

The carbonate-bearing cement, which distinguishes these deposits from the Sariolan deposits is an important characteristic of the Sotkuma conglomerate. Carbonate-bearing quartzites have also been found on the E margin of the phyllite area, but they have usually been explained as breccia features. A larger carbonate-bearing quartzite occurrence of this kind is the hill of Timonvaara, of which we shall have more to say later.

The distribution of the conglomerates also deserves notice. Altogether seven conglomerate occurrences are known on the E margin of the phyllite area, but W of it only the two mentioned on the margin of the Vaivio massif and besides at Timonvaara. But even on the E margin there are enormous distances, in which not a single conglomerate occurrence has been discovered, *e. g.*, the space of 28 kms. between Nunnanlahti and Harivaara, half the length of the whole Koli—Kaltimo quartzite area. And yet the phyllite within this distance seems to be unusually little disturbed.

It seems therefore that originally the conglomerate deposits were not a regular phenomenon at the base of the phyllites, but rather exceptional formations. *E. g.*, in the Kontiolahti district, S of the railway station of Jakokoski, where diamond drill holes were sunk in 1920 through the phyllite down to the granite basement, the quartzite beds which alternate with the phyllite become thicker, coarser and more feldspathiferous for a distance of about 10 ms., merging imperceptibly into granitic rock.

On the W edge of the phyllite area the absence of conglomerates is due above all to the fact that here the phyllites have moved more and the conglomerates in them have been altered beyond recognition.

The Kalevian quartzites.

In referring to conglomerates mention has been made of blue quartzites belonging to the phyllite series. Besides this, dense, quartzitic hard intercalations blackened by carbon pigment, are found in the phyllites, adjoining the black pyritiferous zones. As a third type grey, bedded quartzites alternating with the phyllites may be mentioned.

Larger continuous quartzite zones can only be looked upon as belonging to this series at one point, the Timonvaara—Hallavaara ridge SE of Juuanvaara. This quartzite differs very much from the Jatulian quartzites described above as well as from the allochtonous occurrences of quartzites to be dealt with later.

The quartzites of the Timonvaara—Hallavaara range are coarser than both the former and their coarseness varies considerably in the different layers. Another distinguishing feature is their content of tremolite, carbonates and iron pyrites. Both the former minerals, especially tremolite occur in the quartzite fairly regularly and evenly, but iron pyrites are only found in some horizons. Besides, phyllite intercalations occur here and there in these quartzites. Further west the phyllites predominate. In the transition zone calcareous phyllites and tremolite schists occur, alternating with the quartzites. Round the S end of Timonvaara these tremolitic and pyritiferous schists wind into the basin of Lake Rauanjärvi. These schists have evidently been thrust over the Timonvaara ridge and pushed together on its E side. Phyllite still outcrops in a ledge E of Rauanjärvi, and judging by the fact that it appears to adjoin the granite here immediately, it should be allochtonous.

On the E slope of Timonvaara a gneissic rock with augen appears in the quartzite in the form of long, thin inclusions, the feldspar in it being very crushed. Lower in the E small-grained quartz or quarzite also begins to be seen in the form of similar inclusions. The dimensions of one of these was 145 × 15 cms. Near the highroad the rock in question grades finally into a conglomerate, in which the pebbles are exclusively quartz or quartzite, judging by the indistinct bedding, which is mostly visible in the longitudinal direction of the pebbles, but occasionally, too, on a slant. E of Lake Pitkälampi there is also micaceous, schistose amphibolite among the inclusions and with it in some places blebbed gneissose granite.

The matrix is bedded quartzite, in which there are layers of over $^1/_2$ m. in thickness without inclusions in some places. In others the cement is almost entirely absent. Now and then a tremolite schist occurs as the cement, as in the Sotkuma conglomerate, often too it is carbonate-bearing. At one place there are both diopside and tremolite.

In the N part of the quartzite ridge amphibole schist inclusions predominate in general. The conglomerate is highly schistose here and scarcely recognisable as a conglomerate. The zone continues further NW of Hallavaara, but the quartzite itself only in the form of a narrow belt. The conglomerate accompanies it even here, it exceeds in width the former but is sheared in the same way.

These features have a resemblance to the Sotkuma conglomerate, but in spite of that it does not seem at all clear that it belongs to the basal deposits of the phyllite series, but may rather correspond to the coarse sediments on the margin of the overthrust masses. This is indicated by the occurrence of blebbed gneiss-like inclusions in the conglomerate. The feldspar fragments in it are also much coarser than in the rocks underlying the conglomerate. The conglomerate is strongly sheared, so that movements must have occurred, though not on such a large scale as in the allochtonous series of the Juuanvaarat hills which has been thrust over this.

There are, perhaps, features analogous to the development of rocks described here in some conglomerates of the Mölö area, as in them, too, blebbed gneissic rocks and coarse sericite quartzites are found in the form of pebbles.

The Kalevian phyllites.

The character of the phyllites of the Höytiäinen basin varies to a very considerable degree. The most frequent are fine, dark highly micaceous phyllites, but grey, clearly bedded schists, poorer in mica, are also very common. In some places, such as the point of Jänkäniemi, these grade over into quite quartzitic ones, but in others, especially around the N part of Höytiäinen, to almost unstratified grey schists.

In the bedded schists the same asymmetric structure of layers is often developed as in late glacial varved sediments, so that the direction of the original floor of deposition, the subface of the beds, can be determined. The strata dip in this area now to the E, then to the W and may even lie quite flat (at Jänkäniemi). They have also been clearly thrust into larger or smaller folds. The basement of deposition farthest in the W, to the W of the bay of Rauanlahti, is to be found in the W. The direction is the same nearest to the E shore of the bay, but opposite the island of Kultakallio it is already SE. Proceeding further SE the subface again turns NW, as can be established in the vicinity of the Kinahmo pier. The dip is, however, to the W for the whole distance. Further E on the peninsula of Kinahmo, judging by the dip, the synclines and anticlines alternate repeatedly, and at Jänkäniemi, on the E edge of Kinahmo near Sinilampi, the subface in the varved schists alternating with the quartzite beds is distinctly E and the dip slightly sloping to the W.

In the area of the Höytiäinen basin the deformation of the phyllites and the metamorphism are least of all. In the E, however, the stage of alteration increases and near the margin of the Jatulian quartzites it is strong (Fig. 3). The texture of the phyllites, however, is granoblastic everywhere. Besides biotite and quartz they contain varying quantities of feldspar, usually also muscovite, and often chlorite. The biotite content of the dark phyllites is 50—60 % and often even much more. In those containing more biotite feldspar is often entirely absent, but in the lighter bands it occurs abundantly. In general, however, it is evidently secondary, as it shows a good deal of graphite pigment as a rule, whereas the quartz grains are free from it. The feldspar is mostly oligoclase, but occasionally it may be even highly anorthitic, or also microcline. Graphite and iron pyrites are also frequently present.

In the other Kalevian phyllite areas the metamorphism is generally stronger than in the Höytiäinen basin. In the narrow phyllite zone in the Nunnanlahti district above the Jatulian quartzite in the NE corner of our map, however, the rock still exhibits original sedimentary features, although the phyllite has been strongly plicated. Proceeding W from the Höytiäinen basin the influence of movements constantly increases, the grain becomes coarser and the bedding more and more indistinct. Here the phyllite is evidently so thoroughly disturbed that the stratification is not visible at all throughout large areas, the phyllite being an entirely homogeneous, almost non-orientated rock. The zones adjoining the serpentine intrusions form the sole exception.

Feldspar has often been found in abundance even in slightly metamorphosed phyllites, but in the W parts of the phyllite area the feldspar content is regular and about as large as the quantity of quartz, about 30—40 %. To the W of Outokumpu the amount of feldspar still increases to some extent, and the quantity of quartz occasionally grows small. The feldspar is usually all plagioclase, potash feldspar being present more rarely. The composition of plagioclase varies between An_{10} and An_{30}. The quantity of biotite varies comparatively little, 15—30 %.

ALLOCHTONOUS ROCK SERIES.

The structure and composition of the series.

All the occurrences of rocks described above as allochtonous consist of the succession quartzite—dolomite—phyllite. They all have the same mode of occurrence: in the W one or more quartzite sheets dipping at varying angles to the W, and further E a strongly folded phyllite—dolomite sequence, in which the latter component is contiguous to the quartzite. On the margin of the series adjacent to the gneissose granite there are always coarse gneisses or blebbed gneisses, but never conglomerates *in situ*, as is usual in connection with the autochtonous deposits described above. In the E these gneisses and augen gneisses constitute the floor of the phyllite division, in the W they are situated on top of the quartzites, and each rock may form tectonic lenticles in another. Above, all this was considered to prove that they were so strongly displaced that they were not *in situ*, but allochtonous.

With the exception of the absence of the basal conglomerates these quartzites are entirely identical with the Jatulian quartzites: coarser layers have never been found in them and they are always either pure quartzites or sericitic ones. If what was said above about the probable former spreading of the Jatulian quartzites is taken into consideration, these quartzites must be considered analogous to them.

Nevertheles, these allochtonous series differ from the autochtonous Jatulian quartzites of this region in the respect that there are d o l o m i t i c l i m e s t o n e s a n d p h y l l i t e s among them. These also belong, however, to the Jatulian of the more southern districts, at Soanlahti and Suojärvi as well as in the Onega region. It will be seen from the table (Table 1) that the calcite content of the dolomites of our area fluctuates very considerably: the proportion dolomite: calcite ranges from 3.7—12.9. The autochtonous dolomites both at Suojärvi (Kokonpesät) and Soanlahti (Kintsinniemi) appear to be more or less pure dolomite rocks, carrying at most one or two per cent calcite, but the more deformed carbonate rocks contain more calcite even at Soanlahti. In the area dealt with magnesian calc-silicates, diopside and tremolite have, besides, been formed in the carbonate rocks, a reaction which has reduced the magnesia content of the remaining carbonate.

Table 1. Analyses of allochtonous and autochtonous Jatulian carbonate rocks.

	1	2	3	4	5	6	7
Insoluble	1.58	4.32	8.94	4.00	7.12	14.16	0.48
SiO_2						0.12	
$Al_2O_3 + Fe_2O_3$	0.89	1.43	2.30	1.80	2.10	0.97	0.72
MgO	17.81	15.65	17.01	17.55	17.78	16.55	21.47
CaO	33.52	34.25	29.54	31.94	29.26	27.69	30.36
CO_2	45.97	44.16	(42.07)[1]	(43.99)[1]	(42.97)[1]	(40.71)[1]	(47.04)[1]
	99.77	99.81	99.86	99.28	99.23	100.20	100.07
Dolomite	83.87	75.41	84.02	85.15	84.80	78.33	100.08
Calcite	14.48	20.49	7.60	11.16	6.64	7.10	
Insoluble	1.58	4.32	8.49	4.00	7.12	14.28 [2]	0.48
	99.93	100.22	100.11	100.31	98.56	99.71	100.56

1. Juuanjärvi, E of Juuanvaara. Anal. A. Pönnelin.
2. ,, ,, ,, ,, ,,
3. Petronvaara. ,, B. Aarnio.
4. Koleevaara, Kajoo. ,, ,,
5. Huosiaisniemi, Siikajärvi, Pisa area. ,, ,,
6. ,, ,, ,, ,, A. Laitakari
7. Kintsinniemi, Soanlahti.

[1] Loss on ignition.

[2] Including soluble SiO_2.

The phyllites belonging to the allochtonous series are partly normal, grey, stratified, but also black phyllites rich in carbon substance and related black calcareous schists containing amphibole, which often pass over into pale green tremolite schists, are frequently met with. The amphibole-bearing schists are often, too, garnetiferous and sometimes contain the most beautiful idiomorphic almandite crystals, a couple of cms. in diameter, in large quantities. These have not been discovered in Kalevian phyllites.

The abundant carbon content of the allochtonous phyllites also points to the Jatulian phyllites rich in carbonaceous matter occurring at Soanlahti (on the river Veljakkajoki) as well as at Suojärvi (in the form of shungite boulders). The amphibole-bearing schists, on the other hand, were originally marly deposits, the most calcareous layers of which now occur in the form of tremolite schists. The occurrence of garnet is, perhaps, due to the original content of ferrous carbonate.

The blebbed gneisses.

The author has frequently used the lesser-known designation of ''blebbed gneisses'' to connote gneissoid rocks with conspicuous larger feldspar individuals, the ''eyes'' or ''Augen'', generally of an oval or lenticular shape, which are widely distributed within the area under consideration. The same term was made use of, *e.g.*, by

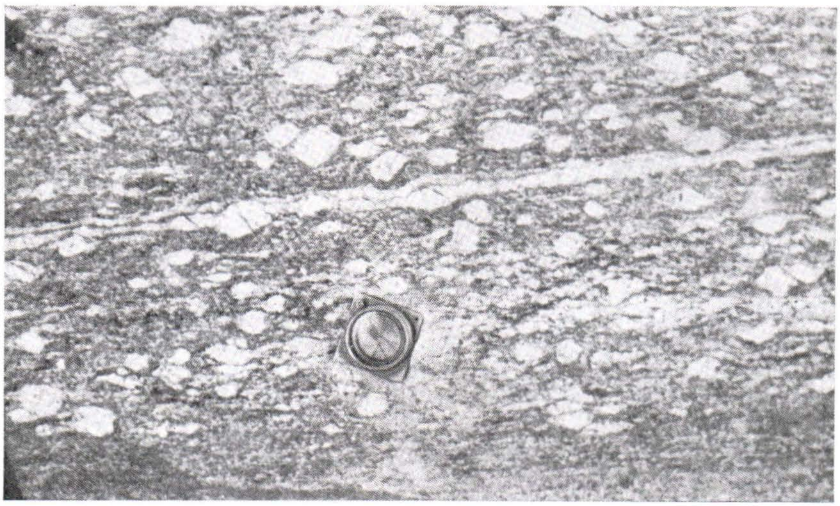


Fig. 5. Blebbed gneiss W of Pisa. Scale 1: 6.

H. H. Read in his study of Valla Field Block, Shetland Islands (1937).

In the region dealt with as well as elsewhere in this country the blebbed gneisses were formerly interpreted as basal formations corresponding to conglomerates, formed of coarse mechanical detritus. This view was first expressed by Frosterus (1902), who described an occurrence of such rocks in this way, found in connection with a conglomerate in the Mölönjärvi district on the E margin of our area.

I expressed the opinion in a former paper (1928) that we should have regard to the fact that elsewhere blebbed gneisses are generally understood in a different way, and showed that at any rate similar rocks investigated by me in Kainuu do not possess a character of basal deposits. Alpine geologists, too, consider blebbed gneisses to be tectonic in origin, and Goldschmidt has described a case, in which identical features have been produced of phyllites through igneous injection (1920). Blebbed gneisses are also formed through shearing of porphyritic rocks (Carstens 1925).

As regards the blebbed gneisses occurring in our region, quite independently of what opinion is held concerning the Mölönjärvi gneisses, at any rate the blebbed gneisses of the Pisa area are not adequately explained as clastic formations. In 1910 Mr Alppi Talvia, who mapped the area carefully, noted that thin red veins of granite, in penetrating into schist-like gneisses, had induced the formation of red "eyes" in them. The present author has corroborated this. The blebs appear in the gneiss, which otherwise may be without them, just in the proximity of aplite veins or directly connected with them, and they are exactly similar to the ones in the blebbed gneisses proper (Fig. 5 and 6).

Moreover, the blebbed gneisses form a veritable series of rocks, which merge on the one hand into even-grained gneisses with a granoblastic or cataclase structure, and on the other into rocks, in which the larger feldspar individuals do not occur as lenticular "eyes", but assume more rounded, ovoidal shapes. In some places these ovoids are crowded, the rock having the texture of a coarse porphyritic granite, in others there are few ovoids and the rock becomes an even-grained granite in appearance. Inclusions of gray mica gneiss also occur, which are resorbed at their margins, and ovoids have been formed in the marginal parts of the inclusions. Actually such coarse blebbed gneisses are more reminiscent of migmatitic rocks.

In some places the gneiss alternating with blebbed gneiss contains sharply bounded inclusions of hornblendite or quartzite, or quartzite, phyllite, and mica-schist as intercalations. Very often a content of calcite has been found in the blebbed gneiss or the gneisses contiguous to it, which is distributed in the manner of very irregular layers or as lenticular patches. Here and there, however, tremolite occurs in its stead. In the village of Petronvaara, NW of Lake Petronlampi, even scapolite has been found in blebbed gneiss.

Fig. 6. Blebbed gneiss from Pisankoski near the bridge of the highroad. Scale 1: 10.

It seems evident therefore that such blebbed gneisses owe their origin to pegmatite and aplite injections in connection with tectonic movements. Where mobility was weaker, a cataclase structure developed, but where mobility was greater, the movements occurred in a paracrystalline manner and even-grained gneisses were formed. The greatest mobility resulted in migmatitic, blebbed and coarse-grained rocks.

The origin of allochtonous series.

The allochtonous rock complexes described above are always so greatly disturbed that it cannot be ascertained by any observations, what the original stratigraphic sequence of the different members was. In every place, where these are to be found, the schists and dolomites have been pushed and folded in front (on the E side) of the respective quartzite sheet dipping to the W. It is not clear, however, at any place that the dolomite—phyllite series continues further below the quartzite. On the contrary it seems just in the Pisa area, where the complex is least disturbed, that this is not the case, but that the schists have been piled up in front of the quartzite into upright synclines and anticlines. It does not seem therefore by any means that the present stratigraphic succession is the original one, but rather the reverse. A comparison with the Jatulian sediments, in particular, and all that has been said concerning the conditions of their origin (p. 40) indicate that the original sequence of layers in the deposits in question, too, was the same. It is difficult to imagine the formation of the sericite-quartzites especially in any other way.

Thus we come again to the former question, where is the point of departure of these thrust masses and did they all start from the same zone, or is it possible that they started from different places.

The complete identity of all these rock series already indicates a common point of departure, and in examining the matter more closely no other possibility can be admitted. As the succession in question is the complete counterpart of the classical Jatulian, it should be concluded on the same basis that this series was spread originally over a larger area. It is therefore not probable that it was formed in the Kalevian flysch area as a simultaneous, local facies, but that it must have originated and been preserved beyond it, further W.

W of the Pisa area, as already stated, the first possibility of this kind is the Kinahmi quartzite ridge, immediately W of the church of Nilsiä (Wilkman 1938). Quartzites, fully analogous to the former, are here strongly pressed and tilted up into a vertical position and small remnants from squeezed out dolomites and phyllites occur in connection with them, *i. e.* just as one would expect in the belt of roots. Besides, the autochtonous conglomerate occurrences immediately W of this quartzite zone and the possibly autochtonous Kasurilanmäki series somewhat to the SW strongly support this assumption.

This quartzite zone of Kinahmi most probably represents the belt of roots, from which all the allochtonous rock complexes referred to were thrust eastward as a continuous nappe. In other words, it is that scar, into which the original geosyncline, the basin of the sedimentary series referred to, was squeezed. It is therefore also probable that these deposits are contemporaneous with the Jatulian, having been submerged by the transgressive sea in the geosyncline. There they were subsequently preserved, while they seem to have been removed by erosion in more eastern areas up to the Höytiäinen district. Thus the older Jatulian was thrust over the younger Kalevian and not the reverse, as was formerly assumed.

This development also provides the best explanation for the allochtonous quartzite—dolomite—phyllite series of Kainuu, which is the continuation of the same geosyncline, nor need it therefore have anything to do with the western facies (Väyrynen 1933, p. 71), which lies too far from the former. Likewise Jatulian has disappeared everywhere W of this geosyncline and in its place a facies more reminiscent of the Kalevian flysch was formed, the Vieremä and Utajärvi series. Further W again sedimentary rocks occur in the Kiiminki and Kemi River regions reminiscent of the Jatulian (western facies, Väyrynen 1933). This, however, is the domain of another geosyncline and occurs as another folding chain, which we might call the Kemides.

ALLOCHTONOUS ZONES IN THE PHYLLITE AREA OF NORTH KARELIA.

The Outokumpu ore field.

Map and sections of the Outokumpu ore field. For this investigation I have had at my disposal the materials collected by the Geological Survey in 1910—19 and by the Outokumpu company during its borings in 1913—15. These refer to the NE part of the ore field from Kaasila to Raiviomäki. No drilling was done later in this area on any large scale. The boring done later from 1926 onwards, which refers chiefly to the SW part of the ore field, the Mökkivaara district and the area W of it, I was not able to make use of.

On the basis of numerous borings and half a hundred outcrops it is possible to draw a fairly detailed geological map of the Outokumpu ore field. Mr J. N. Soikero prepared very accurate reports and sections of the drill holes and mapped the outcrops as exactly as possible. The contour map of the area investigated with the aid of the borings was made by the Outokumpu company on a scale of 1:800, and the drill holes, measured precisely as regards position and elevation, are marked on this map. With the help of these materials and his own observations Eero Mäkinen made in 1919 a very detailed map of the rock ground of the area surveyed (published by Haapala in 1936).

On the basis of Soikero's reports on the borings and the sections of the drill holes Mäkinen drew various vertical sections and by combining them and the outcrops he obtained a picture of the probable character of the rock surface.

The present author has investigated a large part of the drill cores, checking the reports as far as possible and collecting specimens for microscopic study. He has also checked the mapping of the outcrops and collected specimens.

The author has also compiled a new map of the rock ground by the same method as Mäkinen. For drawing the sections, however, the placing of the drill holes is not very appropriate owing to the fact that on account of the imperfection of the drilling methods it was necessary to select such places, in which the bed rock was easily accessible. In consequence the holes are scattered, so that few of them are on the same vertical plane. Besides, the directions diverge in such a way that not even all those holes, whose starting point is more or less on the same line, can be combined on the same plane, at any rate not on a vertical one. In this respect the later borings made by the Outokumpu company in 1913—15, which were no longer dependent on the covering soil, have, however, no advantage as compared with the former.

Many of the drill holes, however, start from the same place in pairs, occasionally three at a time, as Nos. 1—2, 3—4, 5—6, 7—9, 8—10 —29, 13—21, 15—16, 26—27, 33—34. The sections obtained of these correspond very well with the dip of the bedding observed in the mine and determined in the drill cores. It therefore seems possible to make use of these values for the dip in making sections according to single holes and continuing the rock horizons that occur in them towards the surface.

In regard to the drill holes it should be borne in mind that their direction frequently does not remain the same for the whole distance, but that they curve considerably, especially those that slope. In the older holes in the Outokumpu ore field deflection was not always determined deeper down. It is probable, however, that some of them curved considerably. The hole No. 32, *e.g.*, which was started horizontally, was obviously bent downwards and proceeded along the same quartzite layer, as, judging by the other holes sunk in the vicinity, there is no such thick sheet of quartzite at this spot. In general, however, a deflection upwards of the sloping holes is probably more usual.

With regard to the Outokumpu ore field, however, it should be taken into consideration that the greater part of the drill holes were directed at an angle of 30°—60° from the horizontal plane, whereas the dip of the ore-bearing series is 30°—60° in the opposite direction. The holes therefore pierced the layers at a wide angle, often almost 90°. In such cases even a considerable curving only causes very slight errors in the section.

If we further consider that the direction of the folding axis varies comparatively slightly in this area, we have an additional means of making use, too, of the holes belonging to different sections and then drawing as complete cross sections as possible, by placing the holes situated somewhat on the side of the section plane to be constructed at a calculated distance above or below their true position. Thus several holes can be compared with each other and the same rock members can be traced in all directions.

It became evident from this that in different places, such as in the area between Kumpu Hill and the Kumpu A and Kumpu B shafts and further to the SE of Kumpu Hill, the same beds can be traced continuously from one hole to another and a picture of them as a whole can be obtained. This area, the Kumpu block, includes holes Nos. 3, 4, 7, 9, 13, 21, 35, 3a, 14a, and 16a. The area between the shafts Kumpu B and Kaasila C, the Kaasila block, containing holes Nos. 1, 2, 5, 6, 8, 10, 11, 29, 31, 32, 33, 34, 36, 5a, 6a, 7a, 8a, and 17a, and the area round Raiviomäki Hill, with holes Nos. 12, 15, 16, 20, 2a, 9a, 10a, 12a, 13a, and 15a, are similar areas. In these areas the occurrence of the same layer can be established in holes lying as much as 400—600 ms. from each other.

On the other hand there is some difficulty in comparing these divisions with each other. The two former areas, the Kumpu and Kaasila blocks, resemble each other very little. This discrepancy is evidently due to the great fault visible in the shaft Kumpu B, that has also displaced the ore. It seems easier to compare the two areas, Kumpu and Raivio, but on the other hand there is a belt of about 200 ms. in width across the strike between these areas, containing holes Nos. 25, 26, 27, 30, 1a, 4a, and 11a, in which the beds cannot be traced continuously. It is very difficult, *e. g.*, to compare holes Nos. 26 and 27 + 11a, which start from the same place, with hole No. 4a lying at a distance of about 40 ms. from them along the strike, and yet there do not seem to be any disturbances worth mentioning either in the strike or in the dip. In the same way the last-mentioned hole differs from holes Nos. 30 and 1a on the other side of it, which are in harmony with each other. Through a small shift this difference disappears and these holes correspond fairly well. There seems to be a slight difference in level, too, between hole No. 1a and holes Nos. 7 and 9 lying at a distance of about 80 ms. obliquely to the strike and starting from the same place. Here, therefore, there is evidently a whole set of faults, of different magnitude and direction, intersecting the direction of the quartzite zone.

The map drawn by the author differs accordingly from Mäkinen's map in the respect that, while Mäkinen endeavoured to combine the separate rock members traversed in the drill holes and exposed on the surface as far as possible into continuous belts with several bends, the author has assumed the occurrence of certain fault zones, against which the different zones abut abruptly (Map II).

T h e r o c k s o f t h e o r e f i e l d. The prevailing rock in the Outokumpu ore field is quartzite, alternating with thicker or thinner beds or elongated bodies of serpentine, black or grey phyllites, dolomites, and calc-silicate rocks. The quartzite is white or grey, occasionally even rather dark. It is often clearly stratified, but the bands are many times sharply bent or intricately folded, the deformation having resulted at places in a very pronounced mullion structure, which plunges at a low angle of 5°—15° in a SW direction. The rock then splits up into long, rod-shaped plates, and the other field data cannot be measured any more.

The dip of the strata is 30°—45° SE in the central parts of the zone, but towards the NW margin it becomes steeper and finally reaches 75°—80°. On the SE margin, too, there are dips of 60°—75°. Deeper down the dip appears to be gentler in the central parts of the zone, in which diamond drilling has been done, though growing more abrupt in places in between and finally also deeper down.

The quartzite is associated with b l a c k p h y l l i t e occurring as intercalations in it, which contains plenty of fine graphite and usually iron pyrites and often, too, amphibole prisms. It occurs at the entrance into the mine, and a broad belt of it extends on the N side of Kumpu B and Kaasila shafts, and owing to the magnetic disturbance in this belt the first claims were located and the first drill holes were sunk in this zone (holes Nos. 1 and 2).

In some places this phyllite is very dense, hard and rich in quartz, in others softer and coarser containing brown biotite with the colour of phlogopite and often, too, silvery muscovite. The amphibole stalks, which are quite black to the naked eye, appear colourless under the microscope, but filled with much black pigment. These amphibole-bearing varieties are often adjoined by intercalated pale greenish tremolite schists, in which there is also coarse-grained calcite filled with black pigment.

D o l o m i t e as originally exposed only occurs in two small outcrops on the E slope of Mökkivaara and a little on the W slope of Sänkivaara, but it has also been met with in the trenches at Raivionmäki and at the railway excavation near the station. In addition, however, considerable quantities of it have been pierced by drill holes in many places. It is usually grey, of medium grain and unstratified. It often shows an appreciable content of tremolite, but not of diopside.

In the contact of the dolomites with the quartzite a broader or narrower belt of calc-silicate rocks has always been formed. The dolomite then passes first over into tremolite rock or tremolite schist, and further into diopside-tremolite rock, diopside-bearing quartzite and subsequently into quartzite (Väyrynen 1935).

The Outokumpu quartzite contains almost everywhere thinner or thicker seams of diopside and tremolite as intercalations often associated with an intensely green chromium garnet, uvarovite (Borgström 1901). These intercalations may even be considered as the distinguishing feature of the Outokumpu quartzite. As dolomites have never been found thinly intercalated in the quartzite, but appear in the form of remnants enclosed in the thick calc-silicate masses that occur in the quartzite at Raiviomäki, these calc-silicate rocks should be considered as reaction skarns formed by the reaction between the dolomite and quartzite. As the chromium contained also in diopside and tremolite, in addition to the uvarovite, is the only element that is not regularly found in the quartzite and dolomite, there is no reason to assume such a magmatic influence in the formation of the calc-silicates as in the case of a replacement skarn, in which limestone has been replaced by foreign material.

On the other hand it happens in places that the calc-silicate rocks grade over into black, graphite-bearing Garben schists.

The serpentines occur in the form of narrow lenses always conforming with the strike and dip of the quartzites. Neither cross-cutting boundaries nor dykes of serpentine are known. The occurrences on the surface extend in several holes to a depth of 250 ms. They may, however, fork in vertical as well as in horizontal sections, and the individual sheets may thin out entirely and disappear.

The junctions of the serpentine with the adjacent rocks are of two kinds: either the contact is rather sharp, possibly with an intervening layer of talc not exceeding one metre in thickness, or there is a broad series of gradations through ophicalcites, dolomites, and calc-silicates to quartzites.

On a previous occasion (1935) I have already described one case of this succession of rocks near the Outokumpu railway station, a section disclosed by the building of the railway (the place is not so clearly visible now after the new blasting work). Normal, black serpentine was visible in this profile at the NW end. It becomes slightly calcareous to the SE and then changes very gradually to a very typical ophicalcite and subsequently, as the serpentine decreases, to a pure dolomite. Towards the SE, again, tremolite occurs in it, and by the further decrease of carbonate a transition to tremolite schist can be noticed. Only a small horizon of this, however, is pure, as diopside also appears soon after. The diopside-tremolite rock forms an irregular zone, in which diopside occurs in the form of individuals up to 1 m. in length. Subsequently quartzite bands appear in it and further on it passes over into diopside- and tremolite-bearing quartzite and into a pure quartzite, in which, however, beds containing diopside and tremolite are found here and there. Often, too, there are bright green uvarovites or iron pyrites, mostly pyrrhotite, in connection with such layers. A notable amount of chromium also occurs in places in the diopside or tremolite, which then take on a very clear green colour. This content of chromium is, however, very unevenly divided, the colour of the mineral being accordingly uneven.

The relation of the dolomite to the serpentine has given rise to the question, what kind of formations these dolomites are as regards their origin, for the dolomites adjoin the serpentines almost regularly and merge into them very gradually without the slightest boundary. The dolomite becomes serpentine-bearing and grades over into typical ophicalcite and later, as the carbonate gradually decreases, to pure serpentine. For this reason ''the problem of dolomite'' has arisen and the calc-silicate problem is, of course, dependent on it, as Eskola points out (1933). He has reached no decision on the question as to whether dolomite is sedimentogeneous or metasomatic. ''If this is sedimentogeneous, then it is most natural to assume that the skarn is a usual product of a mesomatic replacement of this carbonate rock, *i. e.* an ordinary skarn.'' ''If the dolomite were a product of carbon dioxide metasomatism, then the question of the skarn would be still more complicated; perhaps it would have to be regarded as an intermediate product'' (p. 32).

Before this Mäkinen (1920) considered dolomite to belong to the sedimentary series, but lately Haapala (1936) has adhered to the opinion that ''the carbonate rocks have formed as a result of a strong carbon dioxide metasomatism. The solutions causing carbonatization probably absorbed the material required, viz. lime and carbon dioxide, from the rocks with which they came in contact'' (p. 76).

The formation of dolomite from serpentine, it is true, is not explained by carbon dioxide metasomatism alone, it is rather $CaCO_3$ metasomatism that is essential. The formation of both dolomite and calc-silicates might be considered the result of such a process. It would, however, be necessary to consider the requisite quantities of $CaCO_3$ as deriving from some sedimentary limestone. Thereby an explanation

5674—38

would be obtained only of the origin of the transitional series between serpentine and dolomite, but nothing else. A metasomatic action would, however, be expected to be more irregular, also penetrating sometimes into the deeper parts of the serpentine bodies. This is not the case, however. The postulated replacement is, on the other hand, met with in the soapstones, but the carbonate in them is usually magnesite, and their shapes are, too, much more irregular.

If, however, we take into consideration the result of the tectonic treatment made above, the explanation of the phenomena referred to does not really present great difficulties. We came to the conclusion that the Outokumpu nappe probably consisted of the Jatulian sequence: quartzite—dolomite—carbonaceous phyllite. The dolomite, as the most mobile matter, found its access on to the thrust planes, and its mixing up with the quartzite and the intrusion of the basic magma into the same horizon obtains a reasonable explanation. After the formation of the serpentine both were mobile matter and became mixed together, partly in a solid state, partly by interchange of solutions as probably the introduction of chromite in dolomite mentioned by Eskola (1933).

Later, when the temperature rose, water released by the dehydration of the serpentine acted as a solvent and transferred Cr_2O_3 compounds from the serpentine to its surroundings and fostered the reaction between the carbonates and the quartz, so that calc-silicate rocks were formed and uvarovite and chrome-bearing diopside and tremolite in them. Consequently the calc-silicate rocks in the Outokumpu area need not be interpreted as true metasomatic replacement skarns, nor as any other products of contact metamorphism, but as "reaction skarns" caused by regional metamorphism.

The ore deposit is usually situated in the quartzite and is adjoined in places, *e. g.*, in the excavation close to shaft Kumpu B, by breccia-like impregnations of sulphides. It was the occurrence of just such a type in the first boulder found at Rääkkylä that showed that the ore was associated with a quartzite and suggested the Outokumpu neighbourhood as its possible source. The ore body is to be treated in a later chapter.

The cordierite-anthophyllite rock at Raiviomäki is also evidently connected with the process of the formation of the ore. The cordierite has to a great extent been altered to a mixture of chlorite and mica, and similar alteration products are found in the drill holes in different parts of the ore field.

Magnetically the Outokumpu ore is indifferent, although it contains about 13 % of pyrrhotite. On the other hand, the black phyllites containing iron pyrites are accompanied by a magnetic disturbing zone both in the NW and in the SE of the quartzite belt. To the SW these magnetic anomalies in the district of Lake Jyrinlietukka spread out and even grow stronger SW of it until about 4 kms. from Outokumpu they suddenly cease. The bedrock is covered here by a sandy plain, so that it cannot be established, by what this cessation is caused. In all probability, however, the rocks of the Outokumpu ore field continue up to this point and probably end here at a great dislocation (point 5 on the map Fig. 2). In regard to this, however, it is impossible to say, in what direction the movements occurred, which side has risen and which has subsided.

The Kuusjärvi—Juojärvi zones.

To the E and W of Lake Kuusjärvi there are disconnected, weak magnetic disturbances which are due to the black phyllites and tremolite schists. A few quartzite ledges have also been found in the same district and a number of quartzite boulders containing iron pyrites NW of Lake Kuusjärvi, which gave rise to some prospecting work. Only a small quartzite belt containing iron pyrites was discovered thereby. At this locality the strata form a gentle anticline (Fig. 7), to the SE of which, near Kuusjärvi, they have been tilted steeply to a narrow syncline. S of Lake Kuusjärvi the black phyllites

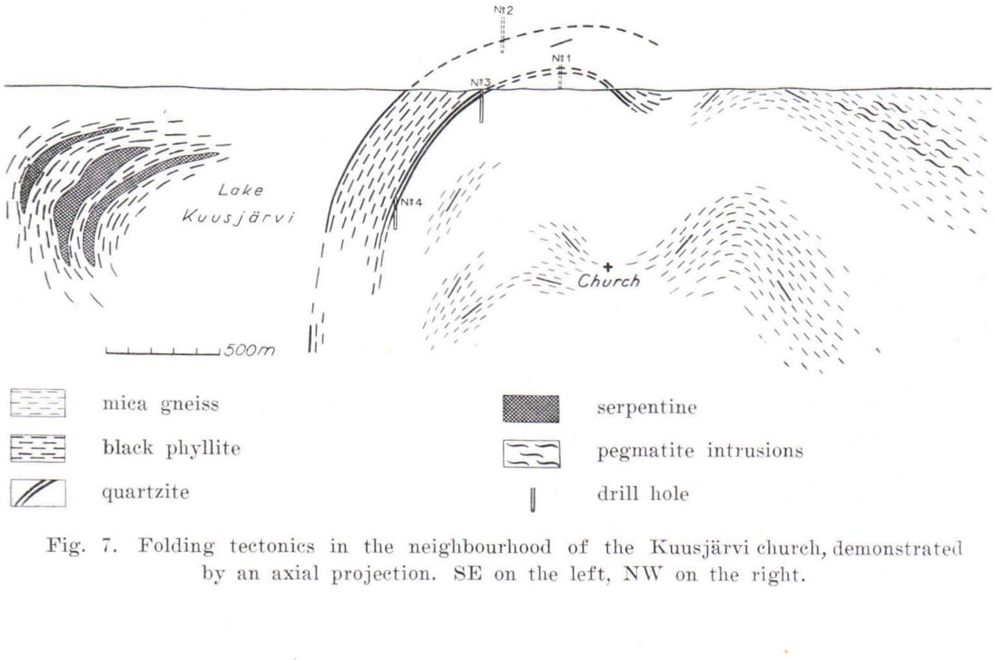


Fig. 7. Folding tectonics in the neighbourhood of the Kuusjärvi church, demonstrated by an axial projection. SE on the left, NW on the right.

have been thrust into an other anticlinal fold inclined to the SE, into whose SE limb lenticular serpentine bodies have found their access. SE of it there is a pegmatite intrusion in the grey gneiss-like schists. Stronger pegmatite invasion has occurred along the gently-dipping NW side of the first-mentioned anticline.

On the NE shore of Lake Juojärvi there are several other zones of magnetic disturbance, which are usually connected with serpentine intrusions.

The Outokumpu—Ruhvo zone.

To the NE the Outokumpu zone appears to continue more uninterruptedly, at any rate judging by the regularity of the magnetic disturbance zone. Not much can be concluded regarding the spreading of the different rocks on the basis of these data. The only exposed ledge near the Sikomäki farm about 7 kms. from Outokumpu, in which there is some diopside-tremolite rock besides the quartzite and in which serpentine was also met with in the diamond drilling, indicates that in this part of the zone the rocks are of the same kind as in the Outokumpu district. The next two small outcrops consist of serpentine, visible near the Ale Karttunen farm in the parish of Liperi, with a few disseminated pyrrhotite grains. In the immediate neighbourhood of the farm there are, besides, abundant boulders of mica-schists and ones showing black amphibole, as well as pale greenish tremolite schists, all of them rich in iron pyrites, and occasional dolomite boulders, while further to the NW of the farm such rocks are entirely absent. Beyond this the disturbance zone turns more to the N. Instead of its direction having been fairly straight N 45° E up to that point, it is thenceforward N 24° E. Ledges occur in this direction at Sukkulajoki River, a little over $1\frac{1}{2}$ kms. upwards from the highroad bridge, showing tremolite schists very rich in pyrrhotite, and E of the river phyllitic schists with some iron pyrites. Then follows the large Teerisuo peat-bog, over which, however, it has been possible to trace the zone of magnetic disturbance by means of the magnetometer to a couple of outcrops of highly pyritiferous phyllite, situated N of the Marjakuiva farm and a short distance NE of them, but no longer in the marshy terrain that follows onwards to the NNE. Ledges of the bedrock only occur in the vicinity of the Ruhvo farm, showing quartzite and light tremolite and dark amphibole schists.

Starting from the Ale Karttunen farm many outcrops have been found both NW and SE of the zone, which consist exclusively of common, grey mica-schists dipping SE.

The Kokonvaara—Ruhvo zone.

The Kokonvaara—Ruhvo zone SE of the described belt and almost parallel with it at a distance of 1.0 km. from the Ale Karttunen farm (Kokonvaara) and of 1.5 kms. from the Marjakuiva farm (near the Kalliola elementary school) is much better exposed for the greater part in comparison with the former. At the hill of Kokonvaara and on its S slope a layer of coarse diopside-tremolite rock, at least 100 ms. in thickness, is accessible to observation. The same rock occurs, too, on the N slope, although the bands are separated from each other by a belt of mica-schist. Further E serpentine also outcrops. On the other side of the highroad which passes N of the hill a ledge of bedded, in places rusty quartzite is encountered, in which there is tremolite schist as intercalations. From here diopside-tremolite rocks and S of them pyritiferous schists continue to the NE apparently in the form of an uninterrupted zone to the other side of Perttilahti, a bay of Lake Viinijärvi, where they are associated with bands of quartzite and with coarse-grained calcite of a black colour owing to its richness in graphite. Judging by the loose blocks this complex contains patches richly impregnated with pyrrhotite in connection with the tremolite schists, even containing a little chalcopyrite.

The last visible occurrence of diopside-tremolite rock in this zone is immediately NE of Sukkulajoki River, higher up from the bridge of the highroad. From here the zone, the thickness of which was about 200 ms. up to this place, continues past the Mertala croft as a belt only about 60—80 ms. in thickness, composed mainly of tremolite schists rich in pyrite, of phyllites, and of small quartzite bands, towards the Kalliola elementary school, where its width increases to about 0.5 km. Here it consists, in addition to black pyritiferous phyllites, of thick quartzite deposits and of many soapstone bodies. The sulphide impregnation in the quartzite and in the schists is exclusively pyrite, while pyrrhotite is entirely absent at this point.

The quartzite, accompanied by the soapstones and tremolite schists continues from here in an almost continuous belt for a distance of about 2 kms. more or less northwards, towards the neighbourhood of the Ruhvo farm, towards which the former zone also seems to be directed. The last portion of a length of 2 kms. is, however, concealed under meadowland.

The strike of the phyllites NE of Ruhvo at the village of Haapovaara makes a curve with Ruhvo as the centre. Here there is distinct stratification in the schists, the strata are folded and wrinkled and the dip, as well as the pitch of the folding axis, is in a SW direction.

The strata thus form a distinct syncline. Nevertheless, both the zones described above cannot be considered as opposite limbs of the same syncline, as the dip in both zones is, at any rate mostly, to the SE. On account of Lake Viinijärvi and the sandy plains which conceal the substructure, the S margin of the allochtonous zone cannot be determined.

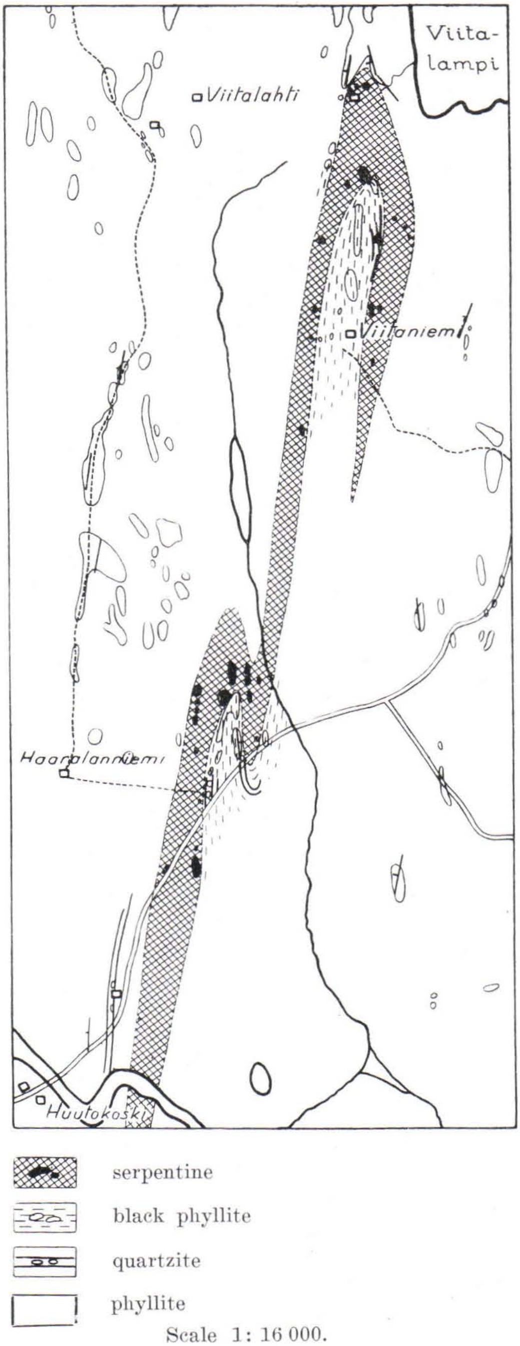
The zone seems to continue also W of Kokonvaara, and even S and SE of Outokumpu zones of magnetic disturbance indicating the same occur, but they have not been investigated more closely.

The Huutokoski—Viitalampi zone.

From the river Kiskonjoki, which falls into Höytiäinen from the NW, NE of Huutokoski sawmill, a belt of quartzite begins in addition containing black phyllites rich in carbon and iron pyrites, tremolitic intercalations, serpentines, and soapstones, which proceeds to the NW in a row of exposures as a continuous zone a distance of little over 2 kms. to the SW of Lake Viitalampi (Fig. 8). Here it ends close to large outcrops of phyllite, and another branch continues backwards parallel to the former towards the S, but is soon hidden from sight. It is interesting that the strike of the phyllites can also be seen to describe a semicircle in the ledges SW of Viitalampi, so that it accompanies the zone referred to all the way. In the SW part of the exposed tract the strike is N 10° E, in the middle very crumpled and in the SE part N 40° W. Extensive meadowland follows to the S, and there are no outcrops in this direction until W of the bay of Vasaralahti. Here, too, serpentine occurs in large ledges on both sides of the Kalliola farm. In connection with them a black carbonaceous phyllite outcrops on the E side, in which there is pyrite, pyrrhotite, and chalcopyrite.

Thus the structure of this zone shows that very closely compressed folds occur in this district. According to the folding axis also this fold appears as a syncline, as the pitch plunges about 25°—30° S. This is the case in all the similar zones in the region, as the belts of Revonkangas, Solankylä, and Kylylahti, of which mention is made below.

The ledge of Kultakallio in the middle of the bay of Rauanlahti, 3.5 kms. SE of the former, consists of phyllite rich in iron pyrites, with a few intercalations of tremolitic rocks and in a neighbouring small cliff carbonate-bearing tremolite rock. In a SW and NE direction from here there are black phyllites and Garben schists on both sides of Rauanlahti.



Scale 1: 16 000.

Fig. 8. The zone of Huutokoski—Viitalampi

In the outcrops that have been found in the area between the church of Polvijärvi and Rauanlahti, grey mica-schist often alternates with darker, fine, pyritiferous phyllites.

The zone of Kylylahti.

At the village of Kylylahti, about 1.6 kms. W of the church of Polvijärvi, there are several occurrences of serpentine and soapstone in places accompanied by black phyllites rich in pyrites and containing tremolite, which cause considerable magnetic disturbance. By reconnoitering and partly by detailed mapping it has been established that the area of disturbance is a separate one, of the shape of a hairpin. The substructure is not seen at many points in this area. Besides the phyllites, a large quartzite ledge with intercalated tremolite schists occurs. In addition there are several mounds formed of exceptionally large serpentine boulders, some of which possibly are to be regarded as solid rock or lying *in situ*, but in no case have the boulders moved much. In the form of loose boulders there are abundant black phyllites, too, containing pyrite and amphibole in the neighbourhood. The magnetic disturbances seem, however, to be restricted in the vicinity of the serpentine occurrences, and do not exist in the area of the pure phyllite ledges. By trenching black phyllites very rich in amorphous graphite have been encountered in these zones.

The Solankylä and Revonkangas areas.

The zones of magnetic disturbance of the village of Kylylahti continue southward towards Solankylä. Here there are three belts of serpentine in a fan-like arrangement going NW, N, and NE, separated from each other by quartzites, tremolite schists and black phyllites. The zone extends southward to the island of Solansaari and beyond to some small islands, which still show black phyllites and serpentine outcrops adjoining them.

NNW of the church of Polvijärvi at a distance of about 15 kms. there are a couple of serpentine occurrences in the middle of the phyllite area near the Revonkangas farm, associated with some quartzite, carbonate-bearing tremolite rock and black phyllite rich in iron pyrites, which cause slight magnetic disturbances that can be traced NW for about 5 kms. In the vicinity of the SW occurrence of serpentine in a mound surrounded by the peat-bog of Sauvasuo the stratigraphic order is as follows: on the W side dense-looking, dark green serpentine, in the middle quartzite rich in iron pyrites, which becomes tremolite-bearing in the W and also contains intercalations of carbonate, and on the E side of the island black pyritiferous actinolite schist. The dip is to the W.

About 1 km. NE of this, next to the road leading to Lipasvaara, SE of the farm of Revonkangas, the succession is reversed: the layers dipping gently to the W consist here, from W to E, first of black phyllites rich in iron pyrites, then in the middle of carbonate-bearing tremolite rocks, containing much green fuchsite, and last of quartzites, and on the other side of a narrow bog black serpentine traversed by a dyke, of about 0.5 m. in width, of greenish, coarse talc. About 0.5 km. NE of Lake Lipaslampi this belt is bounded by a sheared zone, in which there is an occurrence of crushed and brecciated gneissose granite evidently tectonically enclosed among the phyllites. This evidently belongs to the thrust plane along which the Petronvaara granite massif was displaced on to the Juuanvaara quartzite. Still as far as about 5 kms. NW of Lake Lipaslampi, between the upper branches of the stream of Lipaspuro, there is an outcrop of dense, dark green serpentine which merges on its S side into carbonate- and tremolite-bearing rock.

The Saarivaara—Miihkalinjärvi zone.

In the W part of the large phyllite area black schists are only exposed along a belt that extends from the Reponiemi farm E of Lake Teyrilampi towards Lake Miihkalinjärvi. The content of iron pyrites in these is more notable only in the ledges to the SW of Reponiemi. These schists are dense and banded, in the latter place silvery sericite has been formed on the bedding planes.

The occurrence of these schists, including amphibole-bearing ones, in places further S is indicated by numerous loose boulders, which can be found especially in the immediate proximity of the Hööki farm.

The other principal rocks of this zone are represented in the area near the Raiskio farm in the parish of Kuusjärvi by a tremolite schist, and on the E bank of Saarvanjoki River, S of the village of Saarivaara, by the occurrence of a quartzite accompanied by a diopside-tremolite skarn. Between these two outcrops and in the surroundings as well as N of the latter the solid ground is entirely covered by deposits of sand and till.

All the way parallel to the margin of the phyllite area, however, there is a row of serpentine and soapstone occurrences and of talc and chlorite schists. The serpentines and soapstones occur especially abundantly as loose boulders along Saarvanjoki River close to the parish boundary, around the outcrop of quartzite and skarn rock mentioned. W of Sukkulajoki River, N of the highroad, a low ledge of black serpentine exists, in which large flakes of talc occur here and there. At Soinisärkkä, in a straight line with the former, soapstone containing pyrrhotite occurs and on top of it talc schists, in which long greenish tremolite needles are embedded. Next to the phyllites lying on top (eastward) at a dip of 40° there are soft chlorite schists.

Further along the same line 1.8 kms. N of Soinisärkkä there are fine chlorite schists at the ledge of Ilveskallio, with embedded brown amphibole needles and merging occasionally to a tremolite rock.

On the same straight line W of the Reponiemi farm a couple of small crests of rock protrude from the bog, consisting of tremolite-bearing, dark green serpentine. The same rock also occurs in several large outcrops 1.5 kms. NW of Reponiemi, near the Saramäki farm.

These last-mentioned ledges lie about 1 km. eastward of the straight line we have been following. A similar deviation in the basal contact of the schists corresponds to it.

Neither serpentines nor soapstones have been found in the zone N of Saramäki except W of Lake Miihkalinjärvi. The southernmost exposures, opposite the Miihkali croft, are green, partly carbonate-bearing tremolite schists. The same rock occurs very abundantly in the form of loose boulders. On the shore of Lake Miihkalinjärvi, however, most chlorite schists occur containing octahedral crystals of magnetite, being represented by loose boulders, very similar to the Ilveskallio rock already referred to, and the same rock type outcrops in the northernmost ledges. Instead of magnetite, however, amphibole needles occur in it.

On the W limb of the downfold, W of Lake Miihkalinjärvi, the width of the serpentine zone is about 400 ms. the actual thickness being about 250 ms., but on the E limb it tapers out between the schists in a similar manner as seems to be the case at Viitalampi.

The Hanhivaara blebbed gneisses.

If the Saarivaara—Miihkali zone of serpentines is here considered to be the lower limit of the Outokumpu nappe, as elsewhere, there is evidence on the NW margin of the phyllite area of other overthrust movements. In the NW slope of the hill of Hanhivaara, W of Reponiemi and to the NW of it, a belt of blebbed gneisses occurs, about 2 kms. in width and exactly similar to the blebbed gneisses of the Pisa area underlying the Pisa complex. In a slightly (15°—25°) SE sloping position above and between these blebbed gneisses there are quartzite sheets. At the N end of the zone of blebbed gneisses the extensive Suovaara quartzite body is arched above it in the form of an anticline. The quartzite is quite of the same type as the Jatulian quartzites of the Koli district, being not accompanied by dolomites or carbonaceous phyllites, but according to an oral communication Aurola in his recent investigation has found calc-silicate rocks in connection with it. On top of the quartzite sheet there are in several places almost horizontal or slightly eastward sloping patches of amphibolite, and the margin of the phyllite series overlaps the latter. Usually the amphibolite sheet, too, is strongly sheared underneath next to the quartzite, and at one place, between Lakes Miihkalinjärvi and Halijärvi, there is granitic gneiss between the quartzite and phyllite dipping 40° SE like both the quartzite and phyllite at this point. It is therefore evident that the Suovaara quartzite sheet is allochtonous and represents a nappe of its own, which we might call the Suovaara nappe. It does not belong to the same thrust mass as Juuanvaarat, these overlapping it in the N (Lehtovaara) and Lake Halijärvi lying on the separating thrust plane. From the NW the Niinivaara gneisses have also overridden the Suovaara nappe, bending its NW corner downward and causing an imbricate structure at Ukonvaara, W of Lake Halijärvi, in which quartzite and blebbed gneisses alternate. This latter movement evidently proceeded in quite a different direction from the original Suovaara thrust, which probably came from the W. This overthrusting occurred in similar conditions to those of the Pisa area, as the formation of the blebbed gneisses was in both accomplished in a similar manner, bearing a relation to granitisation.

Besides, the phyllites seem to have had a movement of their own, as the granitic gneiss occurs between them and the quartzite, as already mentioned. These, too, seem to have formed an independent flysch-nappe, of the existence of which separately no such clear evidence as in this point has been obtained elsewhere, although we have established that in the Rauanjärvi district the phyllites have been thrust over Timonvaara on top of the granite basement (p. 44).

The Kaavi and Säyneinen zones.

The Palolampi area. In prospecting work carried out by the present author in the summer of 1929 a fairly large chalcopyrite-bearing pyrrhotite deposit was discovered at the village of Luikonlahti in the parish of Kaavi, though its copper content proved to be low.

This sulphide occurrence is associated with a complex, composed, in addition to abundant serpentines, of small layers of quartzite, black phyllites rich in iron pyrites, dolomites, and diopside-tremolite rocks, as well as of penetrating granites, aplites, and pegmatites. The country rock is grey micaceous gneiss, more or less the same as in the Outokumpu district, but it is everywhere cut by reddish gneissose granite, grey homophanous granite, and pegmatite (Fig. 9).

Between Lake Palolampi and Petkellahti, a bay of Lake Retusenjärvi situated about 400 ms. to the W of the former serpentine, diopside-tremolite rock and banded quartzite alternate. In the W near Petkellahti the strike is N—S, but turns NE near Palolampi. In the N, however, these rocks do not continue any longer, only gneisses occurring there. They therefore seem to adjoin the diopside-tremolite rocks that are present at the W end of Lake Palolampi and S of the lake, but are strongly compressed and pushed together. On the S shore of

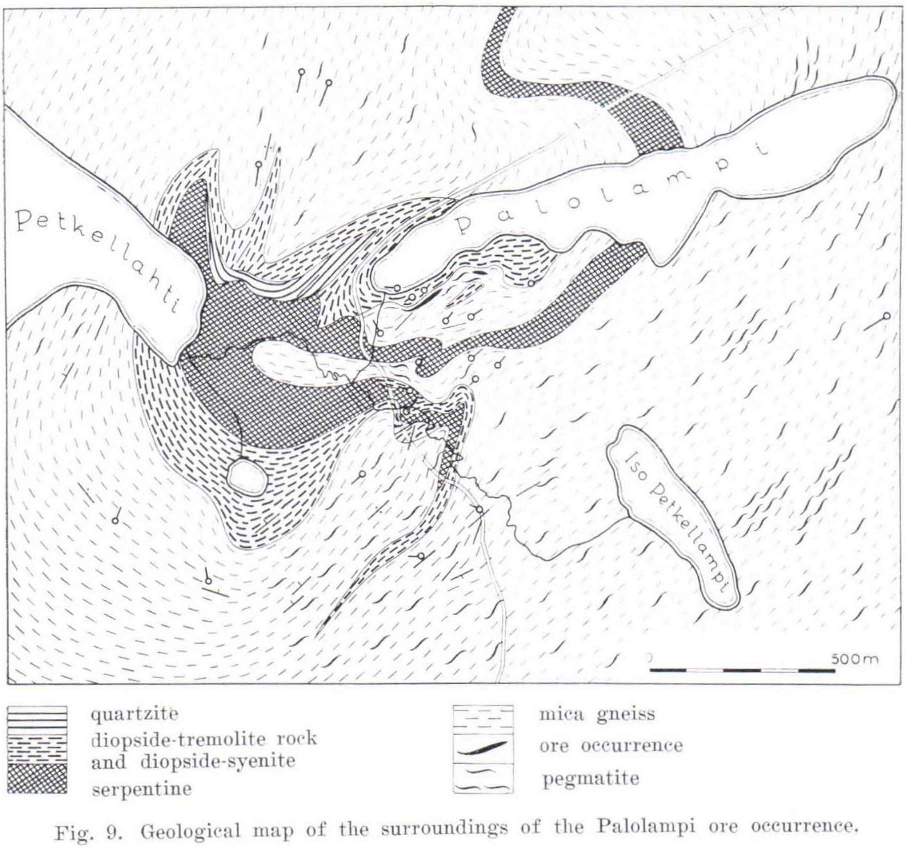


Fig. 9. Geological map of the surroundings of the Palolampi ore occurrence.

Palolampi, however, rock varieties are found close to the lake, which should be disignated petrographically as d i o p s i d e - s y e n i t e s. They are rich in feldspar, quartz is rarely visible, diopside and biotite occur as dark constituents, the former being in part very subordinate. In other places diopside is abundant and its quantity even increases to such an extent that the rock grades into slightly feldspathiferous diopside-tremolite rock, or feldspar may disappear altogether. Near the highroad, S of the W end of Palolampi, this zone is accompanied by a peculiar kind of rock with an augen structure, in which spherical, dull, grey scapolite individuals, 2—3 cms. in diameter lie surrounded by a matrix of tremolite schist. All these rocks seem to belong to the same skarn-like alteration complex, and possibly the syenite-like rock corresponds to the ''salite-syenites'' discovered by Trüstedt at different places in the Pitkäranta region together with skarn rocks (1907).

S of the W end of Lake Palolampi the diopside-syenite is bounded towards the S by a micaceous gneiss cut by aplite and pegmatite dikes, the contact surface dipping 60°—70° N or beneath the syenite. This boundary is followed on the side of the micaceous gneiss by a metasomatically greatly altered zone, in which the mica gneiss and the pervading granites and pegmatites merge here and there into quartzite and are associated besides with diopside-tremolite rocks and at some points, too, with carbonate rock. This zone is also followed by sulphide ore intrusions, mostly accompanying the quartzitic rock portions. In the E the dip of the contact zone becomes gentler and finally the syenite bends in the form of a flat-lying tongue above the gneiss, covering the ore deposits below it. S of the ore zone there are also a couple of outcrops of syenite, constituting probably a detached portion from the thrust mass, which originally was brought onto the ore here, too. At the W end the ore zone is also accompanied by an anthophyllite-bearing rock, and at one point the mica gneiss contains cyanite.

The gneiss zone is followed in the S by a narrow belt of serpentine. This extends to the W up to the bay of Petkellahti, but no further, as the strike of the gneisses, which is SW of Petkellahti N 25° E, turns in the rocky tract surrounding in the shape of an amphitheatre the small fen of Petkellampi SE, E, and then NE. The zone of serpentine thus only makes a sharp bend near Petkellahti turning back to the E, and E of the highroad, where it is adjacent to tremolite schists, in places with diopside, and to impure carbonate rocks, the belt again turns SW and thins out between the gneisses. The micaceous gneiss pressed into the bend is of a common type, also cut by granite and pegmatite dykes. Even the granite veins and gneiss here merge in places into rusty quartzite. N of Lake Palolampi there are still two occurrences of soapstone rich in talc, the last W of the fen of Petronlampi, and they are connected with black phyllites and tremolite schists. It has not been possible to trace the zone further.

The direction of the folding axis is mostly NE—SW, but the inclination varies at different angles in either direction. Often, however, folding axes occur varying in all directions. It seems therefore that originally the same direction of deformation existed in the area as elsewhere in the neighbourhood, but subsequently a compression of the zone in the direction of its trend occurred, which was evidently due to the NW side having been thrust in a SW direction. There are examples of such movements, too, in the structure of the folds in the Kaavi district.

The Kortteinen zone. From the village of Sivakkavaara a zone trends E of Lakes Kortteisenjärvi and Kärenjärvi towards the N to the Putikko district, composed of quartzites and serpentines as well as black phyllites in places and occasional dolomites.

Although quartzites are found in numerous exposures along this zone, they do not form a continuous range, but a series of rather small, parallel strips, separated from each other by strongly gneissose granite, more rarely by the mica gneiss that predominates generally in the area. The quartzite grades into gneissose granite without any clear boundary and is often thoroughly feldspar-bearing. In some smaller occurrences the quartzite merges into aplite, gneissose granite or gneiss in such a way that it must evidently have originated metasomatically from these rocks, but mostly the quartzite is a sedimentary one. In general the dip of the quartzites is 45°—60° W, but E of Lake Kärenjärvi, about 200 ms. W of the Alapotku farm, the dip of the quartzite is gentle and below it there is stratified, fine-grained dolomite.

Serpentines occur in this zone only at two points, on the E shore of Kärenjärvi and near Putikko. In each place, however, there are several exposures of serpentine in a row.

Black phyllite occurs only at the S end of the zone at Sivakkavaara and at the N end of the zone in the Putikko district.

Besides the gneissose granite referred to non-orientated Maarianvaara granite as well as pegmatite and aplite also occur in the zone as sills in the same way as elsewhere in the schists.

In the W of the zone there are several scattered highly talcose serpentine occurrences.

The Niinivaara, Poskijärvi and Suuri Säyneinen areas. In the Niinivaara district close to the E margin of

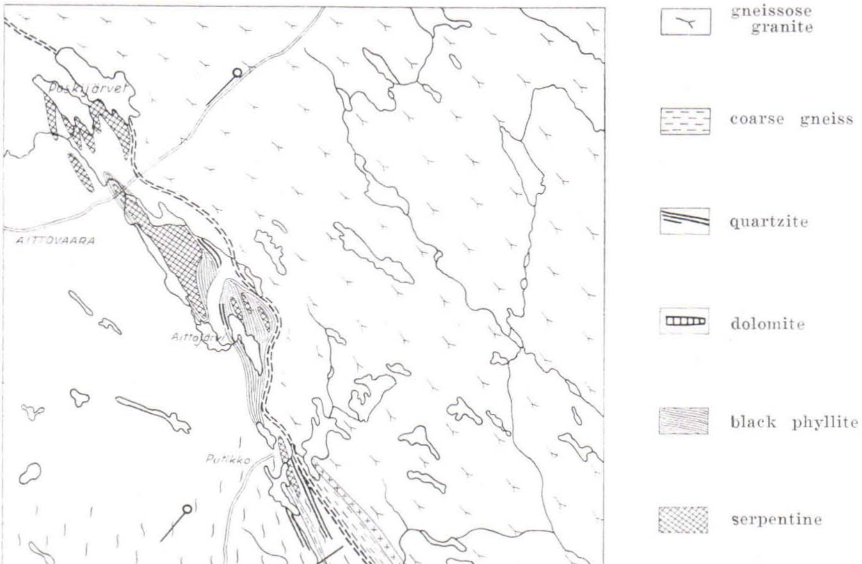


Fig. 10. The zones of Palolampi—Kortteinen and Niinivaara—Poskijärvet.

the phyllites against the gneisses and blebbed gneisses, there are thick, partly parallel belts of serpentines, accompanied by frequent black phyllites and tremolite schists, but quartzites are not conspicuous here. These belts form a bend, of which the northern part trends NW, the southern part SW. The dip of the phyllites W of the serpentines is in general 45° W, and the dip of the gneisses in the E is 10°—35° W. The zone of the serpentines shows, however, a dip of 50°—75° W, occasionally even vertically or steeply E. At different points it is also noticeable that, when the strike makes a sharper bend, the folding axis assumes a steeper position. Here the serpentines have quite evidently found an access into the lee of the folding movements coming from the NW, where the strike turned SE. The granite intrusion is due to the same cause, although it is not as broad as is shown on the map sheet of Joensuu.

The occurrences of serpentines in the Aittojärvi neighbourhood form an area analogous to the previous one. Here the curve of the phyllite margin is less and the dips are in general 45° SW in this area.

S of both the Poskijärvi Lakes the curve of the phyllite margin is much more pronounced and the dip and pitch are vertical in the area of serpentines situated along this bend, the dip being also occasionally steeply E. Here it is also to be noted that the dip becomes gentler both to the W and to the E.

At the S end of Lake Suuri Säyneinen there is another smaller serpentine body in the same zone as the former, but not lying so clearly in the same manner.

With the exception of the one last mentioned, the serpentine bodies of this zone have obviously been placed tectonically. Their position is, however, probably not primary, but secondary in the same way as we concluded in the Outokumpu zone.

The Vehkalahti—Säyneinen zone. This is the innermost of the bow-shaped folding ranges built up of allochtonous rock series and is situated on the edge of the Pisa—Keyritty segment. Sloping at an angle of 45°—60° W and NW below the gneisses of the Pisa area, quartzites and tremolite schists, as well as a small quantity of black phyllites and carbonate rocks occur in this zone in the form of narrow strips, but no serpentines except in the Vehkalahti district, at the S end of the zone. At this last point the zone, which trends SW in the Unimäki district, SE of Lake Vuotjärvi, suddenly turns SE and then NE. If we consider that the pitch plunges SW here and the bedding of the schists is in general gently-sloping, this evidently means that here, too, the serpentines have been placed on the leeward side of a flat anticline ridge.

In the Vehkalahti district, however, the serpentines do not occur in the form of such an extensive uninterrupted area as is shown in the Joensuu map sheet, but as smaller lenses in connection with tremolite schists. This is evidently due to the development of an imbricate structure in connection with the overthrust movement. The area between the church of Kaavi and the villages Kortteinen and Vehkalahti is evidently a flat downfold and in that case the numerous occurrences of talc and soapstone spread throughout the whole of this area are explained.

POST-JATULIAN IGNEOUS ROCKS.

GABBROID INTRUSIVES.

Basic rocks occur in connection with all the Jatulian sedimentary rocks, either in the form of dykes or sills, which now may cover them. They all possess the texture of intrusive rocks in the area dealt with; tuffitic rocks have not been discovered at all in this area among these sediments. These rocks, however, only penetrate the Jatulian series, they have never been found to cut through the Kalevian (flysch) deposits. But similar rocks have very rarely been found, too, as pebbles in the Kalevian basal conglomerates, so that their pre-Kalevian age should be considered doubtful. However, at one point at the base of the phyllite division, at the village of Puso in the parish of Kontiolahti, near the Kuuskallio farm, there is an occurrence of conglomerate, the pebbles of which consist for the greater part just of such basic rocks outcropping in the vicinity (Väyrynen 1933). The Timonvaara quartzite and conglomerate also contain basic rocks as inclusions, but they are so altered that nothing can be said regarding their origin. Besides, there are basic rocks as pebbles in the conglomerates of the Mölö area, but in regard to them again it has not been established, what division the Mölö conglomerates adjoin, nor is it certain, whether there are any basic rocks in the Mölö area belonging to the group now to be dealt with or whether they are all pre-Jatulian.

In the Kainuu area I discovered (1928) extrusive rocks with a corresponding relation to sedimentary series and found that they intercalated with the quartzites of the Jaurakka series, the latter again lying unconformably on top of the Kainuuan facies of the Jatulian quartzites. The Kalevian phyllites of this region seem to bear relation to the younger group, but even here some conglomerates (at Pääkkö) support the assumption that these basic rocks are older than the phyllites of the region.

The igneous rocks belonging to this category are divided in the papers published by Frosterus and Wilkman into two classes: Kalevian metadiabases (''metabasites'') and Jatulian uralite diabases, according to whether the quartzite penetrated by them is considered Jatulian or Kalevian. Sederholm also treated them in the same way. Some basic dyke rocks found outside our area have even been considered Jotnian by Wilkman (1924, cf. Väyrynen 1938 a). If, however, the chronological sequence of rocks in this area is interpreted in the same manner as in the present work, these basic rocks cannot be divided on a geological basis, but they all belong together.

Nevertheless, some difficulty is presented in dealing with the rocks of this group by the fact that pre-Jatulian rocks exist, which are very similar in character to the ones now in question, but owing to their having been thrust and squeezed, in connection with the formation of an imbricate structure, especially in the Koli—Kaltimo quartzite area, between the quartzites, they have been considered to be cross-cutting dykes and have been classed in this category. I have found such cases both in the Koli district and in Ahveninen.

It should be noted in addition that while occurring in connection with allochtonous rock series these post-Jatulian basic rocks are usually greatly sheared and have been converted into amphibolites. In such cases they were formerly looked upon as belonging to pre-Jatulian formations.

The structure and texture in these rocks varies very much depending both on their metamorphism and partly on their origin. The uralite diabases that have been discovered as thinner dykes have in some cases preserved their original texture, so that only the pyroxene has changed to fibrous amphibole, uralite, and the feldspar has become somewhat turbid, but in composition it is labradorite. Often, however, considerable quantities of epidote appear in association with plagioclase, but the content of anorthite in it has not been reduced below 20 % An. Mostly, however, the shape of pyroxene has not been preserved during the alteration into amphibole, nor has the amphibolization resulted in finely fibrous uralite, but in diverging stalks of pale green amphibole, which I have described more fully in a former paper (1928). Then the shape of the feldspars also changed, having been resorbed in some places and growing in others, so that the original texture is only indistinctly visible. The original texture is usually ophitic in the thinner dykes, but gabbroid in thicker masses. Albite rocks, generally found in abundance associated with basic rocks, in which the spilitic alteration has occurred, are rarely found in the area dealt with. These rocks, which are characterised by pure albite, exceptionally poor in the potash feldspar component, and in addition by small quantities of quartz, carbonate and chlorite, I recently suggested should be called karjalites (1938 b). They are found comparatively often both in the Kainuu area and in Lapland in connection with basic metamorphic rocks, which are of quite the same kind as those mentioned above. In the area dealt with here karjalites occur mostly in connection with quartz-carbonate dykes, which contain pyrrhotite and chalcopyrite, and mining experiments for copper ore have been made in them, but have been abandoned as useless.

In the W parts of the region these basic rocks have been altered even more. A granoblastic texture has appeared in them, the amphibole is common green hornblende and the rock is often distinctly schistose amphibolite. In such a case it is impossible to distinguish it from the old pre-Jatulian amphibolites.

SERPENTINES.

A couple of years ago Haapala made a special investigation (1936) of the serpentines of the North-Karelian sedimentary area, in which he made valuable observations and greatly increased our knowledge of serpentines. Earlier researches are also summarized in his work.

Frosterus already divided the serpentines of this area into two types, antigorite serpentines, to which the E occurrences chiefly belong, and mesh-structure serpentines, to which in broad lines the occurrences more in the W belong. In the antigorite serpentines, however, remains of mesh-structure serpentines are often found, which seem to have been replaced by the former. Olivine has been found as scattered remnants in both, but more commonly in mesh-structure serpentines and more generally in the area intruded by granite dykes, in the marginal region of arterites, as Frosterus established (1902). In the E zone, in the outer portions of the serpentine bodies an alteration occurs very usually to talc-carbonate rocks, soapstones. Such features have also been found in the W zone in some places, *e.g.*, in the Outokumpu area, but more rarely. On the other hand, here and especially in the region more intensely intruded by granite and pegmatite, amphibole asbestos consisting of fibrous anthophyllite in the form of lumps and bundles which have a random orientation has been formed. In broad lines the area is to be divided, as to the mineral paragenesis of the serpentines, into similar zones, as I established on a previous occasion (1935) in regard to the sulphide deposits and calc-silicate rocks.

Haapala explains the present mineral assemblage of the serpentines as having been originated from dunites, which he regards as the primary crystallisation habit of these rocks, in the following order:

''amphibolization as a first step during the metamorphism, followed by serpentinization, carbonatization and formation of talc'' (p. 69).

The amphibole often shows immediate contacts towards an unaltered olivine and has grown through it. The amphibole, however, has usually undergone serpentinization for the greater part or entirely, but has been preserved where the olivine persists. The amphibole therefore seems to have been formed before the general serpentinization. Besides, the amphibolization is most common within the area abundantly traversed by younger granite and therefore it seems to have been caused by the latter. Nevertheless, the serpentinization does not seem to be connected in any way with the granite dykes and is therefore to be looked upon as an autometamorphic process, as Haapala also concludes. The formation of skarn, again, was according to him a much later process than this, as carbonatization must have occurred in the interim. And yet the Outokumpu ore was formed, at any rate partly, by replacement of the skarn, and the granite dykes intersect both the skarn and the ore. The granite dykes, again, as is shown in connection with the discussion on tectonics, belong in the Outokumpu area to the same period of intrusion. No considerable hiatus can be shown between the young granites in this area, the intrusions being Maarianvaara granite or pegmatite accompanying it.

Such apparent contradictions between the facts have been known to the present author for a long time. I therefore expressed the view (1935) that the olivine occurring in the serpentines was not original, but secondary, formed under the influence of granitization. Haapala was aware of this, but he did not go into this question with sufficient thoroughness. The matter must therefore be dealt with more precisely here. The following facts provide evidence against the primary character of the olivine and in favour of its secondariness:

1. In the structure of the serpentines of this area there is not even a trace of the same crystal accumulation texture that, *e.g.*, I described in the serpentines of the Petsamontunturit region (1938 c). In the serpentines now in question there is also generally no such mesh-structure as produced by the serpentinization along the fissures of the olivine, but in the W part of the region such a structure as Weinschenk calls ''Gitterstruktur'', or in the E the spherulitic antigorite formed later. Nor does even the distribution of oxide ore, which frequently betrays the original structure in the most strongly chemically altered serpentines, display any primary features in this area, but shows the same streaky arrangement as in the most mechanically deformed Petsamo serpentines. It is therefore improbable that the large, uniformly orientated olivine grains are primary.

2. Next to the olivine grains a field of serpentine has often been observed different from the main mass and showing the true mesh-structure. This indicates that the serpentine adjacent to the olivine grains was formed by the serpentinization of these grains, but the bulk of the serpentine was formed in another manner before this.

3. The occurrence of olivine more abundantly in serpentines included in strongly metamorphic schists points to its secondary origin, for here the conditions during the metamorphism of the schists were the same as in the Kuopio district, where Wilkman established that olivine was formed in limestones (1923 and 1938).

4. The occurrence of the best preserved olivine in the outermost parts of serpentine bodies and especially in serpentines rich in carbonate, as ascertained by Haapala, prove the formation of olivine by the dehydration of serpentine, as the possibilities of dehydration at such places are greater, the water being able to escape off into the less hydrous country rocks. Evidently equilibrium was achieved between the olivine and the serpentine corresponding to the temperature and the vapour pressure of the water released by the formation of the olivine. It is less probable that the serpentinization began in the central parts of a dunite body, as that requires an addition of silica, or that the olivine was preserved in connection with carbonatization, notwithstanding whether this was a process of metasomatic replacement or of tectonic mixing.

5. The occurrence of olivine as intergrowths together with amphibole and penetrated by the latter is of such a kind that the olivine cannot be said to have altered to amphibole, but that both occur in full paragenetic equilibrium with each other. This can only be explained by both crystallizing contemporaneously, for the dehydration of the serpentine occurs according to the following formula:

$H_4Mg_3Si_2O_9 = Mg_2SiO_4 + MgSiO_3 + 2\,H_2O.$

Serpentine = olivine + anthophyllite + water.

Thus the reaction results both in olivine and in anthophyllite, and their renewed serpentinization, when the temperature dropped, is quite naturally presumable.

6. The disappearance of all other primary minerals, while olivine was preserved, is improbable. Haapala assumed that the serpentines, with a few exceptions of saxonites, were originally dunites, but it is improbable that the dunites in the whole of this large area were so pure that they did not contain at least a little biotite and pyroxenes.

7. Conspicuous quantities of oxide ore should appear as a bye-product of the serpentinization of dunites without the addition of silica. There is none in these serpentines, thus silica must have been added

by the serpentinization. Haapala assumes that the silica came from outside, but at the same time he presumes that the autometamorphism took place from inside. In my opinion both of them are incompatible with each other.

According to the above and to the previous tectonic treatment the development of the serpentines appears to be as follows in its main features: They were formed from basic magmas forwarded below the Outokumpu nappe, their emplacement having essentially been due to the movements of the latter. From these olivine began to crystallise, at first sinking to the bottom of the magma chambers. The magma was evidently rather hydrous, so that the ultrabasic rock that was formed was evidently soon serpentinised and the crystallisation temperature of the rest magma was low. Besides, the temperature of the enclosing rock underneath the thick thrust masses was evidently so high that the crystallisation ceased or became so much slower that the rest magma was able to move to the edge of the overthrust sheet and pour out, so that no other intrusive bodies could be formed of this magma. Serpentines never occurred so plentifully on the whole thrust plane as, *e.g.*, at present in the Outokumpu section. When finally the overthrust from the NW, from the Pisa area, shaped the curved folds in the nappe, serpentines transported in a solid state with the moving thrust mass accumulated on the leeward side of the downfold, *i.e.*, in such places of the thrust plane that dipped to the SE (the Outokumpu—Ruhvo and Saarivaara—Miihkali zones), but not on the opposite limb that sloped to the NW. The serpentines of Niinivaara etc. were also situated on the protected bends of the thrust planes (p. 72), and possibly the occurrences at Revonkangas and evidently also at Huutokoski and Polvijärvi occupy similar positions.

Owing to this movement the serpentine bodies were subjected to such severe deformation that they were thoroughly kneaded and their mesh-structure was replaced by a lattice structure. At that time all the primary minerals disappeared from the serpentine, even the oxide ore formed during the serpentinization. Then, too, so much mixing of both serpentine and quartzite occurred with dolomite that phenomena of a gradual transition between them were produced. Thus it is superfluous to assume a metasomatic carbonatization of the serpentines otherwise than in connection with the formation of soapstone. Soapstone, again, is quite a different feature from ophicalcite, which is so common, *e.g.*, at Outokumpu.

It was only when these movements were almost brought to an end that the formation of skarn, apparently owing to the general rise of the temperature, and subsequently the intrusion of the ore occurred.

The formation of olivine and anthophyllite, possibly also of enstatite and the crystallisation of talc into big flakes also occurred, when the movements of the Outokumpu nappe were ceasing (Fig. 11). Possibly they, too, may have begun to appear at the same time as the former ones, but the dehydration probably continued up to the occurrence of the granite intrusions. The partial serpentinization of the secondary olivine, anthophyllite, and enstatite only occurred after the temperature had again begun to fall.

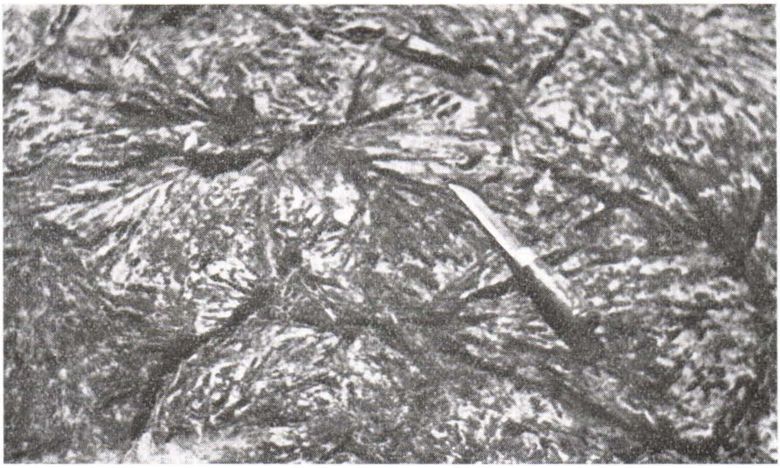


Fig. 11: Radiate groups of anthophyllite in the serpentine at Putikko. Scale 1: 8.

In regard to the point of departure of the intrusions of the basic magma from which the ultrabasics were formed, the remarkable fact should further be noted that it evidently did not derive from the Kinahmi belt of roots proper in the Nilsiä district, as these rocks do not occur below the Pisa sedimentary series nor in the area between Pisa and Nilsiä. The point of emergence of these magmas was the Vehkalahti —Säyneinen zone, and their intrusion evidently only occurred after the zone of roots at Kinahmi had already been closed and the Pisa—Keyritty area had been soldered together with the Iisalmi block. The serpentine intrusions of the Saarivaara—Miihkali zone also show that the overthrust movements in connection with the emplacement of the serpentines proceeded, at any rate partly, along other movement surfaces than the earlier thrusts of the Pisa complex (Suovaara nappe, p. 67). Therefore here, too, the serpentine intrusions do not adjoin the blebbed gneisses in the zone W of Hanhivaara, but occupy a position of about 1—1.5 kms. higher, lying in the present earth's surface at a distance of 2—3 kms. E of them. It is owing to this, too, that in this zone the serpentines are not connected with quartzites and black phyllites except in its S part, S of Saarivaara.

YOUNGER GRANITES AND PEGMATITES.

In the neighbourhood of the village of Maarianvaara there is a large area of younger granites in the central part of the region inside which the serpentine intrusions are met with. A large part of this body consists of a very typical grey, medium-grained biotite granite, the Maarianvaara granite proper, but a reddish modification also occurs, especially in the SE part of the area. The reddish rock, in particular, often assumes a more or less parallel structure and often shows gneissose belts. The strike and dip are always the same as the general trend of the gneisses in the area, N 40°—50° E. A great deal of pegmatite also occurs in the area, sometimes, indeed, cutting across the direction of the schistosity referred to, but mostly closely connected with the granite imparting a streaky structure (Schlierenstructure) to it. Thus the relation of the pegmatite to the main granite is very intimate.

In its chemical composition the granite is yosemitic, rich in quartz, but the feldspar is principally oligoclasic, An_{15}; the content of microcline is very low. A fair amount of biotite and a little chlorite appear regularly, but muscovite is usually lacking. The pegmatite, again, is a rock rich in microline and often contains magnetite.

To the N, NW, and W of this granite area the schists are abundantly permeated by granite. The intrusions are conformable without exception and as a rule belong to the type of grey Maarianvaara granite. Besides, there are pegmatite intrusions, which appear, as it seems, independently from the granite veins, at times showing conformable, at others cross-cutting relations to the country rock. The thickness of the granite veins varies from a few dozen centimetres to a few dozen metres. Nevertheless, the granite is equally coarse both in the thinner veins and in the thicker sills and throughout similar up to the edge of the sills. The schist is also homogeneous up to the margin of the granite bodies, without any sign of palingenesis. This is, however, natural, as the components of the granite: quartz, oligoclase, and biotite, are exactly the same as the constituents of the penetrated gneiss, so that the magma that pervaded the latter here was already saturated with these minerals. Nor has the author observed any sign of any increase of feldspar in the gneisses in the proximity of the granite and pegmatite intrusions.

Pegmatite intrusions are so numerous in places that one might be justified in speaking of veined gneisses. They occur copiously, *e.g.*, in the district between Luikonlahti and Kortteinen, but these features, too, are of a type, in which the veins are distinctly separated from the gneiss penetrated by them. No very intimate arterite formation in the gneisses nor any development of such migmatites, which Sederholm called nebulites, is visible at all in the area dealt with. In fact, there are no such migmatites in the whole Karelidic folding chain, as far as I know, and I have travelled a good deal in this zone from Lake Ladoga to Kuusamo as well as in the Kiiminki—Utajärvi area and to some extent in other regions also.

It therefore seems that in the Karelidic orogeny we cannot speak of a migmatite front that spread like a spot of grease on paper (Wegmann 1935), the granite intrusions rather following the zone of overthrusting here. In this respect the downfold area surrounding the church of Kaavi is worth noting, in which the schists are distinctly gneissose and are largely pervaded by granite intrusions, though not by such extensive continuous bodies as is shown on the Joensuu rock map sheet. These schists seem to have ridden over as an overthrust nappe from the NW above the Vehkalahti anticline, where the schists have been much less affected by metamorphic and igneous processes (see p. 72). The gneiss-like and heavily folded schists, intruded by granites, of the Tuusniemi and Juojärvi district, in which serpentines occur very generally, likewise seem to belong to the same overthrust mass. The pitch is very regularly gentle to the SW in the whole of this area. It seems very probable that this cover of migmatitic gneisses formerly extended further E above less metamorphic phyllites, but has been removed by erosion. The lower limit of these gneiss masses seems in broad lines to have coincided with the lower boundary of the occurrences of serpentines. Thus further SE, to the SE of Lake Petrumanjärvi, where there is a large area without granite intrusions, also serpentines are absent. Here the slightly metamorphic phyllites are adjacent to the Savo schists. The intrusion of the granites into these gneisses must only have occurred in connection with overthrust movements, because, if it had occurred earlier, the gneiss block would have been more rigid and hardly yielded to the stress by folding to such an extent as the many continuous zones of serpentine indicate.

The intrusion of the granite magma into such a zone of differential movements is a very natural thing, and the very intimate arterite formation and the thorough permeation of the schist rocks by the granite magma may be explained most naturally as formed by such a mechanical injection. Without such movements it is difficult to understand the pervasion of a schist by a magma, in which the minerals of the schist: quartz, biotite, and acid plagioclase are in a state of saturation. In that case the components of magma are not able to react with the constituents of the schist, and the diffusion of the magmatic liquids into the wall-rock proceeds slowly. The minerals of the schist cannot then either be resorbed by the solutions deriving from magma and therefore it is also very difficult to explain a partial anatexis of conspicuous extent from a physico-chemical point of view in this case. By thrusting together and folding (ptygmatic folding) such a zone of mechanical injection, possessing a considerable thickness already at its origin, can be piled up in enormous masses, whereby the formation of extensive migmatite areas is readily explained.

It must, however, be admitted that the conditions, in which the migmatites of South Finland were formed, were evidently very different from those in the area described here. In the Svecofennidic zone much larger granite massifs of a different nature have been uncovered. Nevertheless, it would be worth while in regard to them, too, to take the points of view expressed into consideration.

The intrusion of the veins and sills of granite referred to is connected with orogenic movements caused by the Pisa block coming from the NW, evidently with their later phases. They were thus not able to affect the Pisa area to any great extent, as it had already become a rigid sheet. We have seen, however, that here, too, the formation of blebbed gneisses implies a considerable granitisation. In our area therefore granitisation must have occurred during the Karelidic orogeny in two separate periods. The point of departure of the first granite intrusions was evidently the Kinahmi zone of roots and the area E of it, and they extended to the Pisa area, probably even to Hanhivaara (p. 67). It follows from this that in this area several sets of granite dykes intersecting each other can be found, as Frosterus showed in 1902 (p. 29). The granite massifs of the Muuruvesi district evidently belong to this earlier period of granitisation. We cannot go into the question here, whether the very intimate injection gneisses of the Kuopio area also belong to it or to a still earlier period, for it is just the Kuopio district where the Kinahmi belt of roots and the W folding zone, the Kemides, diverge from each other. As the Kemidic geosyncline W of the phyllite area of Vieremä must have been closed before the compression of the Kinahmi zone, at any rate the granites cutting through the phyllites of the Vieremä area seem to belong to a still older period of intrusion than those referred to.

ORE DEPOSITS.

THE OUTOKUMPU ORE BODY.

The Outokumpu copper ore forms a sheet-like mass enclosed throughout almost its whole extension in quartzite, its wall-rock being only seldom mica-schist. The ore has been introduced into the quartzite usually along a bedding plane and dips with it 45° SE on an average. The ore is dislocated by a fault at the Kumpu B shaft, along which the SW side of the ore has been thrust upward over the NE side. Consequently the ore outcrops on the rock surface at two points: at the Kumpu B shaft, where it was at first uncovered by trenching, and at the Kaasila shaft, where the point of the sunken NE part of the ore, the Kaasila ore, was brought to view. Each outcrop is only about 100 ms. in length, and at no place did the ore originally protrude through the glacial deposits. The pitch in the area of the ore field is gentle, 5°—15°, and usually plunges SW, only in a few places 5° in the opposite direction. Owing to this the upper margin of the ore body in both outcrops rakes downward to the SW below the surface of the ground. The upper margin of the Kaasila ore lies at a depth of about 65 ms. at the Kumpu B fault, the main body of the ore at the Kumpu A shaft at a depth of 40 ms. and at Raiviomäki, 1 km from Kumpu B, at a depth of 145 ms. from the surface.

Ore has not been found at a greater depth than 250 ms. in those diamond-drill holes, the results of which were at the author's disposal, but so far neither the form nor the character of the lower margin of the ore body have been fully investigated. As stated in the recent short reports given by Mäkinen (1938) the ore body so far traced by diamond drilling extends for at least 3.5 kms. but its depth does not exceed 350 ms. owing to the reason that its axis further in the SW assumes an almost horizontal position conforming to the pitch. The width of the ore body on the dip is 300—400 ms. and the thickness varies from as little as 0.5 m. to 15—17 ms. Its total amount has been estimated at 20 millions of metric tons.

The other faults that intersect the rock strata of the ore field have not caused displacements in the ore and are therefore older than the emplacement of the ore. In reality the dislocation of the geologic structures at the Kumpu B fault is far too great to be adequately explained by the displacement of a hundred of metres, by which the Kaasila ore has sunk. The structure of the NE part of the ore field differs from that of the SW part to such an extent that no detailed features corresponding to each other can be found in both halves. This fault-line must therefore be assumed to be of older date than the *mise-en-place* of the ore, and its influence on the geology of the ore field is due to these earlier displacements, which were much larger than the movements that occurred after the formation of the ore.

But faulting also occurred after the deposition of the ore several times or at least twice. After its formation the latter was cut by pegmatite dykes at various points, and after their formation at any rate the Kumpu B fault still moved and brecciated the pegmatite intruded along it. This latter movement belongs to the late dislocations referred to. Thus the ore is younger than the serpentines, which are intersected even by the oldest faults mentioned, but older than the pegmatite dykes which intersect the ore.

In general the ore shows very sharp boundaries against the wall-rock. Usually the drill runners in the mine feel clearly, when the drill reaches the quartzitic wall-rock, and in blasting the ore often breaks loose from the quartzite along a perfectly smooth surface. In some places, however, ore impregnations are met with in the quartzite. This is seen in the ledge exposed by digging close to the Kumpu B shaft. In the impregnated portion the quartzite has not remained unbroken, but pieces of it have been forced into different positions and have been bent to some extent, so that a breccia-like formation has been created. The impregnation is of varying intensity at different places in the quartzite, and it seems evident that the pyrites have here metasomatically replaced some pre-existent component. In some impregnations fragmentary and for the greater part altered remnants of diopside have even been found, just sufficiently preserved to be recognised with certainty. It seems therefore that such impregnations occurred here at least partly through the replacement of diopside-bearing layers in the quartzite, in the same manner as I have found (1938 c) the nickel-bearing sulphide ore of Petsamontunturit to have replaced a brown amphibole. At Kaasila, in the outermost end of the ore body, too, such a relation has been discovered between the ore and the skarn, to which the mining engineer, Mr K. Järvinen, drew the attention of the author.

In other respects the Outokumpu ore is very even in quality. The usual type is a rather coarse mixture of sulphides, in which the pyrite forms euhedral crystals (pentagondodecahedron + cube) in the matrix formed by the pyrrhotite and quartz, the chalcopyrite filling the last interstices. The mutual proportion of pyrite, pyrrhotite and quartz does not seem to vary much, but the quantity of chalcopyrite fluctuates to some extent, the copper content varying between 4—6 %. In some places the chalcopyrite is abundant and coarsely crystallised. Occasionally in the upper margin of the ore a great deal of it has been found as a component in small-grained ore modifications.

In addition to these chief minerals there are varying, but generally small quantities of dark sphalerite in the ore.

The average composition of the ore is as follows:

Cu	4.5 %
Fe	27.5 ,,
S	27.0 ,,
Zn	1.0 ,,
SiO_2	40.0 ,,
	100.0 %

In addition the ore contains 0.2 % of cobalt and 0.1 % of nickel as well as 1 gr. of gold and 12 grs. of silver per metric ton. According to its composition quoted above the average mineral composition of the ore is as follows:

Chalcopyrite	13.0 %
Pyrite	31.7 ,,
Pyrrhotite	13.8 ,,
Sphalerite	1.5 ,,
Quartz	40.0 ,,
	100.0 %

The ore body is very regular, and those ramifications and bends that have been discovered were usually formed originally in connection with the intrusion of the ore. Crushing phenomena have not been found in the ore to any extent worth mentioning. The most considerable of them accompanies the Kumpu B fault. Cross-joints showing minor displacements have been discovered here and there, but there are no breccia formations in connection with them.

The pegmatite dykes cutting the ore do not run continuously across the ore, but are broken into pieces, so that it would seem that they were older than the ore, or that deformations had occurred in the ore after their formation. But neither of these views seems to have any validity. The pieces of the pegmatite dykes have not been dislocated, but proceed along the same line across the ore. If they were really older than the ore and had still remained in this manner, when the ore body was formed, the ore should be considered to have been formed entirely through metasomatic replacement. There is, however, too little evidence for such a conclusion. It is to be admitted that there are scattered remnants of quartzite more or less impregnated with sulphide minerals, so that the ore can, broadly speaking, be looked upon as a breccia, but the fragments are rather few and lie in haphazard directions, not indicating replacement *in situ* but considerable movements. The structure of the prevailing ore type is thoroughly massive, its quartz content is so even, and the boundaries against the wall-rock are so sharp that all these features prove rather an origin trough intrusion of an ore magma. Besides, the thickness of the ore fluctuates in such a manner that its spatial form is necessarily due to an intrusion, for the ore is almost regularly thickest where it occupies the flattest position and *vice versa*. In that case the pegmatite dykes penetrating the ore must be younger. This is also indicated by the fact that the ore between the separated portions of the dykes is different both in texture and composition from what it is at the side, as Mäkinen first pointed out. It seems from this that in connection with the formation of the dykes the ore was partly refused or was dissolved and recrystallised, which is very natural, seeing that the sulphides are generally mobile in such conditions.

A more exact determination of the period, in which the ore body came into existence in the succession of geological events discussed above, is based on the fact that the ore is younger than the calc-silicate rocks. This means that in the time when the ore was formed, the thrust movements of the Outokumpu nappe were ceasing, and the mountain chain had attained such a great thickness that the complexes visible at present on the earth's surface in this region were pressed down so deep into the crust that the dehydration of the serpentines and the formation of the calc-silicate rocks attained at any rate considerable proportions. It was only then, but before the granite invasions reached the Outokumpu district, that the emplacement of the ore occurred.

This opinion, arrived at on a tectonic basis, is in perfect harmony with the result of the investigations I made before into mineral paragenesis (1935). According to them the assemblages found both in the calc-silicate rocks and in the sulphide deposits in the area dealt with have been adjusted so as to obey regional principles, local peculiarities which would be incompatible with the former being decidedly absent, except the most eastern parts of the region. All the data available indicate that successively lower temperatures prevailed during the metamorphic development of the Outokumpu region, in its wider sense as here understood, the further one proceeds towards the E. In this respect the Outokumpu ore itself forms no exception.

THE PALOLAMPI ORE.

On the S shore of Lake Palolampi, at the village Luikonlahti in the parish of Kaavi, the present author discovered an occurrence of sulphide ore in 1929 (cf. p. 67), which can well be compared to the Outokumpu ore in the respect that it is closely connected with occurrences of serpentine adjoining a complex composed of quartzites, black phyllites, dolomites, and calc-silicate rocks.. The ore is a slightly nickel-bearing, rather low-grade intrusive copper ore. The metasomatic features accompanying it are not conspicuous.

The principal constituents in the Palolampi ore are quartz and pyrrhotite, and its copper content is much smaller than in the Outokumpu ore, in general scarcely 1 % Cu. The appearance of pyrite is rare. In some places, however, it may show considerably higher figures for copper. Owing to its low percentages of copper and sulphur the ore has not come under exploitation.

OTHER PYRITE OCCURRENCES.

Pyrite occurrences are very common in association with the allochtonous complexes I have described, and attention has been devoted to several of them and prospecting work has been done, but so far no mining industry has arisen based on them except at Outokumpu. The prospecting in the Kuusjärvi district, W of Outokumpu, has already been mentioned. In the Outokumpu—Ruhvo zone some attention has been given to the sulphide occurrences, principally in the Sukkulajoki district, N of Lake Viinijärvi. In the neighbourhood of the church of Polvijärvi boulders have been found, in which pyrite is the only sulphide mineral, and by their ore type they seem to indicate that the two ore boulders discovered in 1919 in the village of Selkie in the parish of Kontiolahti, 45 kms. SE of Polvijärvi, consisting of copper ore with 3 % Cu in addition to pyrite, derive from this region. Pyrite impregnations have also been found in the Sotkuma, Huutokoski and Revonkangas districts. In the N parts of the phyllite area attention has been attracted especially by the districts of Petrovaara, Niinivaara, Kortteinen and Poskijärvi. On the S edge of our area an ophiolitoid intrusion that follows the overthrust movements is responsible for the small Karhunsaari pyrite ore deposit, which has already been described (Saksela 1933). Mining experiments proved it to be of too small a size to have any importance from the practical point of view.

Besides, an occurrence of molybdenite was discovered by Aurola during his prospecting work on behalf of the Outokumpu mine. Molybdenite accompanies a calc-silicate rock connected with the quartzite of Suovaara (cf. p. 67).

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N:o 2. Sederholm, J. J. Ueber einen metamorphosirten praecambrischen Quarzporphyr von Karvia in der Provinz Åbo. S. 1—16. 12 Fig. 1895 .... 15: —

N:o 3. Ramsay, Wilhelm, jemte Bihang 1 och 2 af Hackman, Victor och 3 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 .... 25: —

N:o 4. Frosterus, Benj. Ueber einen neuen Kugelgranit von Kangasniemi in Finland. S. 1—38. 11 Fig. 2 Taf. 1896 .... 20: —

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N:o 7. Ailio, Julius. Über Strandbildungen des Litorinameeres auf der Insel Mantsinsaari. S. 1—43. 8 Fig. 1 Karte. 1898 .... 25: —

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 .... 60: —

N:o 9. Sederholm, J. J. Esquisse hypsométrique de la Finlande. P. 1—17. 1 carte. 1899 .... 25: —

N:o 10. Sederholm, J. J. Les dépôts quaternaires en Finlande. P. 1—28. 2 Fig. 1 carte. 1899 .... 25: —

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N:o 14. Borgström, Leon. H. Die Meteoriten von Hvittis und Marjalahti. S. 1—80. 8 Taf. 1903 .... 25: —

N:o 15. Hackman, Victor. Die chemische Beschaffenheit von Eruptivgesteinen Finlands und der Halbinsel Kola im Lichte des neuen amerikanischen Systemes. S. 1—143. 1905 .... 30: —

N:o 16. Sundell, I. G. On the Cancrinite-Syenite from Kuolajärvi and a Related Dike rock. P. 1—20. 1 plate. 1905 .... 15: —

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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 bild. 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 .... 50: —

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*N:o 19.	Trüstedt, Otto. Die Erzlagerstätten von Pitkäranta am Ladoga-See. S. 1—333. 80 Fig. 19 Taf. 1 Karte. 1907	120: —
N:o 20.	Tanner, V. Zur geologischen Geschichte des Kilpisjärwi-Sees in Lappland. S. 1—22. 3 Fig. 2 Taf. 1 Karte. 1907	15: —
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	50: —
N:o 22.	Borgström, L. H. Granitporphyr von Östersundom. S. 1—20. 3 Fig. 1 Taf. 1907	15: —
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.	50: —
*N:o 24.	Sederholm, J. J. Les roches préquaternaires de la Fenno-Scandia. P. 1—39. 20 fig. 1 carte. 1910	25: —
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	15: —
N:o 26.	Mäkinen, Eero. Bestimmung der Alkalien in Silikaten durch Aufschliessen mittelst Chlorkalzium. S. 1—8. 1911	10: —
N:o 27.	Sederholm, J. J. Esquisse hypsométrique de la Finlande. P. 1—21. 5 fig. 1 carte. 1911	20: —
*N:o 28.	Sederholm, J. J. Les roches préquaternaires de la Finlande. P. 1—27. 1 carte. 1911	20: —
N:o 29.	Sederholm, J. J. Les dépôts quaternaires de la Finlande. P. 1—23. 5 fig. 1 carte. 1911	20: —
*N:o 30.	Sederholm, J. J. Sur la géologie quaternaire et la géomorphologie de la Fennoscandia. P. 1—66. 13 fig. 6 cartes. 1911	30: —
N:o 31.	Hausen, H. Undersökning af porfyrblock från sydvästra Finlands glaciala aflagringar. S. 1—34. 9 fig. Deutsches Referat. 1912	20: —
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	20: —
N:o 33.	Wilkman, W. W. Kvartära nivåförändringar i östra Finland. S. 1—40. 9 fig. Deutsches Referat. 1912	25: —
N:o 34.	Borgström, L. H. Der Meteorit von St Michel. S. 1—49. 1 Fig. 3 Taf. 1912	25: —
N:o 35.	Mäkinen, Eero. Die Granitpegmatite von Tammela in Finnland und ihre Minerale. S. 1—101. 23 Fig. 1913	30: —
N:o 36.	Eskola, Pentti. On Phenomena of Solution in Finnish Limestones and on Sandstone filling Cavities. P. 1—50. 15 fig. 1913	25: —
N:o 37.	Sederholm, J. J. Weitere Mitteilungen über Bruchspalten mit besonderer Beziehung zur Geomorphologie von Fennoscandia. S. 1—66. 27 Fig. 1 Taf. 1913	35: —
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	150: —

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N:o 39. Hackman, Victor. Der gemischte Gang von Tuutijärvi im nördlichen Finnland. S. 1—41. 9 Fig. 1914 .... 20: —

*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 .... 75: —

N:o 41. Borgström, L. H. Die Skapolithlagerstätte von Laurinkari. S. 1—30. 7 Fig. 1914 .... 15: —

N:o 42. Hackman, Victor. Über Camptonitgänge im mittleren Finnland. S. 1—18. 3 Fig. 1914 .... 15: —

N:o 43. Wilkman, W. W. Kaleviska bottenbildningar vid Mölönjärvi. S. 1—36. 11 fig. Résumé en français. 1915 .... 20: —

N:o 44. Eskola, Pentti. Om sambandet mellan kemisk och mineralogisk sammansättning hos Orijärvitraktens metamorfa bergarter. S. 1—145. 4 fig. English Summary of the Contents. 1915 .... 30: —

N:o 45. Ailio, Julius. Die geographische Entwicklung des Ladogasees in postglazialer Zeit und ihre Beziehung zur steinzeitlichen Besiedelung. S. 1—158. 51 Abbild. 2 Karten. 1915 .. 50: —

N:o 46. Laitakari, Aarne. Le gisement de calcaire cristallin de Kirmonniemi à Korpo en Finlande. P. 1—39. 14 fig. 1916 .... 20: —

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 .... 50: —

N:o 48. Sederholm, J. J. On Synantetic Minerals and Related Phenomena (Reaction Rims, Corona Minerals, Kelyphite, Myrmekite, etc.). P. 1—148. 14 fig. in the text and 48 fig. on 8 plates. 1916 .... 60: —

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 .... 15: —

N:o 50. Sauramo, Matti. Geochronologische Studien über die spätglaziale Zeit in Südfinnland. S. 1—44. 5 Abbild. 4 Taf. 1918 30: —

N:o 51. Laitakari, Aarne. Einige Albitepidotgesteine von Südfinnland. S. 1—13. 5 Abbild. 1918 .... 15: —

N:o 52. Brenner, Th. Über Theralit und Ijolit von Umptek auf der Halbinsel Kola. S. 1—30. 4 Fig. 1920 .... 15: —

N:o 53. Hackman, Victor. Einige kritische Bemerkungen zu Iddings' Classifikation der Eruptivgesteine. S. 1—21. 1920 .... 15: —

N:o 54. Laitakari, Aarne. Über die Petrographie und Mineralogie der Kalksteinlagerstätten von Parainen (Pargas) in Finnland. S. 1—113. 40 Abbild. 3 Taf. 1921 .... 30: —

N:o 55. Eskola, Pentti. On Volcanic Necks in Lake Jänisjärvi in Eastern Finland. P. 1—13. 1 fig. 1921 .... 15: —

N:o 56. Metzger, Adolf A. Th. Beiträge zur Paläontologie des nordbaltischen Silurs im Ålandsgebiet. S. 1—8. 3 Abbild. 1922 .. 15: —

N:o 57. Väyrynen, Heikki. Petrologische Untersuchungen der granitodioritischen Gesteine Süd-Ostbothniens. S. 1—78. 20 Fig. 1 Karte. 1923 .... 25: —

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 .... 60: —

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 .... 15: —

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 .... 50: —

N:o 61. Hackman, Victor. Der Pyroxen-Granodiorit von Kakskerta bei Åbo und seine Modifikationen. S. 1—23. 2 Fig. 1 Karte. 1923 15: —

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N:o 62. Wilkman, W. W. Tohmajärvi-konglomeratet och dess förhållande till kaleviska skifferformationen. S. 1—43. 15 fig. 1 karta. 1923 .... 20:—

N:o 63. Hackman, Victor, Über einen Quartzsyenitporphyr von Saariselkä im finnischen Lappland. S. 1—10. 2 Fig. 1923 ...... 15:—

N:o 64. Metzger, Adolf A. Th. Die jatulischen Bildungen von Suojärvi in Ostfinnland. S. 1—86. 38 Abbild. 1 Taf. 1 Karte. 1924 .... 30:—

N:o 65. Saxén, Martti. Über die Petrologie des Otravaaragebietes im östlichen Finnland. S. 1—63. 13 Abbild. 5 Fig. auf 1 Taf. 2 Karten. 1923 .... 30:—

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 .. 20:—

N:o 67. Sauramo, Matti. Tracing of Glacial Boulders and its Application in Prospecting. P. 1—37. 12 fig. 1924 .... 20:—

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5674—38

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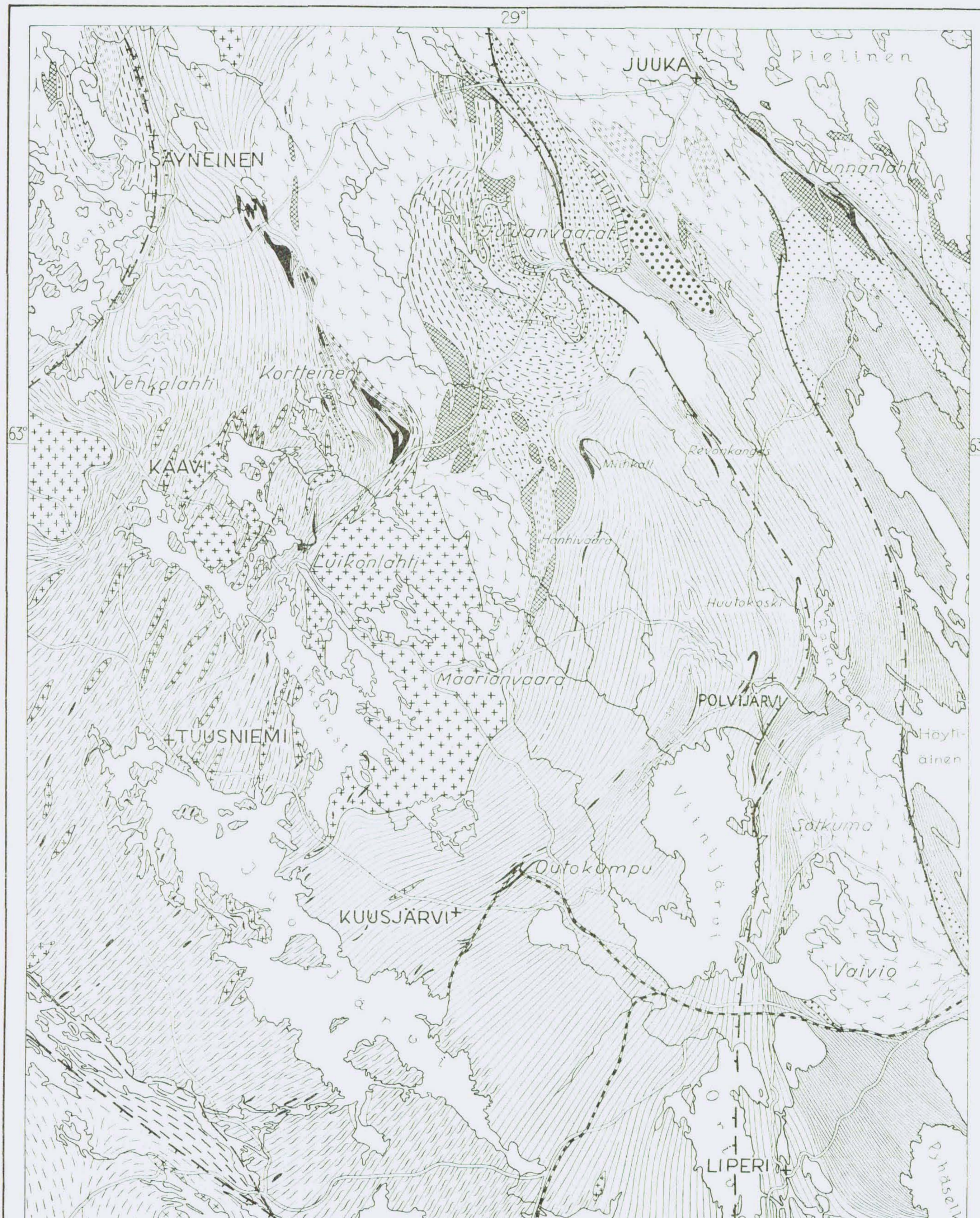
N:o 124. Väyrynen, Heikki. On the Geology and Tectonics of the Outokumpu Ore Field and Region. P. 1—91. 11 fig. in the text. 2 maps. 1939 .... 50: —

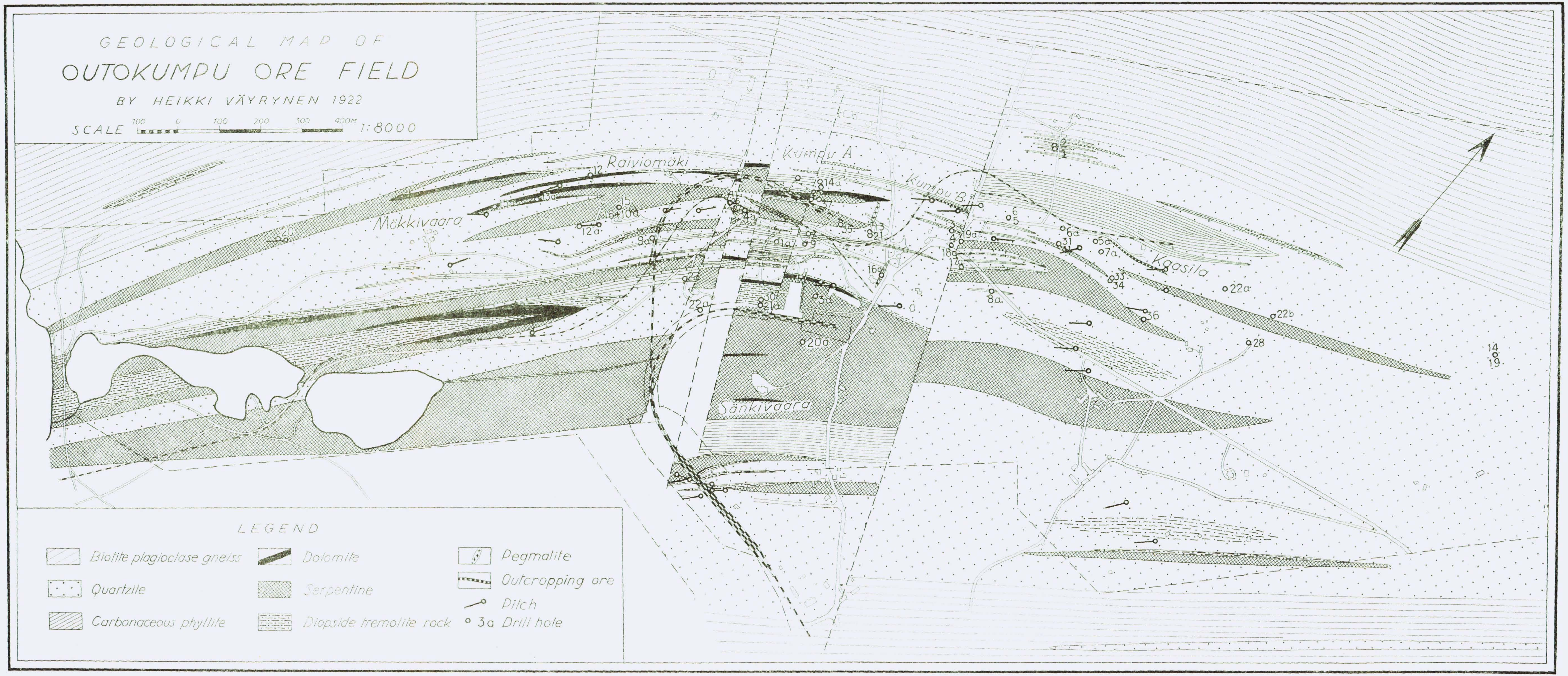
GEOLOGICAL MAP OF THE OUTOKUMPU REGION

Scale 1 : 400 000. By Heikki Väyrynen.



Pre-Jatulian	Jatulian	Kalevian	Post-Kalevian
Schists	Autochtonous quartzite	Quartzite	Gneiss (tectonitic)
Gneissose granites	Allochtonous ,,	Phyllite	Breccia ,,
Massive ,,	,, tremolite ,, dolomite	Mica gneiss	Ophiolitic intrusives
Post-Kalevian Overthrust	schist	Blebbed gneiss	Post-Kalevian granite
	Basic rocks		

Heikki Väyrynen: On the Geology and Tectonics of the Outokumpu Ore Field and Region.


GEOLOGICAL MAP OF
OUTOKUMPU ORE FIELD
BY HEIKKI VÄYRYNEN 1922
SCALE 100 0 100 200 300 400M 1:8000
Raiviomäki
Mökkivaara
Kumpu A
Kumpu B
Kaasila
Sänkivaara
LEGEND
Biotite plagioclase gneiss
Quartzite
Carbonaceous phyllite
Dolomite
Serpentine
Diopside tremolite rock
Pegmatite
Outcropping ore
Pitch
3a Drill hole