SUOMEN GEOLOGINEN TOIMIKUNTA

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ON THE PETROLOGY OF FINNISH QUARTZITES

BY
ANNA HIETANEN

WITH 29 FIGURES IN THE TEXT, 8 PLATES AND 3 MAPS

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CONTENTS.

PREFACE.

The field investigations for this work were carried out in the summers 1935, —36, —37. The geological map of the Simsiö area was made during the summer 1935 and the specimens for petrofabric analysis were collected in the summers 1935and—36. Besides this I visited during these summers nearly all the occurrences of quartzites in South-west Finland, which are few in number, making field observations, collecting orientated specimens, which were later analyzed structurally in the laboratory of the Mineralogical and Geological Institute at the University of Helsinki in order to collect examples of the orientation rules present. The areas thus investigated in S.W. Finland are marked by numbers 1—9 on Map I. The quartzite areas in North and East Finland were visited during the summer of 1937; field observations were made far more widely during my travels along the route Muonio—Enontekiö—Kittilä—Rovaniemi—Petsamo —Kemijärvi—Salla—Vuorijärvi—Kuusamo—Puolanka—Paltamo— Sotkamo—Koli—Kiihtelysvaara. The collected specimens from certain areas of Lapland and Karelia were subjected to laboratory examination during the winter of 1937.

I wish to take this opportunity to express my gratitude to those who have promoted my work. My most sincere thanks are due to my teacher, Professor Pentti Eskola, for many valuable suggestions and helpful discussions of the problems in the course of my research, as well as for his criticism of the manuscript.

Dr. Th. G. Sahama I thank for introducing me in the methods of petrofabric analysis.

To Professor Aarne Laitakari, Director of the Geological Survey of Finland, I am indebted for publishing my paper in the Bulletin and for financial support on the part of the Geological Survey during the field investigations of the summers 1935 and 1937. During the summer of 1937 I also received grants from the F. J. Wiik Funds of the University of Helsinki and from the Geographical Society of Finland.

Miss Elsa Ståhlberg had the laborious task of executing most of the chemical analyses published in the present memoir and I wish to express my cordial thanks for her valuable collaboration. I also acknowledge my gratitude to Mr. J. J. Carlberg and Mr. Pentti Ojanperä, who took an active part in my investigation; the former carried out the separation and made the analyses of the diopside and the grünerite from the quartzite of Orismala, while the latter did the same with the rhodonite from the quartzite of Simsiö, point 3.

I also heartily thank Miss Jean Hall of Cambridge, England, for pleasant companionship during camping and excursions in Lapland in the summer of 1937.

Miss Lyyli Dammert I thank for drawing most of the maps and diagrams.

INTRODUCTION.

Outline of the Pre-Cambrian geology of Finland. The great sub-divisions of the Pre-Cambrian of Finland are the Svecofennidic territory in West Finland and the Karelidic range in East Finland. Sederholm (1932) distinguished in the Svecofennidic range the Svionian and the Bothnian formations with an unconformity between the two. In the Karelidic territory three types of quartzites were distinguished according to the degree of the deformation, viz. 1) the Ladogan, nearly glassy types, supposed to belong to the age-group of the Bothnian formation according to Sederholm; 2) the Kalevian, schistose types, and 3) the Jatulian, clastic varieties. Younger than these is the Jotnian cycle, during which the Jotnian sandstone and olivine-diabase of Satakunta and the rapakivi granites have formed. Since the time of Sederholm geological thought has changed in certain respects and already different classifications have been provisionally proposed. Polkanow (1935) regards certain formations in Lapland, including the Kola Peninsula, as formed during their own cycle, which he calls the Saamian cycle. According to his opinion a part of the quartzites of Lapland may belong to the remains of the mountain chain folded during the Saamian orogenic period. Backlund (1936) has given the name Goto-Karelidic chain to that complex to which the Karelidic formations of Karelia and Lapland belong and that of »Norwegosamiden» to Polkanov's Saamian formations. These classifications still rest upon a more or less tentative basis. In this paper the word »Karelidic» is regarded as comprising the whole mountain chain from Ladoga through Karelia and Lapland to Northern Norway. The orogenesis of the Karelidic range is younger than that of the Svecofennidic territory. Evidences of their age relations are visible in the following facts: 1) The strike of the Svecofennidic range — directed W.-E. — is intersected by the south-northerly Karelidic strike 2) Conglomerates of the Karelidic zone contain pebbles which consist of rocks of the Svecofennidic territory. The possible age differences between the distinctive formations of the Karelidic range have not been considered in the present memoir, because from the view-point of the quartzites this twofold classification is still satisfactory. Thus we get two territories with conspicuous and important differences between them, as will be pointed out below.

These differences appear lithologically and petrologically as well as tectonically. The quartzite occurrences of the Svecofennidic zone are few in number and small in size. The quartzite is in most cases glassy and wholly recrystallized, as for instance in the quartzite areas of South Ostrobothnia (No. 1—5 on Map I) and Tiirismaa (No. 7). Traces of a clastic structure are, however, in some cases visible and one of these quartzites, viz. that of Taalikkala (No. 9), shows a well preserved clastic structure. A red colour is characteristic of some quartzites, as for instance those in Tiirismaa and Kiikala. This red colour seems to hint at the persistence of the red sandstones through the ages, as pointed out by Eskola (Eskola and Nieminen 1938). The quartzites of South Ostrobothnia form chemically their own group, being rich in ferrous minerals.

The quartzites of the Karelidic formations differ from the former in many respects. Characteristic of the Karelidic quartzites is the Jatulian type. This variety has a clastic structure and in many places types are met with in which larger and smaller quartz balls occur abundantly in the psammitic quartzite. Sericite is a common accessory. Hausen (1930) has described this type of the Jatulian quartzites from Soanlahti, East Finland. Their structure is comparable with the structure of the date-quartzites of Krummendorf, Silesia, whose true nature Scheumann (1932) has demonstrated. Quartzites of this type do not occur in the Svecofennidic territory. The quartzites of the Kalevian type show in a greater degree traces of deformation, being often wholly tectonized. Glassy varieties are common. Sericite occurs also in these as an accessory, but generally in smaller amounts; for instance in the Kalevian quartzite of Vuokatti, Kiehimä (No. 14), well-orientated small sericite scales appear as inclusions in the crystalloblastic quartzite. This mode of occurrence is similar to that described by Scheumann (1937) in the quartzites south of Strehlen, Silesia.

Varieties containing feldspars occur mainly in Western Lapland, while the quartzites of Karelia are very poor in these minerals. Also the occurrence of granites penetrating quartzites is different. In the quartzite areas of Lapland and Kainuu they are common. In the Svecofennidic quartzite areas they appear also, but they are not met with in the extensive quartzite areas of Central Karelia which consist of Kalevian or Jatulian types.

Other types of sedimentary rocks, viz. phyllites and mica-schists, occur in wide areas of both territories and they are very similar in their composition. In Karelia they are found in wide zones west of the eastern quartzite areas. Their »flüsch» character is evident (Wegmann 1928).

The difference between these two territories appears also in the character of the limestones. They consist, namely, of calcite in West Finland, but are dolomitic in East Finland. This difference appears also in the cement of some quartzites: the dolomite quartzites are common in the Karelidic range, but in the Svecofennidic zone, where carbonatic cement has been present, it has commonly been calcitic, as for instance in Kuparsaari, Antrea (No. 10).

The rocks of the conglomerate pebbles indicate a marked difference between the geological conditions during the time of the formation of these two mountain chains. Migmatite pebbles which occur in the Karelidic conglomerates are not met with in the Svecofennidic zone, indicating that, with few exceptions, no infracrustal formation has been exposed during the time of the Svecofennidic mountain building.

The occurrence of ophiolitic rocks is closely connected with the mode of tectonics and shows a most marked difference between the Karelidic and Svecofennidic ranges. Ophiolites are common in the Karelidic zone but — on the contrary — do not occur in the Svecofennidic formations.

The ophiolitic rocks of the Karelidic mountain chain consist of various types of gabbros and peridotites or their metamorphic derivates, viz. amphibolites, serpentine rocks, greenschists and chlorite-schists. Talc-dolomite and talc-magnesite rocks occur besides the former. A glassy type of quartzite is common in connection with the ophiolites. For instance the quartzite of Outokumpu copper mine belongs to this group. These quartzites have not been investigated in connection with the present work. The ophiolites occur in zones parallel to the elongation of the ancient mountain chain west of the eastern quartzite zone within the phyllite and mica-schist. This mode of their occurrence shows a closest approximation to the occurrences of ophiolites in the younger mountain chains. Kossmat (1937) has recently discussed their occurrence and their role during the time of mountain building in the Alpine Mediterranean chain. A comparison of the Karelidic ophiolites with the general picture of these rocks given by Kossmat and, from the whole world, by Benson (1926) indicates them to be of a similar origin. Together with other geological circumstances they give an evidence of that mode of tectonics, which is assumed in the cases of younger mountain chains, viz. the so-called Alpine tectonics.

The occurrence of gabbros, peridotites and their metamorphic derivates in West Finland differs in the greatest degree from the mode of the occurrence of the Karelidic ophiolites. The femic rocks of the Svecofennidic territory are typical plutonic rocks, occurring as members of the differentiation series and, as a rule, being connected with the synkinematic granites. They therefore appear as scattered masses among other deep-seated rocks and have sometimes been changed into serpentine rocks. Consequently they have not that orogenic origin which is characteristic of the ophiolites. The tectonics of the Svecofennidic chain show a resemblance to the so-called »Schlingen» tectonics with chiefly steeply or vertically standing folding axes.

Diabase rocks as well as granites and migmatites occur in both territories. The plutonic rocks have been intruded into their places as smaller or larger masses belonging to different phases of each cycle.

When observing the differences and similarities between these two large territories of the Pre-Cambrian of Finland there arises a question, which has been often discussed by various geologists — as for instance by Backlund (1936, 1937) — viz. the question of the rare occurrence of the quartzites in the Svecofennidic zone. This is the more marked, as the quartzites occur very abundantly in the Karelidic chain.

Scope and goal of the present investigation. In the title of the present memoir the word Petrology is regarded as including the study of petrofabrics, or structural petrology, besides the common aspects of descriptive petrography and the interpretative study of the genesis, the primary lithological characters, and the later changes and metamorphic mineral development of the Pre-Cambrian quartzites. During the last few decades the scope of petrology has been extended to comprise petrofabric analysis to complete the geological field investigation, to compare the micro-orientation of the rock constituents with the megascopic structures and tectonics, and thus to illuminate the conditions of strains and differential movements under which the metamorphism has taken place and the present geological structure has originated during the orogenic processes.

So far the Pre-Cambrian rocks of Fennoscandia have been little studied by the methods of petrofabric analysis. It must be remembered, however, that Br. Sander, the founder of modern petrofabric study, himself subjected an arkosic paragneiss from Someronvuoret, Tampere region, to petrofabric analysis (Sander 1928) and thereby showed that this paragneiss with well preserved current-bedding is actually a typical girdle-tectonite. The investigation of the granulites of Lapland by Th. G. Sahama (1936) was the pioneer work on a comprehensive areal complex along this line. In the Pre-Cambrian of Sweden petrofabric work has been carried out by Habetha (1936) on the granite of Karlshammar, by Wenk (1936) on the rocks of Ornö Huvud, and by Larsson (1938) in the Svinesund—Kosterfjord region. In Norway, Barth (1936) has executed a few petrofabric analyses of some Telemark granites. Bubnoff (1938) has recently investigated the petrofabrics of the Hammer granite, Bornholm.

The Pre-Cambrian quartzites of Fennoscandia have not so far been studied by the methods of petrofabrics. Being almost monomineralic rocks, often strongly sheared during the orogenic movements, the quartzites could be expected to supply an especially valuable subject for petrofabric analysis. After three years' work I have the satisfaction of being the first to show what the Finnish quartzites are like in this respect. So much can be said at the outset that expectations have been fulfilled: petrofabric study of the Finnish quartzites has much to offer for a better understanding of the tectonics of the Pre-Cambrian and its rock metamorphism. But the subject is immense, and I am quite conscious of the fact that I could merely bring together a few rather fortuitous samples of quartz orientation and by no means furnish any systematic investigation of the Finnish quartzites.

The work was commenced at the quartzite area of Simsiö in Lapua, South Ostrobothnia (point 1, Map I). This locality has become well known for its manganese minerals, on which a preliminary investigation has been published (Hietanen 1936). The very first petrofabric analysis of the Simsiö quartzite revealed an orientation according to the so-called Trener α-rule (c of the quartz at right angles to the schistosity). It was therefore decided to investigate quartzites from different parts of the country to find out in the first place what rules of quartz orientation were most common in the Pre-Cambrian quartzites of different areas and different age-groups. I therefore examined microscopically all the thin sections of Finnish quartzites existing in the collections of the University Institute and the Geological Survey and carried out a preliminary determination of the quartz orientation by means of a gypsum plate. In most cases no regular orientation could be proved by means of a gypsum plate. The orientation c parallel to the schistosity of the quartzites of Western Lapland was, however, found already in this preliminary investigation. A U-stage investigation showed an orientation to exist, but to follow more complicated rules also in many such cases, where no orientation can be revealed by means of simple optical reactions. In other fairly numerous cases no orientation exists.

After a preliminary survey I decided to concentrate the petrofabric work more especially on two small quartzite areas, viz., those of Simsiö in Lapua and Olostunturi in Muonio, Western Lapland. The Simsiö area was selected as a representative of the Pre-Karelidic Territory of South-west Finland, while the Olostunturi area was to represent the Karelidic zone in which the orientation rules were expected to be materially different from those of S.W. Finland. From the wide quartzite areas of the Karelidic territory only the quartzites of Olostunturi and Jyppyrä were studied more closely. Samples for petrofabric analysis were collected from the Kiehimä area in Paltamo, from Vuokatti in Sotkamo and Koli in Juuka. All quartzites from the areas in South Ostrobothnia as well as those of Tiirismaa and Tytärsaari were subjected to petrofabric study.

In the course of the fabric analyses the phenomena of the undulose extinction and the Böhm striations in the quartz from the hill Simsiö in Lapua suggested some ideas that may have some general bearing with regard to the mechanics of the lattice orientation in quartz. This led to a series of comparative observations in quartzites from different parts of Finland. These observations and the conclusions drawn from them will be presented in connection with the description of the Simsiö area.

A marked difference in the tectonics of the Karelidic and Svecofennidic formations offers to the petrofabric study a suitable opportunity of comparing the orogenic movements which have taken place at the time of their folding, or later.

The quartzite areas in South Ostrobothnia brought forth the problem of the relations between granite and quartzite. In the Simsiö area, namely, small granite masses occur inside the quartzite area and this mode of occurrence seemed to hint at the easy granitization of the quartzites. The quartzite areas of Kälviä and Western Lapland were found suitable to throw light on this matter, as feldspar was a common minor constituent in these quartzites, and the investigation of its origin seemed to illuminate the granitization of the quartzites.

I. SVECOFENNIDIC QUARTZITE AREAS.

A. QUARTZITE AREAS OF SOUTH OSTROBOTHNIA.

1. SIMSIÖ AND SURROUNDING QUARTZITE AREAS.

Geological outline.

Map II shows the district comprising areas of quartzite rocks in Lapua (area 1 of Map I). The quartzite forms bigger and smaller lenses lying on their edges among the other rocks, which consist of amphibolites, granites, and migmatites. The hill Simsiö represents a horizontal section of the largest of the exposed quartzite lenses. It is 9 km in length and 3 km in breadth. The strike is mostly N. 0°—15° E. with many small and two bigger folds. The schists dip from 75° to 85° to the east, or their plane of schistosity is vertical. The smaller quartzite lenticles have the same strike. Near the farm Takaluoma it, however, arches in an E.—W. direction.

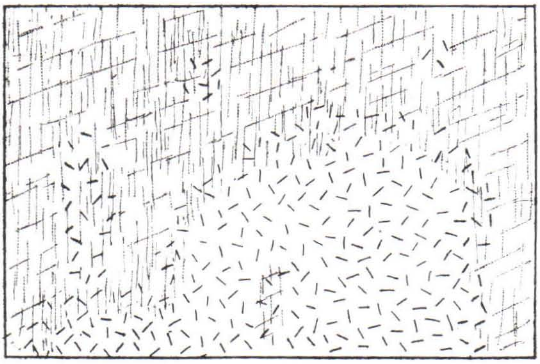


Fig. 1. Contact between granite and quartzite, Simsiö. Scale 1:30.

As we can see on the map, quartzite, amphibolite and granite alternate in the whole area, the quartzite sometimes being next to amphibolites and sometimes next to granites and all the rocks having the same strike. Contacts between the quartzite and granite were found in many places and they are of different character. Near the farm Tervasmäki the granite joins the quartzite, forming migmatite. Occasionally we can meet with definite contacts but usually the passage from the one rock to the other is gradual. The amount of the feldspar decreases according to its distance from the contact. The dark components of the granite are the first to disappear and then the feldspar. Quartz increases at the same time. The most interesting fact is, that the strike continues undisturbed across the contact. The contact relations look as if the feldspar had taken its place in the quartzite by corrosion. Fig. 1 shows schematically a contact zone of this kind situated in the middle of Simsiö. The strike of the schist is distinctly visible. Feldspar grains occur very close together near the granite boundary, but soon their number decreases, and about 10 cm from the contact line they are absent. On the west side of Simsiö (point 7) we meet with a contact between quartzite and a continuous gneissose granite mass. The middle of this outcrop belongs to a narrow quartzite zone situated within the granite. The strike of the quartzite is N.—S. and the dip vertical. Diopside layers occur abundantly and they build boudinages (Wegmann 1932). The granite has penetrated into them both (fig. 1, Pl. I). We can see in this outcrop dark diopside lenticles in a distinctly schistose, fine-grained quartzite. Light-coloured, coarse-grained granite rich in feldspar may be seen as a larger mass, while smaller masses of granite and grains of feldspar are quite common in this contact zone. Occasionally the granite occurs in the quartzite as rather long lenses parallel to the strike of the country-rock. The strike continues undisturbed here also, but near to large granite masses we can occasionally see disturbed strikes or no schistosity at all. In the latter case the quartzite is glassy.

In many granite lenses we can see the same strike as in the surrounding quartzites. It looks as if the quartz grains of the granite were lying in their original positions and the feldspar grains had penetrated the rock afterwards, taking their places by corrosion and replacing the quartz as in the previously described contact zones.

A contact zone of a different kind occurs on the west side of Simsiö at point 51 Map. II. The continuous granite here penetrates like fingers between quartzite and amphibolite and encloses small lenticles of both. The strike of some though not all lenses is conformable with that of the granite. It seems to me that here the granite has intruded more mechanically. Similarly, at the southern end of Simsiö, near Tervasmäki, we can see lenticles of quartzite lying within the gneissose granite, the strike of the granite winding around the lenticles. Here, however, feldspar may also have come into the quartzite without disturbing the strike. The huge southern granite mass has obviously assumed its position partly mechanically, but its energy has not been very strong, as only at a few places has it been able to cut the neighbouring schists. Its internal pressure, however, has been strong enough to press granite into the schists, while the granite must have gradually corroded its way into the quartzite. The same granite has penetrated the whole quartzite area, building fairly small, elongated lenticles inside the quartzite, and outside it long, narrow masses orientated along the schistosity. One might expect that a granite which has originated in this way would be richer in quartz than the normal variety. However, the analysis of a granite specimen from Paasinmäki (Table I) by Miss Elsa Ståhlberg showed quite a normal composition. The metasomatic interchange of the components must have been complete, or this granite mass has intruded mechanically.

Table I.

Granite, Paasinmäki, Lapua.

	%	Mode	%
SiO_2	74.46		
Al_2O_3	13.36		
Fe_2O_3	0.83		
FeO	0.99	Quartz	33.6
MnO	0.02	Microcline	15.8
MgO	0.34	Plagioclase (An_{29})	45.5
CaO	1.63	Biotite	5.7
Na_2O	4.42		100.6
K_2O	3.82		
TiO_2	0.19		
P_2O_5	0.01		
H_2O+	0.50		
H_2O-	0.02		
	100.59		

Generally the quartzite lenses are surrounded by amphibolites and, where granite masses appear, the granite has penetrated them as well as quartzites. Thus for instance in Paasinmäki granite occurs as small masses and veins in amphibolite rocks. On the west side of Simsiö it seems as if the granite had found an easier way in quartzite than in amphibolite. The westernmost of the quartzite lenses is surrounded by amphibolite and it is much larger than the other. The one in the middle is shortest and it seems as if the granite had corroded away its southern end, for at the north end of the narrow zone between amphibolite rocks there is quartzite, but at the south end gneissose granite is found. However, it is in these granite rocks that fragments of amphibolite and quartzite occur enclosed in the granite as described on p. 14. This indicates a common mechanical way of intrusion.

Petrology.

Amphibolites. These rocks are rather variable. We meet with all sorts, from a quite massive type to a well foliated variety in which hornblende appears needle-like and the light components are in the minority. The amphibolite of Jänismäki differs from all the others, consisting either of light-coloured, diopside-rich lenticles enclosed in dark hornblende-schist, or of hornblende-rich lenticles in a diopside-plagioclase rock. Plagioclase is of the same composition (27 % An) in both varieties of the rock. The contact between this schist and its country-rock, migmatite, is exposed on the railway line east of Jänismäki. Diopside-rich amphibolite occurs as lenticles in the migmatite, which is similarly enclosed by the amphibolite. On the west side of this outcrop there is a rather small mass of granite which adjoins both the rocks mentioned above. Their strike is N.-S. The small lenticles have the same strike. In Paasinmäki we meet with the same variety of diopside-rich amphibolite. In the east part of the area the rock is diopside-plagioclase schist and it has dark hornblende lenticles about 5 cm in length and 1 cm in breadth, exposed at regular intervals on its surface. The amphibolite at the south end of the area is more massive, like that on the west side, nearest to Simsiö. The amphibolite bordering upon the migmatite, west of point 51, looks rather intrusive, distinctly foliated, partly fine-grained. A coarse-grained type, however, may occur occasionally. Hornblende appears there in about 3 cm long crystals. Narrow bands of limestone are intercalated in this rock. The outcrops south of Takaluoma are made up of dark-coloured, distinctly foliated amphibolite, orientated along the strike. The small amphibolite lenticles upon Simsiö consist in part of medium-grained, foliated schist, but a more massive variety also occasionally occurs. The amphibolite and the quartzite have always the same strike. On the west side of Jänismäki quartzite occurs at one outcrop in very narrow, only a few cm broad beds in the amphibolite.

Phyllite. Beds of this rock are lying here and there in quartzite, mainly on the slopes of Simsiö and in Ritamäki. They are usually rather narrow, about from 5 to only 10 cm broad. Occasionally they may be somewhat broader, as for instance in Ritamäki. The phyllite is always rusty and weathered and usually comparatively coarse-grained. Its mineral components are quartz, feldspar, mica, graphite and ores, viz., magnetite, pyrite and pyrrhotite. In many places diopside occurs in addition, as in Ritamäki. Massive-looking fine-grained phyllite and coarse-grained quartzite often alternate irregularly, both of them containing grains of the ore-minerals mentioned before. Occasionally, again, the narrow phyllite-beds are fairly regular, and their vertical folding axis is distinctly visible.

The granites of the Simsiö area are gneissose, as already mentioned and belong to the synkinematic eruption series (analysis on Table I, p. 15). Their parallel structure has the same direction as the strike of the adjacent schists, but the direction of their linear structure is variable, on the west side of Simsiö 55°N., and at the south end of the hill and in Paasinmäki vertical. The colour is reddish or gray. The mineral components are quartz, plagioclase, microcline and biotite. Besides the gray-coloured biotite-granite, another type in which the feldspar appears as lath-shaped phenocrysts occurs as small masses upon Simsiö. This variety is massive and non-orientated. Its components are the same as those of the former type. The colour is reddish. Pegmatitic granites occur occasionally in small masses.

Quartzite. The colour of this rock is bright blue in the main part of the glassy type, and pale bluish in the more schistose variety. A reddish, coarse-grained type occurs occasionally, especially near the View-tower. The grain size is variable in different types. The blue varieties are very coarse-grained, glassy-looking, and consist of nearly pure quartz. Only a little graphite in the form of scales may be found. This blue type appears mainly in the middle of the hill. Here and there it is accompanied by a pale-bluish, foliated, fine-grained variety.

The strike is usually difficult to observe because of a perpendicular jointing. It is distinct only in such places where certain mineral components are orientated parallel to the schistosity.

The smaller quartzite occurrences around Simsiö are composed of the same kind of blue or pale-coloured rock. The pale-bluish, fine-grained type prevails for instance in Paasinmäki and near the farm Sorvari, but the other varieties also occur generally.

Constituents occurring in minor quantities are very few. Only a little graphite and occasionally garnet have been observed. The latter, probably a manganese-garnet, is found in two places on the path leading to the View-tower on the east side of the hill, about 150 m and 300 m from the border. But in these places, too, this mineral occurs in such a restricted area that the occurrences may be regarded as mineral accumulations which are very common upon Simsiö, represented by other minerals, namely, 1) diopside-bearing layers and lenticles, 2) ore minerals, and 3) manganese-bearing minerals. Even graphite may appear as veins and small masses.

Mineralogy of the Quartzite. The Manganese Minerals.

1. *Diopside.* Among the accumulations of accessory minerals those of diopside are most common upon Simsiö. They occur mainly on the hill slopes. In fig. 1 (Pl. I) we see a picture of an outcrop, where diopside lenticles occur rather abundantly. They are apparently parts of once continuous layers which have been subjected to a tensional strain, thus giving rise to the pieces now occurring in the manner of boudins in foliated, pale-coloured quartzite. Their size is variable. 1—10 cm broad and 10—100 cm long masses are most common, but occurrences of different shapes are also met with, as for example at the north end of the hill where narrow beds of diopside ranging from 1 mm to 5 mm in breadth are intercalated in the quartzite at a distance of about 1 cm from each other. An outcrop, measuring 3 m in breadth and 10 m in length, composed of diopside with almost colourless, actinolitic (?) hornblende is met with on the path leading to the View-tower. It also occurs abundantly at a pond about ½ km south of the former place. The mineral components of the rock from this place are diopside and a little plagioclase (62 % An), pale-coloured biotite, and actinolitic hornblende. Minor constituents are clinozoisite, zircon, apatite, and titanite.

The diopside lenticles usually consist of almost pure diopside with only a small amount of colourless amphibole. Scaly graphite appears in small quantities. Calcite and manganocalcite occur occasionally. The latter is met with in accumulations of manganese-bearing diopside, which can be identified from its dark-coloured weathering surface. The manganocalcite, of rhombohedral crystal form, was found to be transparent and pink in colour. A qualitative test indicated the presence of manganese. The refractive indices determined by immersion were (Hietanen 1936) $\varepsilon = 1.496$, $\omega = 1.666$. According to Harada (1935) they indicate a content of 4.45 % MnO. As a rule, however, the original dolomitic calcite has reacted with silica to the exhaustion of either the quartz or the calcite. Feldspar is found in a few diopside occurrences, though in rather small quantities.

The hornblende is a very pale-green actinolitic variety and occurs occasionally in the quartzite as columnar grains orientated parallel to the schistosity and lying in narrow beds. The refractive indices of the mineral measured by immersion are $\alpha' = 1.644$, $\gamma' = 1.660$. The optic axial angle measured by the U-stage is $(+)\ 2\,V = 73.5°$. The refractive indices of the diopside were determined from two specimens as follows: $\alpha = 1.678 \pm 0.001$, $\beta = 1.687 \pm 0.001$, $\gamma = 1.707 \pm 0.001$; $(+)\ 2\,V = 59°44'$. The diopside in the amphibolite of Paasimäki gave the same optic data.

The amphibole occurring in diopside masses and also often associated with the manganese minerals has the refractive indices $\alpha' = 1.673$, $\gamma' = 1.700$ and the optic angle $(+)\ 2\,V = 97.5°$. It shows a high birefringence and twinning. The colour is golden-brown. These properties indicate that it belongs to the grünerite series. The [FeO]: [MgO] ratio is about 2.85 according to Winchell. In the accompanying diopside the same ratio is about 0.79, or much lower than in the amphibole.

The mica accompanying the diopside and occasionally present in the quartzite is a pale-coloured biotite. The pale colour indicates a large proportion of magnesia.

In some specimens of manganese minerals the biotite is of a deeper colour and shows a strong pleochroism, α pale yellow, γ greenish gray shading into violet, and absorption $\gamma > \alpha$. Its grayish colour indicates a content of manganese, as also found by a qualitative analysis. This manganeous mica has a refractive index $\gamma = 1.596$.

2. *Ore minerals.* Grains of sulphidic and oxidic minerals are rather common in the quartzite and in the phyllite beds. The surfaces of the ore-bearing rocks are rusty and weathered and, in dry weather, covered with white iron salts. In quartzite the ore minerals occur as accumulations with a diameter varying from one to three meters. These ore impregnations are usually small and poor. Only in a few places on the slopes of the hill, where they appear in greater numbers, are they richer and more extensive. One of them is found on the road leading over Simsiö on the west side of the hill. In addition to the pyrrhotite and magnetite generally occurring in the quartzite we have here also crystalline pyrite. As a rule the quartzites in the hill-slopes are rusty owing to pyrrhotite, and are magnetite-bearing. Thus all the rocks on the road passing the farm Isoluoma are ore-bearing. On the west side of the hill we meet with a bed consisting of a very rusty ore-bearing phyllite.

The southern part of Simsiö, where the outcrops are few and flat, is underlain by rusty ore-bearing quartzite together with phyllite.

On the east side of Simsiö rusty quartzite and phyllite zones alternate; both are ore-bearing. The middle part of the hill is mainly composed of pure quartz with a few patches of ore, ranging from one to two m in diameter. In the small quartzite occurrences around Simsiö ore impregnations are met with, especially in Paasinmäki and in Jänismäki. As mentioned earlier, the schists of Ritamäki are composed of rusty phyllite-quartzite rocks. Pyrrhotite is also found in fresh quartzite as grains with a diameter of 1—5 mm.

3. *Manganese minerals.* Very numerous accumulations of manganese minerals are found upon Simsiö. They are generally rather small and only two of them are of larger size. In addition several diopside occurrences are manganese-bearing, as described previously. One of the two larger occurrences of manganese silicates, discovered by Dr. Saksela (1933), is situated on the path leading to the view-tower, 300 m from the eastern border of Simsiö. The manganese mineral is of a brown colour with dark weathering-surfaces. The grain size is variable. The biggest crystals are over 12 cm long and they contain abundant inclusions. These inclusions mainly consist of the same mineral as the big crystals themselves, but also of other minerals, e. g. quartz and calcite. They are often big enough to be visible even to the naked eye. The fine-grained mineral contains also plenty of inclusions visible under the microscope. They are, however, so small, that their character cannot be determined.

This mineral has two cleavages; one of them, viz. (110) is more perfect. The cleavage angle $110 \wedge 1\bar{1}0$, measured by a goniometer, is $= 91°53'$, which is an average of five different readings from cleavage splinters of the same crystal. Several of the measurings differ considerably from each other. The mineral seems to have »vicinal cleavages» in connection with the less perfect cleavage $(1\bar{1}0)$. The axial plane is near the plane bisecting the acute angle $(110) \wedge (1\bar{1}0)$; the axial angle $(+)\ 2V = 39.5°$, determined by means of the Fedorow stage. The direction of extinction on (010) is 5.5° and on $(0\bar{1}0)$ it is 41°. In immersion liquids the refractive indices were determined as follows: $\alpha = 1.738 \pm 0.001$; $\beta = 1.742 \pm 0.001$; $\gamma = 1.754 \pm 0.001$. α and γ were determined in one cleavage splinter and β in a thin section from the same splinter.

The values differ from those determined in the same material and published in an earlier paper (Hietanen 1936, p. 392). They were determined in cleavage splinters from separated material and show a higher birefringence. The error in this respect was due to a variation in the composition of the mineral.

The analysis of this mineral has been published earlier, it then being called rhodonite, and is quoted below.

Table II.

Pyroxmangite, Simsiö. 2.

	%	Mol.	
SiO_2	46.51	0.7713	
FeO	19.12	0.2661	0.7808
MnO	29.34	0.4137	
MgO	1.96	0.0486	
CaO	2.94	0.0524	
H_2O	0.25	0.0139	
	100.12		

Spec. gravity 3.762—3.750.

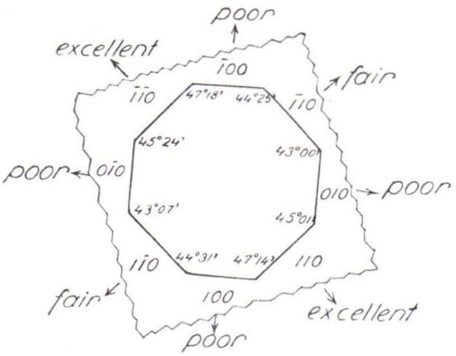


Fig. 2. A cleavage splinter of pyroxmangite, Simsiö 27 a. Each side shows two reflections of which the quality is marked. The directions of the crystal faces are drawn perpendicular to the reflections.

The analysis shows the closest approximation to the pyroxmangite from Idaho described by Henderson and Glass (1936). The optic data approximate those of the same mineral, but the specific gravity shows a considerable difference from the value 3.66 of the Idaho pyroxmangite. The smaller optic axial angle distinguishes this mineral from the rhodonite and, with the other properties, permits of it being determined as pyroxmangite.

The second accumulation of manganese minerals situated at the southern part of Simsiö, point 27 on map III, consists of one larger mass and several smaller ones around the larger mass. The small masses occasionally build boudins and the passage into quartzite is gradual. The mineral of the largest mass is brownish red and mostly fine-grained. Brown-coloured porphyroblasts ranging from 4 to 6 cm in length are enclosed in this fine-grained mass. The properties of this brown mineral differ in some respects from those of the pyroxmangite from the northern part of Simsiö. The colour is paler and the refractive indices lower, namely: $\alpha = 1.731 \pm 0.001$; $\beta = 1.734 \pm 0.001$; $\gamma = 1.749 \pm 0.001$. It has, however, a similar small, positive axial angle, (+) 2 V = 40°, measured by means of the U-stage, and it shows the same cleavage angles as pyroxmangite (viz. 91°44.5′). These properties indicate that it belongs to the pyroxmangites. One cleavage splinter of this pyroxmangite showed, besides the prism cleavage, two other cleavage directions (fig. 2). One of them forms an angle of 45°12.5′ with the perfect cleavage direction (110) and the angle of 43°3.5′ with the plane $(1\bar{1}0)$. These values show an approximation to the values which Ford and Bradley (1913) found to belong to the plane (010). The second cleavage plane forms the angles of 47°16′ and 44°28′ with (110) and $(1\bar{1}0)$ respectively and, it may be the plane (100). The angle between (010) and (100) was in this case the same as the prism angle of rhodonite viz. 92°28.5′. Fig. 3 shows the optical orientation of this pyroxmangite.

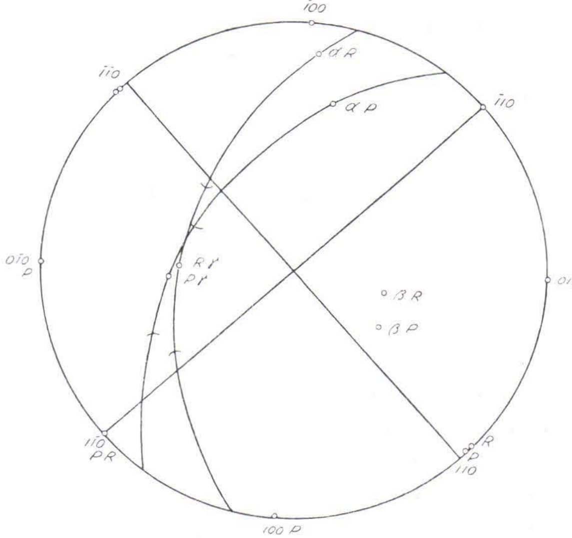


Fig. 3. Optical orientation of the pyroxmangite, Simsiö 27 a, and the rhodonite 27 c.

Pure mineral for an analysis from a big single crystal was separated by means of the Clerici solution, the specific gravity ranging from 3.679 to 3.688.

An analysis made by Miss Elsa Ståhlberg shows the following result:

Table III.

Pyroxmangite, Simsiö 27 a.

	%	Mol.	
SiO_2	47.04	0.7801	
TiO_2	trace		
Al_2O_3	0.00		
Fe_2O_3	0.66	0.0041	
FeO	12.35	0.1719	0.7800
MnO	33.37	0.4705	
MgO	3.48	0.0863	
CaO	2.88	0.0513	
H_2O-	0.08		
H_2O+	0.57		
	100.43		

The manganese mineral of the small lenticles was found to be rhodonite and was described in the earlier paper (Hietanen 1936, p. 391). It shows a brownish red colour and a grain size ranging from 1 mm to 4 mm. The refractive indices measured in one single crystal were: $\alpha = 1.729 \pm 0.001$; $\beta = 1.734 \pm 0.001$; $\gamma = 1.741 \pm 0.001$. The axial angle shows variable values ranging from +68° to +73.5°. The optical orientation is shown in fig. 3.

The analysis may be quoted below:

Table IV.

Rhodonite, Simsiö 27 c.

	%	Mol.	
SiO_2	46.84	0.7768	
FeO	7.33	0.1020	0.7822
MnO	38.92	0.5487	
MgO	2.83	0.0702	
CaO	3.44	0.0613	
H_2O	0.26	0.0144	
	100.12	99.62	

spec. gravity 3.641—3.647.

The properties of the brownish-red fine-grained mineral from the largest mass in locality 27 show approximation partly to the neighbouring pyroxmangite and partly to the rhodonite of the small lenses. The spec. gravity is the same as that of the pyroxmangite, viz. 3.678—3.688. The grains, ranging from 1 mm to 4 mm in diameter, show the cleavages for rhodonite, averaging $(110 \wedge 1\bar{1}0) = 92°35'$, the different measurements differing considerably from each other. Some cleavage splinters give the cleavage planes (010) and (100) and the angle between them was also found to be close to the cleavage angle of the rhodonite. The measurement of the optic data gave the following results: $\alpha = 1.729 \pm 0.001$, $\beta = 1.734 \pm 0.001$, $\gamma = 1.744 \pm 0.001$. $+2V = 66.5°$. The value of the birefringence, 0.015, is lower than that of the pyroxmangite (0.018) but higher than that of the rhodonite (0.012). Also the optic axial angle shows a value lying between the measurements of the optic axial angles of rhodonite and pyroxmangite, but shows, however, a closer approximation to the rhodonite. Several small pyroxmangite crystals are found in thin sections among this rhodonite and it may be that the material separated for analysis contained some pyroxmangite, as they have the same spec. gravity.

The analysis of this mineral made by Miss Elsa Ståhlberg shows the following result:

Table V.

Rhodonite, Simsiö 27 b.

	%	Mol.	
SiO_2	46.40	0.7695	
TiO_2	0.00		
Al_2O_3	0.00		
Fe_2O_3	1.09	0.0068	
FeO	10.45	0.1454	0.7733
MnO	35.36	0.4987	
MgO	2.06	0.0511	
CaO	4.38	0.0781	
H_2O+	0.64		
H_2O-	0.08		
	100.46		

These three manganese minerals from one and the same locality show only inconsiderable differences in their chemical composition. The rhodonite 27 c is poorest in iron and has the lowest refractive index α and the largest optical angle. Seeing that the mineral 27 b is a rhodonite it has an exceptionally small optic axial angle and a high birefringence which shows an approximation to the pyroxmangite group. Now, as we can see, the iron percentage of the pyroxmangite 27 a is about 2 % larger than that of the rhodonite 27 b and it has all the optical properties of pyroxmangites. All three minerals have the same value of the index β. The most marked difference between the pyroxmangite 27 a and the rhodonite 27 b is shown in the measurement of the optic axial angle.

The smaller manganese mineral accumulations, which occur most abundantly on both sides of the path leading to the View-tower, consist of brownish-red fine-grained rhodonite, or of partly fine-grained and partly coarse-grained pyroxmangite. At many places these minerals and quartz occur together as fine-grained brown masses.

A sample of rhodonite from point 3 shows the refractive indices $\alpha = 1.732 \pm 0.001$, $\beta = 1.737 \pm 0.001$, $\gamma = 1.744 \pm 0.001$ and the axial angle 2 V varying from + 72° to —88°.

The analyses made by Mr. Pentti Ojanperä gave the following result:

Table VI.

Rhodonite, Simsiö 3.

	%	Mol.	
SiO_2	46.28	0.7675	
TiO_2	trace		
Al_2O_3	0.00		
Fe_2O_3	0.23	0.0014	
FeO	10.88	0.1514	0.7674
MnO	39.72	0.5599	
MgO	0.14	0.0035	
CaO	2.87	0.0512	
H_2O+	0.18		
H_2O-	0.08		
	100.22		

Spec. gravity 3.647—3.650.

This rhodonite is richer in iron than that from point 27 analysed by me (see p. 23) and its refractive indices are higher. γ is similar to that of No. 27 b, but the birefringence has the same value as rhodonite 27 c, viz. 0.012.

A pyroxmangite from point 5 contains abundant inclusions of graphite and magnetite. Its colour is a darker brown than that of the other pyroxmangites. The cleavage angle between (110) and (1$\bar{1}$0) is measured as 91°40′. The optic data are as follows: $\alpha = 1.734 \pm 0.001$, $\beta = 1.737 \pm 0.001$, $\gamma = 1.751 \pm 0.001$; 2 V = 37.5°.

The analysis made by Miss Elsa Ståhlberg gave the following result:

Table VII.

Pyroxmangite, Simsiö 5.

	%	Mol.	
SiO_2	46.48	0.7708	
TiO_2	trace		
Al_2O_3	0.00		
Fe_2O_3	2.37	0.0148	
FeO	22.32	0.3106	0.7677
MnO	21.09	0.2973	
MgO	3.11	0.0771	
CaO	4.64	0.0827	
H_2O+	0.45		
H_2O-	0.20		
	100.67		

Spec. gravity 3.723—3.730.

The considerable amount of Fe_2O_3 may be due to a high degree of weathering of the material and to the inclusions of magnetite.

Table VIII. *Pyroxmangite.*

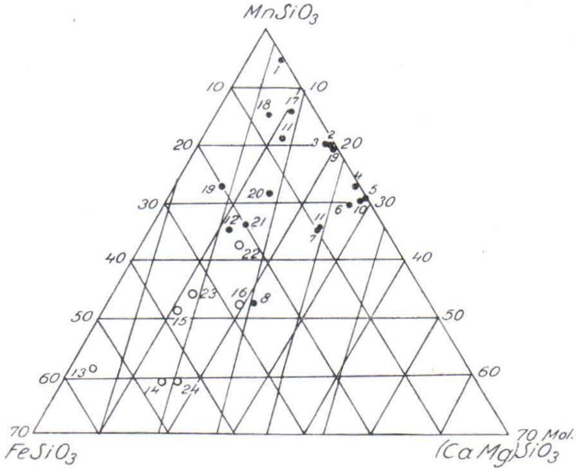
	13	14	24	15	23	16	22
Locality	Iva, South Carolina	V. Silvberg Sweden	Simsiö 5 Finland	Idaho	Simsiö 2 Finland	Glenelg Scotland	Simsiö 27a Finland
Data by	Glass	Sundius	Hietanen	Glass	Hietanen	Tilley	Hietanen
Anal. by	Bradley	Bygdén	Ståhlberg	Henderson	Hietanen	Bennett	Ståhlberg
m : M	91°50′	92°12′	91°40′	91°44′	91°53′		91°44.5
m : b	45°14′			45°22′			45°12.5
M : b	42°56′			43°18′			43° 3.5′
a : b				96°—			92°28.5
m : a							47°16′
M : a							44°28′
ć : c	63°	70°		65°			
α	1.748	1.738	1.734	1.737	1.738	1.732	1.731
β	1.750	1.740	1.737	1.740	1.742	1.735	1.734
γ	1.764	1.755	1.751	1.754	1.754	1.750	1.749
$\gamma—\alpha$	0.016	0.017	0.017	0.017	0.016	0.018	0.018
+2 V	37°	42°	37.5°	39°	39.5°	41°	40°
Disp.	$\varrho > v$		$\varrho > v$	$\varrho > v$	$\varrho > v$		$\varrho > v$
$FeSiO_3$	55	46	43	38	35	28	23
$MnSiO_3$	41	39	39	51	54	55	62
$MgSiO_3$	0	2	8	5	5	11	6
$CaSiO_3$	4	12	10	6	6	6	9
Spec. gr.			3.72	3.66	3.75	3.63	3.68

Table IX. *Rhodonite.*

Locality	8 Tuna Hästberg Sweden	12 Broken Hill N.S.W., Australia	19 Simsiö 3 Finland	21 Simsiö 27 b Finland	20 Simsiö 27 c Finland	11 Bald Knob N. Carolina
Data by	Sundius	Glass	Hietanen	Hietanen	Hietanen	Glass
Anal. by	Bygdén	Henderson	Ojanperä	Ståhlberg	Hietanen	Henderson
α	1.725	1.726	1.732	1.729	1.729	1.724
β	1.728	1.730	1.737	1.734	1.734	1.728
γ	1,737	1.739	1.744	1.744	1.741	1·737
γ—α	0.012	0.013	0.012	0.015	0.012	0.013
2 V	70°	74°	+72°—−88°	66.5°	68°—73.5°	70°
$FeSiO_3$	26	23	20	20	14	5
$MnSiO_3$	53	65	74	66	72	82
$MgSiO_3$	6	1	0	5	7	3
$CaSiO_3$	15	11	6	9	7	9
Spec. gr.		3.68	3.65	3.68	3.64	3.75

TableVIII shows the chemical compounds and the optical properties of the known pyroxmangites. Pyroxmangite from Simsiö 27 a (No. 22 in Table VIII) is poorest in iron. In the optical properties it shows the closest approximation to the pyroxmangite of Glenelg. The chemical composition is close to that of the rhodonite from Broken Hill (No. 12 in Table IX) but the optical properties are distinctly different. While the rhodonite of Broken Hill has a large optic axial angle, 74°, the corresponding value of the Simsiö mineral is 40°. The refractive indices of the rhodonite are lower than the corresponding values of the pyroxmangite of a similar chemical composition. A comparison of the Tuna Hästberg rhodonite (No. 1, Table IX) and the Glenelg pyroxmangite also indicates this. Comparison of the optical properties of the Simsiö rhodonite with those of the described rhodonites shows that the refractive indices of the Simsiö rhodonites are relatively higher than the refractive indices of the rhodonites to which they stand near in chemical composition. In this respect they show an approximation to pyroxmangites. The ternary diagram, as used by Sundius and Tilley, seems to be applicable for visualizing of the variations in the refractive indices and the chemical composition (fig. 4). In this diagram the pyroxmangites 16 and 22 and the rhodonites 18, 20, and 21 are situated near the same line and their refractive indices are near to each other, but the refractive indices of the rhodonite from South Carolina (No. 11) show lower indices. The same fact appears from the rhodonite 12 which is in this respect comparable to the pyroxmangite 24.

The stereographic projection (fig. 3) plots the optical orientation of the Simsiö pyroxmangite and rhodonite. The Simsiö pyroxmangite shows in this respect a closest approximation to the Idaho pyroxmangite (Henderson and Glass 1936) and the orientation of the rhodonite is in accordance with Winchell's diagrams. The difference between rhodonite and pyroxmangite thus appears in their optical properties. Pyroxmangite is characterized by higher birefringence and a smaller optic axial angle in comparison to rhodonite. Another difference between these two triclinic iron-manganese silicates exists in their cleavage angles and consequently in the angles between their crystal-faces. While the angle m:M of pyroxmangite is about 91°45′, the same angle of rhodonite is 92°28.5′. The refringence of rhodonite is lower than that of pyroxmangite. Some Simsiö rhodonites form an exception in this respect. Simsiö 27 b is an intermediate member between rhodonite and pyroxmangite. Whether it belongs to one or another species cannot be settled with certainty. For that purpose X-ray determination of the crystal structure would be necessary. The question whether these two minerals form two separate species or if they are members of one and the same isomorphic series arises also in this connection as not yet being definitely settled.



1—8	Sundius (1931).
9	Hey (1929).
10	Larsen and Shannon (1922).
11—15	Henderson and Glass (1936).
16	Tilley (1937).
17—18	Hietanen (1936).
19—24	Simsiö minerals.

Fig. 4. Ternary diagram for plotting the chemical compounds of the pyroxmangites (○) and rhodonites (●).

Grünerite, apatite, and the afore-mentioned manganeous mica occur as accessories in all manganese mineral accumulations. Graphite is occasionally met with in some abundance.

Spessartite appears in quartzite near to the other manganese minerals. In the southern accumulation it is found in crystals up to 0.9 cm in diameter. This mineral was described by me in the earlier paper (Hietanen 1936, p. 398). Spessartite is also found with pyrrhotite within the migmatite east of the quartzite area. This spessartite shows a different composition. According to an analysis made by Mr. Pentti Ojanperä the ratio [FeO]: [MnO] was 1.66, while the same ratio in the spessartite from area 27 was 0.20, and the refractive index, measured by means of goniometer in a prism, was 1.8074.

Apatite is found very abundantly in some specimens of manganese minerals. It occurs in small grains.

Sillimanite appears as fine needles at the northern end of Simsiö. The needles are usually found in a radiating arrangement around ore grains.

Genesis of the manganese minerals. Similar iron-manganese ores in quartzitic rocks occur in several localities, such as at Mazkamezö in Siebenbürgen (T. Kossmat and C. von John 1905, Quiring 1919) and in quartzites of the Dharwar series in India (Fermor 1919, L. Hezner 1919). Vittinki, situated in the parish of Ylistaro, Finland, however, shows the closest resemblance to the ores in question. This area was surveyed by Saksela (1925) and it will also be briefly described in this memoir.

In the manganese-ore deposits of Central India, ores are associated with the manganese garnet, spessartite, and the manganese pyroxene, rhodonite, forming a series of rocks known as the gonditic series. These gonditic ores are younger than the pegmatites which penetrate them and they are interbedded with crystalline schists and phyllites of the Dharwar series. Two series of manganese ores are distinguishable according to the degree of metamorphism, but without a difference in time. Crystallization lacking the formation of new minerals characterizes the lower degree of metamorphism. Psilomelane and pyrolusite, some braunite, and hollandite are intercalated with the quartzites and phyllites. Small occurrences of mica-schists contain manganese-bearing silicates, tourmaline and ottrelite. The ores of the highly metamorphosed rocks consist of braunite, psilomelane and some hollandite, sitaparite and vredenburgite. These ores are associated with gonditic rocks and occur together with quartzites, phyllites and conglomeratic gneisses. All the rocks are schistose and the schists generally stand steeply, seldom horizontally. Fermor supposes the banding of the gonditic ores to be in part the result of segregative changes during metamorphism of the original sedimentogeneous rocks. According to Fermor, the deposition of the ores has taken place mainly as oxides, seldom as carbonates, and in a few cases as sulphides. The manganese silicates have been formed by reactions between chemical manganese sediments and quartz with aluminous silicates. In the areas of lower metamorphism the substances have not reacted, showing only a recrystallization.

In the iron manganese-ore deposit of Mazkamezö a large content of iron has given rise to the formation of knebelite, dannemorite and manganiferous magnetite. Spessartite and rhodochrosite occur together with these ores. The origin of the ores has been explained as sedimentary in the same manner as in the case of the occurrences in India.

The manganese ore deposits of Långban, Sweden, are to a certain degree mineralogically comparable with those of the Simsiö and Vittinki areas, but their genesis is different. The occurrence of the ores is similar to the occurrences of the general metasomatic iron-ore deposits of Sweden in connection with leptitic rocks. The origin of the manganese ores has been explained according to this in the same manner. Dolomites occur as associated rocks (Magnusson 1924, Beyschlag-Krush-Vogt 1922).

In the manganese bearing ore deposits of Franklin Furnace and Stirling Hill, New Jersey, zinc is characteristic, building minerals such as jeffersonite, willemite, franclinite and ropperite. Limestone occurs as an associated rock. A metasomatic origin of this deposit has been assumed by different authors.

The comparison of the Simsiö area with the known iron-manganese ore deposits indicates many analogies and supports the assumption which would seem most acceptable also from the results of the present study, viz., that the accumulations of manganese minerals are of a sedimentary origin. Manganum and part of the iron have been originally deposited from bicarbonate solutions as carbonates, together with quartz sand. Another part of the iron has been precipitated as oxides or hydroxides, and this part is now present as the iron ore accumulations occurring in separate places and not directly associated with the manganese-iron silicates. The manganese and ferrous carbonates, again, have reacted with silica, but not the ferric hydroxides. The manganese silicates have accumulated during the metamorphism. The occurrence of abundant diopside indicates that the cement of the original sandstone has been dolomitic. The mode of its occurrence — lenticles and layers — shows that also the compounds of the diopside have been very mobile during the metamorphism, but not to such an extent as the iron manganese silicates.

Petrofabrics of quartz.

Interpretation of the undulose extinction and the Böhm lamellae. In 1906 Trener noted that in dynamically metamorphosed rocks from the valley of Tonale quartz crystals generally show an orientation of axis c approximately perpendicular to the schistosity. In 1911 Sander found a similar tendency in some quartzites in the Tyrol and he named this type of orientation the »Trener α-rule». These first orientation observations were made by means of a gypsum plate. Trener carried out the first observation of the orientation phenomenon, but Sander investigated it and showed that the Trener rule was only one type of quartz orientation and also that it is rather uncommon in tectonites. He found that axis c more commonly lies parallel to the schistosity, which type of orientation he named the »γ-rule», the axis of quartz standing perpendicular to the linear structure of the rock, or tectonic 'b'.

The various types of quartz orientation are different, according to the deformation by which the rock has obtained its present structure. The orientation generally belongs to the last period of deformation but also traces from an earlier period may be visible. The second fabric is then »overprinted» upon the earlier one. The first stage of the deformation we can see in an undulose extinction of the quartz grains, as several investigators have admitted. If we follow the development of a deformation and orientation process we must find traces of it in single quartz grains. If the consequence of the deformation, the lattice orientation, is of various types, the whole process and also the development of the undulose extinction may be different. Sander distinguishes two types of quartz deformation, a ruptural and a plastic deformation. The former is connected with translation parallel or subparallel to the prism faces. Sander (1930, p. 175) writes: »Die Zerlegung in Stengel nach c (wie sie die rupturelle und wahrscheinlich jede undulöse Auslöschung des Quarzes kennzeichnet) und minimale Verlagerung dieser Stengel bzw. ihres c gegeneinander ist die einzige Antwort des Quarzes auf ganz verschieden gerichtete Durchtrennungen». Sander has measured the angle between these ruptures and the vertical axis of grains as varying from 0° to 6° or 12°. The orientation rule of quartz is called in this case »prism rule».

In the Pre-Cambrian of Finland I have found quartzites which show well developed orientation according to the Trener α-rule. This discovery caused a closer investigation of this kind of orientation process. In this investigation I started from an elaborate scrutiny of the deformation of individual quartz grains and found that this mode of orientation process is in close connection with the plastic deformation of quartz.

The plastic deformation of quartz is connected with the Böhm striations. In 1885 Böhm, a German geologist, noted fine striations on several quartz grains of a gneiss from Wechsels (Böhm 1883). The character of these Böhm lamellae has been interpreted by some writers as a system of fine lamellae (Fischer 1925), by Judd (1888) as twinning lamellae, and by some as liquid or gas inclusions (Böhm 1883, Becke 1924). In both cases they were regarded as the result of gliding (Mügge 1892, Becke 1924, Fischer 1926, Sander 1911, 1928). Fischer regards the crystal faces (0001), $(10\bar{1}1)$, $(01\bar{1}1)$ and probably still more obtuse rhombohedral faces as possible gliding planes. Sander (1930, p. 178) has measured the inclination of the poles of the lamellae to the optic axis of quartz and has found it to be on an average from 20° to 23° in the date-quartzite from Krummendorf, Silesia and in mica-schists. According to his measurements Sander assumes the crystal faces $(01\bar{1}3)$ and $(01\bar{1}2)$ to have acted as gliding planes during the deformation process (Sander 1928, p. 20; 1930, p. 178).

The optic orientation of quartz connected with this translation after the Böhm lamellae is called »basal» or »rhombohedral rule». The orientation of quartz grains shows in the latter case a close correspondence with that of calcite and, on the other hand, the rocks which show similarity with calcite in their orientation are deformed after the rhombohedral rule, even if there is no visible evidence of Böhm lamellae.

In the case of plastic deformation, strongly undulose extinction and ruptures may occur together with Böhm striations, but the latter are found also in quartz grains which have only a very weak undulose extinction or which show no undulosity at all. The Böhm striations are in this case regarded by several investigators as relict liquid or gas inclusions. They appear as darker streaks just before extinction. All these Böhm striations are seen more distinctly and as smaller streaks on sections which are parallel to the c-axis.

Examination of individual quartz grains by the U-stage throws further light on the deformation process which gives rise to the Böhm lamellae. Investigations of this kind were made on quartzites in which the quartz grains show Böhm striations and an undulose extinction. Some of these quartzites were orientated but some were not. The method of examination applied by me is in short as follows: The position of the c-axis is measured by means of the U-stage in different points of undulose quartz grains. The method of marking the axis is the same as in the marking of folding axes on the map. Fig. 2 (Pl. I) shows such a map of axes made from one quartz grain in quartzite from the hill Petäjänvaara in Rovaniemi. A photograph of the same grain is reproduced in fig. 3 (Pl. I). The direction of a mark corresponds to that of the c-axis and its length characterizes the pitch or dip of the same axis. The angles are multiplied by three to make the marking clearer. Whenever this has been found necessary in the following figures, it has been notified in the explanation under the figure.

Fig. 5. The varying directions of the c-axis in a strained quartz grain.

The Böhm striations are seen in the photo as darker streaks perpendicular to c. In fig. 2 (Pl. I) they are marked with lines. Ruptures which we can also see in the photo are drawn with finer lines. The comparison of the »map of axes» with the photo shows that the c-axis has a constant direction along the »waves» (i. e. the lines of the same extinction) of the undulose grain. In this grain it has also a constant dip, but in most quartz grains the dip is variable. Perpendicular to the waves the direction of the c-axis varies, being the same at certain intervals. The dip of the axis shows a tendency to a similar recurrence. If the dip remains constant, the variation of direction may be marked as shown in fig. 5.

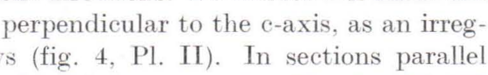


Fig. 6. The varying pirections of the basal pinacoid in the quartz grain of fig. 8.

As we see, the position of the basal pinacoid varies regularly, as if this crystal face had been folded (fig. 6). In short, the undulose extinction of this type may be regarded as the folding of the basal pinacoid. As the directions of closest packing $[2\bar{1}\bar{1}0]$ on the basal pinacoid are equal, every section parallel to the c-axis shows a similar curving. The folding is consequently equal in different directions. We can see this under the microscope in sections nearly perpendicular to the c-axis, as an irregularity in the strain shadows (fig. 4, Pl. II). In sections parallel to c this fact causes the variation of the axial dip. Fig. 5 a (Pl. II) shows a quartz grain in a blastopsammitic quartzite of »Jatulian» type from Maaselkä, Aunus, and fig. 5 b [Pl. II] the axial map of the same grain. The turning of the c-axis is regular and also the undulose extinction. We can see one strain shadow sweeping over the grain by turning the thin section under the microscope. The dip of the axes varies and indicates a distortion of the basal pinacoid in a perpendicular direction or its projection in this plane. If we construct a crumpled basal plane perpendicular to the c-axes this basal plane resembles a hilly landscape.

Along the ruptures the direction of the c-axis varies suddenly and, according to it, also the position of the basal pinacoid. In fig. 7 this variation is shown schematically, and the ruptures are marked by lines. The line which symbolizes the directions of the basal pinacoid seems to be broken on the lines of the ruptures. According to this, the ruptures in the case of plastic deformation may be considered as breaks in the folded basal pinacoid. The lattice of the quartz crystal is flexible up to a certain limit and when this limit has been passed the lattice breaks off.

The assumption of the folding or crumpling of basal pinacoids postulates a gliding plane along the same crystal face. This supposition has earlier been put forward by several authors in connection with the problem of the Böhm striations (see p. 32). Mügge and Fischer regarded the Böhm striations formed from liquid or gas inclusions as relicts that are seen in quartz which shows no undulose extinction. The striations, the directions of which differ from that of the basal pinacoid, are considered as traces of rhombohedral gliding. Now my observations seem to indicate that in certain cases also they may be relicts and traces of an earlier position of the basal pinacoid. Fig. 6a, b (Pl. III) grain 2 shows an evidence of this. We can see here that Böhm striations are perpendicular to the ruptures and waves of the undulose extinction belonging to the earlier deformation. Axis c of the quartz grain of the present shape forms an angle with the earlier direction of the same axis. Generally the position of the basal pinacoid forms rather small angles with Böhm striations and we can suppose that the same deformation which had formed the Böhm striations, later on caused the turning of the c-axis to its present direction.

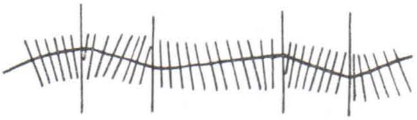


Fig. 7. Variation of the c-axis in the presence of ruptural strain shadows.

In fig. 7 a, b (Pl. III) we can see marked strain shadows and Böhm striations, which differ in largest extent from the direction of the basal plane. On the left hand side there is only one series of Böhm striations, but on the right hand side two series are visible, and a narrow zone between these two parts contains all three series. If these striations are formed by gliding along the rhombohedral faces or the basal plane, a later deformation must be assumed in any case, as the direction of the present rhombohedral faces as well as that of the present basal plane deviates from the Böhm striations. Moreover, this deviation has different values in different parts of the quartz grain, indicating that the deformation, which has turned the c-axis to its present direction, has not disturbed the relict Böhm striations. This was observed in many other cases — as for instance in a quartz grain from the quartzite of Vaaksaus, Suojärvi (fig. 8a, b, Pl. IV) — and it seems to be a general rule, that the positions of the streaks are not affected by the strain which causes the marked deviation of the optic axis from its original position. This fact indicates that the material in the orientation of quartz is not moved, as a whole. (Cf. also fig. 10 p. 39)

Thus the mechanics of the deformation of the quartz may be interpreted as follows: When strain first acts upon an undeformed quartz lattice, gliding along (0001) takes place, but only to a limited extent, as the translations in the quartz lattice are slight. This gliding is connected with glide-folding and unruptural strain shadows. In the continued deformation there appear Böhm striations or ruptural strain shadows, or both together. In the case of Böhm striations the gliding causes a feeble breaking of the crystal lattice. Probably owing to the screwlike structure of the quartz this breaking may give rise to the cavities now seen in the striations.

When the mechanical strain, or deformation, grows stronger, fractures appear perpendicular to the Böhm lamellae and gliding along the prism faces begins. In other cases the gliding along (0001) has taken place in the beginning of deformation only to so limited an extent that Böhm striations do not appear at all. During the continuation of the deformation the quartz lattice breaks also in this case into needles parallel to the c-axis.

This breaking seems to be the process in which the quartz lattice is able to »turn its front». This turning of front may take place in such a way that one or another of the three preferred translation directions turns parallel to the glide direction caused by a shear (Schmidt 1932, p. 174). The Si-atoms build the lattice planes of the closest packing parallel to the gliding and one or another of the gliding surfaces is formed, subparallel to the shear surface.

The characters of the gliding parallel to (0001) and parallel to the prism planes are different. In the former case the gliding at first seems to proceed smoothly and to be accompanied by glide folding (undulose extinction), but soon it causes broad streaks of twinning along rhombohedral faces or broken zones in the quartz lattice (Böhm striations), whereas in the latter case breaks appear as fine ruptures parallel to the c-axis. The friction in the translation along (0001) seems to increase to such an extent as to set a limit to gliding in this plane, and it is probably at this stage that breaking takes place instead of continued glide-folding. Breaking parallel to the c-axis is probably connected with the strength properties of the quartz. As the crushing strength of quartz is smaller parallel to c than normal to it, a breaking into needles soon appears when the shear grows stronger. The gliding strength of the quartz has not been determined, but probably it should be smaller perpendicular to c than parallel to it, if the Böhm striations are traces of gliding, as supposed. Besides immediate breaking of the lattice, gliding along the prism faces in the direction [0001] must be assumed.

The breaking of the quartz lattice into needles has been assumed previously by Sander (see p. 31) and Johnsen (1926, p. 168). Johnsen writes: »Ich erkläre mir das Zustandekommen der Trenerschen Gefügeregel (Hauptachse des Quarzes annähernd senkrecht zur Schieferung) etwa so: Ein Quarzkorn geht bei Schubbeanspruchungen in gefaltete Gleitlamellen über, die entsprechend der sogenannten Böhmschen Streifung ungefähr parallel der Basis orientiert sind, so dass die Basis annähernd parallel der Schieferungsebene des Gesteins liegt. Mit der Fältelung der Lamellen sind Spannungen verbunden, so dass bei der folgenden Rekristallisation jede Gleitlamelle in ein Aggregat von Quartzkristallen zerfällt, deren gegenseitige Grenzflächen zirka parallel der Faltungsachse liegen müssen und die, ebenso wie die ursprüngliche Gleitlamelle ihre Hauptachsen (optische Achsen) mehr oder weniger senkrecht zur Schieferungsebene gerichtet haben».

Which of the two deformations — plastic or ruptural — takes place depends upon the geological circumstances and in many cases both occur at the same time. In the occurrences of quartzites in the Pre-Cambrian of Finland both types are represented. The quartzite of Simsiö 4a is an excellent example of quartzites which have undergone a plastic deformation; in the quartzites of Western Lapland the prism faces have acted as gliding planes, and in the quartzite of Vittinki, Ostrobothnia, traces of the plastic deformation are visible, but intensive shears have caused also ruptural glidings.

An examination of the character of Böhm striations has shown them to be liquid or gas inclusions. Fig. 8 shows schematically the quartz grain No. 1 of figure 6 b (Pl. III). The darker streaks are filled with inclusions which (500 × magnified and illuminated by a beam of strong light) appear like foam, while the lighter positions, showing a higher birefringence, are without inclusions. The striations are irregular and form an angle of about 20° with the basal plane. No other series of Böhm striations can be seen in this grain.

In several cases there occur Böhm striations which are evidently due to translation along the rhombohedral faces. Thus in the quartzite of Vittinki (fig. 9a, b, Pl. IV) two series of Böhm striations form an angle of about 85°, which corresponds to the angle $(10\bar{1}1) \wedge (\bar{1}101) = 85°46'$ (Niggli). The present basal plane (A in fig. 9) forms an angle of 26° with the supposed rhombohedral faces I and an angle of 82° with face II. The basal plane and also the c-axis had earlier — according to the supposed rhombohedral faces — another position. In those cases in which the Böhm striations are recognizable, we can determine the original position of the c-axis and from this and its present position we can follow the re-orientation of individual quartz grains and consequently also the forming of the orientation of the rock. These Böhm striations are, however, visible only in very few grains and usually there is only one series of them. If this series forms an angle with the basal plane, one cannot establish whether it is a trace of the original basal plane or of a rhombohedral face.

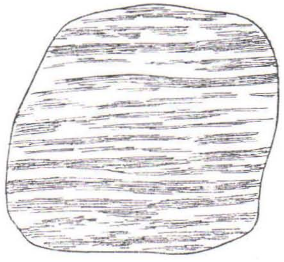


Fig. 8. A schematic picture of the Böhm striations, Petäjävaara, Rovaniemi.

In the quartzites now examined there are no traces of external rotation of quartz grains visible. Moreover, the crystalloblastic structure and curved boundaries of the grains seem to give evidence to the contrary, viz., that it has not been possible for them to rotate. Consequently, if the grain has not been in a favoured position when the strain has acted upon it, it has undergone an intragranular deformation. In this deformation the quartz lattice is re-deformed, so that one or another of the three directions $[0001]$, $[2\bar{1}\bar{1}0]$, $[2\bar{1}\bar{1}3]$ of readiest gliding assumes a position parallel to the glide direction. The process of this deformation seems to be as follows:

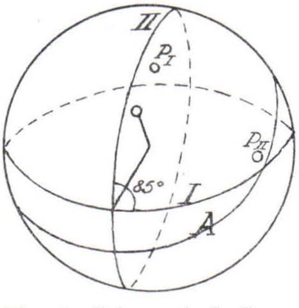


Fig. 9. Schematical figure showing the positions of the Böhm striations and the basal pinacoid, Vittinki.

1) A glide-folding parallel to (0001), visible in plastic strain shadows.

2) a. Breaking of the lattice according to the Böhm lamellae. Plastic deformation.

b. Breaking of the lattice parallel to the c-axis. Ruptural deformation.

1) and 2) a may occur together in nonorientated rocks and also in the presence of a well developed orientation. In the latter case a shear belonging to a later period of deformation has caused these

processes in a rock which was previously orientated. The orientation process is always connected with 2) b but it may take place in two ways, viz.: 1) and 2) b occur together, or 1), 2) a and 2) b are all represented. The former case is the ruptural deformation. Gliding has taken place along the prism planes. In the latter case a gliding along (0001) acts first and gives rise to Böhm lamellae. These lamellae break into needles which arrange themselves so that the quartz grain reaches a favoured position and may begin to yield by gliding. The Böhm lamellae remain as streaks consisting of liquid or gas inclusions as an evidence from an earlier stage of deformation. Thus the gliding along (0001) and rupturing along [0001] seem to constitute the process which makes the quartz able to »turn its front» and consequently makes the orientation of quartz possible in those cases when external rotation cannot take place.

Petrofabric diagrams of the Simsiö quartzite. Dimensional orientation of quartz-grains is visible only at a few places. The quartzite is mostly coarse-grained, nearly glassy, as described earlier, but already an examination with a gypsum plate gave evidence of an optic orientation. Because γ is mostly perpendicular to the schistosity, the sections for orientation analysis were made parallel to the schistosity. The measuring was performed with a Universal stage of Leitz by means of the method described by Berek (1924). The data are recorded on an equal-area projection, so, that the points are plotted on the upper half of the theoretical sphere, not on the lower half. The contouring of diagrams was done with a one per cent circle and by means of the method of W. Schmidt (1925 b). The symbols used for the contoured areas are shown in fig. 18, Pl. VIII.

The diagrams drawn on map III have been rotated constructively into the horizontal plane. Some of these diagrams, viz. D.S. 4 b, 4 c, 9, 28, 30, are represented also in their original position parallel to the plane of the schistosity. The strike and dip are shown by great circles.

D.S. 4 a. The quartzite at point 4 a is a blue-coloured, glassy variety in which the strike is visible only as an arrangement of a few graphite scales. The boundaries of the quartz grains are curved and fringed.

Böhm striations penetrate the whole rock in the direction which forms an angle from 35° to 45° with the plane of the schistosity.

They consist of gas or liquid inclusions and appear as darker, irregular streaks (fig. 10, Pl. V). The Böhm striations are mainly parallel to the basal plane or form only small angles with it. In fig. 11 (Pl. V), from point 1, the striations are broad and the lighter lamellae between them narrower than the striations themselves. In another section from the same outcrop the Böhm striations appear regularly parallel to the basal plane and they show a wave-formed curving, as seen in the schematical fig. 10. Fine shear-joints appear at the points of steepest curving. Similar shear-joints parallel to the basal plane were found also in grains in which no Böhm striations are visible. They show a similar curving and are partly healed. The cleavage-lines, as well as the Böhm striations, indicate a gliding parallel to the basal plane. Glide lines arrange themselves paraller to the directions of maximum resolved shear. In the case of 4 a $[2\bar{1}\bar{1}0]$ may be parallel to s_2.

The position of the main maximum of D. S. 4 a differs about 35°—55° from the 'ab'-plane. The angle between the Böhm striations and the basal pinacoid varies from 0°—25°, being, however, in some grains about 30°. Several grains show also another series of Böhm striations, forming an angle of from 110° to 120° with the former series. The poles of these grains arrange themselves in the 'ab'-zone of the diagram. Böhm striations appear in these cases parallel to the rhombohedral faces. One of these series is parallel to the same gliding, s_2, which has caused the Böhm striations parallel to the basal plane in those grains the poles of which are comprised in the main maximum. As one degree of freedom is left, two maxima appear symmetrically about 'a'. A gliding parallel to s_2 has caused also the orientation of some grains with their prism planes parallel to this gliding. The poles of these grains are in the same point as the main maxima in the neighbouring points 4 b, 4 c and 5.

Fig. 10. Böhm striation with shear-joints, Simsiö 1. Magn. about 500 diam.

At point 4 b (D.S. 4 b, Pl. VIII) the shear parallel to s_2 is visible in the arrangement of small quartz grains and in the quadrangular shapes of several quartz grains. The strain shadows are ruptural. Relict Böhm striations appear very weakly in some grains. In this case plastic deformation has probably been dominant at the begining of the deformation process, but later shear has caused the breakning of the crystal lattice and gliding parallel to the prism faces has taken place. The Böhm striations are evidently due to translation in the direction of s_1, which was another glide direction also at point 4a.

In D.S. 4 c and in D.S. 5 the main shear s_2 has caused the main maxima at points differing about 30° from 'c'. Another maximum is due to s_1. The division of this second maximum of D.S. 4 c (Pl. VIII) into two separate maxima is probably due to a rotational strain. This rotational strain has caused also the elongation of the main maximum at point 4 a. In the central part of Simsiö (D. S. 1, 4 a, 4 c, 5, 9, 31) 'b' has been the axis of rotation.

An alternative explanation of the third maximum in D. S. 4 c is the same as the explanation of the main maximum in diagrams 3, 15, and 17. The main maximum occurs here in the 'bc'-zone about 20° or 30° from 'c'. In the quartzite from point 15 weak Böhm striations are visible in some grains, but mainly the quartz grains show ruptural strain shadows, and gliding along rhombohedral faces can be assumed. Two shear directions, s_1 and s_2, are visible, and the grains have their rhombohedral faces arranged parallel to the shear surfaces.

At point 17 Böhm striations appear in some grains parallel to s_1. The quartz grains have their rhombohedral faces parallel to s_1 and s_2, which are visible in a section perpendicular to 'b'. Ruptural strain shadows are very marked (fig. 12, Pl. VI).

In D. S. 1 the two principal maxima and one sub-maximum are situated near to 'c'. Two other sub-maxima lie near to 'b'. The quartz shows distinct Böhm striations parallel to the basal plane. The structure of these striations is different from that of the earlier cases. Fig. 11 shows this schematically. The size of the inclusions varies regularly, so that all the bigger inclusions are situated along the streaks which form an angle of about 60° with the Böhm striations. Shear s_1 might have caused Böhm striations parallel to these streaks. Another gliding has taken place parallel to s_2 and caused the overprinted Böhm striations and only partly obliterated the former streaks — due to s_1. The angle between s_1 and s_2 is about 60° and the main maximum is also here formed by s_2.

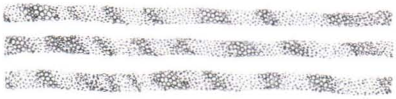


Fig. 11. Böhm striations, Simsiö 1. Magn. about 1000 diam.

In all these cases the existence of two shears, s_1 and s_2, can be established. s_1, has been in every case weaker. It has caused the Böhm striations in those grains which are orientated with their vertical axis nearly parallel to s_2. The main shear s_2 has caused the orientation according to the prism rule or rhombohedral rule and in two cases (points 4 a and 1) according to the Trener rule.

D. S. 2, 6, 25, 27, 28, 30, 33 and 35 show an inclined girdle perpendicular to the schistosity. The position of the main maximum is variable. In D. S. 6 it is situated near to 'c' in the 'bc'-zone. The quartzite of point 6 shows traces of shearing movements in the direction of the main maximum. In point 2 the quartz grains are elongated parallel to 'b', and it resembles the glassy types with the curved boundaries of their quartz grains. In the former case — point 6 —, as well as in the rocks from points 28, 30, and 31, there are still traces of the clastic structure in the impure boundaries of the grains and in the scattered occurrence of the accessory minerals, viz. diopside and magnetite. The main maxima of D.S. 2 and 6 are situated in a triclinic position near 'c' and elongated in the girdle. A comparison of the structure of the rocks and the diagrams indicates the orientation process to have been similar to that in the central part of Simsiö, with the difference that the rotational strain in these has been stronger. In the neighbouring point 9 the same strain has caused the elongation of the maximum.

In D.S. 28 the position of the main maximum is near to 'a' and in D.S. 31 it has been divided into three separate maxima, one situated near to 'a' and the two other near to 'c'. One of these girdle figures, viz. D.S. 28 is represented also in a position parallel to the schistosity (Pl. VIII). The quartzite of this point is fine-grained and shows the recrystallization to have taken place only to a limited extent, as impure boundaries are still visible in the quartz grains. The orientation is caused by shear in the direction of the main maximum which is situated near to 'a', and the girdle is due to a rotational strain.

The girdles of diagrams 30, 33, and 35 consist of two or three main maxima. The rotation axis is in the plane of schistosity, the axial dip being about 45°. The main maxima are near to 'c'. In D.S. 30 another strain is visible in the division of the main maximum into a girdle parallel to the horizontal plane. This »crossed strain» is evidently the same which has been the main strain in the neighbouring point 31. Or, the maximum belongs to different shears, s_1 and s_2. If this is the explanation, we have here three different shears, s_1, s_2, and s_3. s_1 corresponds to the shear s_1 of D. 4 a and s_3 is caused by the dividing of the shear s_2 into two separate shears. This way of explanation is applicable if we suppose that the main shear s_2 does not coincide with one of the two plaiting shears. In such cases Sander prefers to assume the existence of several shear surfaces and orientation according to the prism rule. In the quartzite of Simsiö traces of one or two gliding directions are visible in the Böhm striations or in the arrangement of the small quartz grains. The basal pinacoid and rhombohedral faces as well as prism faces have acted as gliding surfaces. Schmidt has explained the formation of different orientation types by the orientation of the directions of the closest packing parallel to the glide directions, which he supposes to be parallel to 'a'. This way of explanation seems to be applicable for instance in point 27. A shear surface forming an angle of about 30°

with the plane of schistosity is visible in a section perpendicular to 'b'. The maximum in the 'bc'- zone is caused during this shearing movement by the orientation of the rhombohedral faces $(1\bar{1}01)$ parallel to the shear surface, and the direction $[2\bar{1}\bar{1}0]$ has acted as a glide direction. In those grains which the main maximum near to 'b' comprises, prism faces have probably acted as gliding planes and the same direction $[2\bar{1}\bar{1}0]$ as glide direction. The rotational strain has caused the formation of the girdle and also the inclination of the main maximum. Fig. 13 a, b (Pl. VI) shows a strongly strained quartz grain, typical of the rock from this point.

In Jänismäki the quartzite shows an elongation along the general vertical 'b', but some mica which is present in this rock indicates another 'b', perpendicular to the former, and the orientation analysis of quartz shows a well developed girdle perpendicular to this horizontal 'b' (D.S. 40). This girdle comprises two elongated sharp maxima, one of them situated at 'c' and another at 'a'. In D.S. 39 the same girdle is represented but in an inclined position, the maxima at 'a' and 'c' are divided into two separate maxima, one of them being stronger than the other in both cases. Traces of intensive shears are visible in the irregularly ruptural strain shadows and in the rows of inclusions. The dip of 'b' in the field is 45° N. Another diagram (D.S. 41.), made from the neighbouring small lens, shows maxima in two girdles. The direction of 'b' deviates from its general direction also in the small lens west of Simsiö. D.S. 49 and 50 are from this district.

D.S. 50 shows a girdle perpendicular to 'b', the strike of which is here N. 80° E. and the dip 60° E.N.E. The larger quartz grains are elongated in the direction of the 'b'-axis and their orientation mainly belongs to the 'ac'-girdle, while part of the smaller grains show a more scattered distribution in the diagram. The quartzite at point 49 is more even-grained than that at 50. Petrofabric analysis shows the main maximum at 'c elongated nearly perpendicular to 'b'. It has originally been formed by the main strain acting around 'b' as a rotation axis. In addition, a rotation around 'c' has caused some occupation of the 'ab' zone in an asymmetrical position according to the elongation of the main maximum. Also in D.S. 50 occupation is seen in the 'ab'-girdle and in this case it is due to the smaller quartz grains, as mentioned above. The alternative explanation in this instance may be that the orientation process of the 'ac'-girdle has not acted on the smaller grains so completely as on the larger ones.

Paasinmäki: Between the larger strained quartz grains there are clusters of smaller, unstrained grains, which show a welldefined orientation similar to that of the larger grains (D.S. 46 a and 46 b). A similar tendency towards recrystallization is common in the grain boundaries of metals when cold-worked (Andrade 1936, Rüger 1933). A disturbing influence causes in the grain lattice the formation of a point from which the growing of a new crystal begins. In recrystallization of this kind disturbance of the orientation is to be expected. As the small grains, however, show an orientation similar to that of the larger crystals, the orientation process must have taken place later than the recrystallization or contemporaneously with it.

The minor constituents of this rock are calcite, magnetite, biotite and apatite.

As a whole, the larger quartz grains of this rock show, under the microscope, traces of strongly mechanical deformation which evidently has taken place later than the recrystallization of these grains. Probably the boundaries of the quartz grains were granulated during this deformation process. Shear surfaces are visible in lines of inclusions. The direction of these lines is parallel with the elongation direction of the quartz grains and consequently parallel with 'b', which here stands vertical, as usual in the Simsiö area. This quartzite resembles the rock of locality 27 upon the Simsiö hill with its strongly strained quartz grains. The position of the quartzitic rock 27 in the tectonics gives an explanation of this kind of deformation. Situated at the point of a great distortion in the fold, there must have been greater shearing movements than in other localities. With their asymmetrically situated main maxima the diagrams of both these rocks show some resemblance to each other.

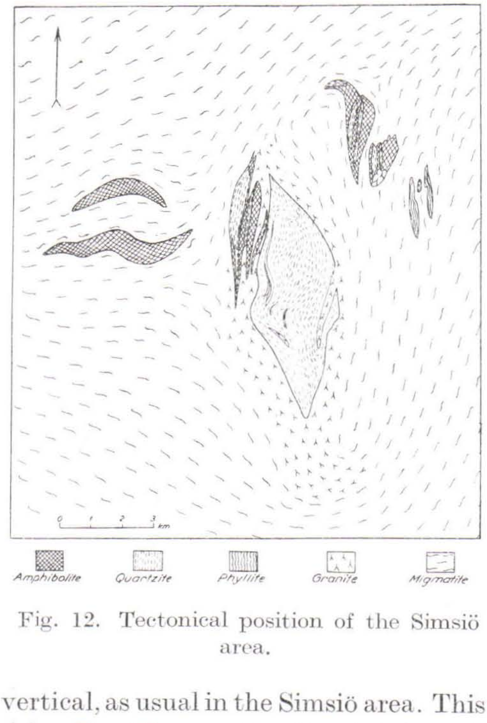


Fig. 12. Tectonical position of the Simsiö area.

The sketch map, fig. 12, shows the tectonical position of the Simsiö area. The quartzite lenses are situated as »inclusions» in the central part of a migmatite fold. The tectonic axis 'b' stands vertically and the direction of strike forms S-lines, so that west of Simsiö they coincide with the direction of the general Svecofennidic strike, which is E.-W., but on the eastern side they are S.-N. arching to N.-E. The quartzite lens of the hill Simsiö seems to have assumed its shape in this folding movement of the migmatites. In the southern part of the quartzite lens the strained shearing movements have been dominant, as appears from the diagrams, which show girdle orientations. In diagram 31 the girdle is nearly horizontal, indicating the 'b'-axis to be vertical. Mainly the axis of the girdles forms an angle of about 45° with the vertical direction. In the central and northern parts of the Simsiö hill stress seems to be connected with shear. The original position of the Simsiö lens may have been E.-W. In the beginning of the migmatite folding the stress in the direction of the original bedding has caused some folding in the quartzite. In the course of the folding the southern end of the lens has turned to its present position and caused the girdle-orientation of the quartz. The orientation of the central and northern part according to the Trener α-rule is partly due to the folding movement which took place in the beginning of the folding and continued during its course, and partly to the recrystallization under stress which has probably acted during the folding. This folding is now seen in the smaller and also partly in the larger folds in the strike of the Simsiö quartzite. The position of the lens in the migmatite fold indicates the possibility of stress having acted from a westerly direction. In the structure of the Simsiö quartzite the existence of two shear directions, s_1 and s_2, in inclined positions to the direction of this stress, gives evidence to the same effect. The direction of the shearing movement of the folding process coincides with another of these plaiting shears (Sander 1930, p. 220) viz. with s_2, which therefore has acted as the main shear.

The maxima at 'c' show a tendency to elongate in the 'ac'-girdle, or there are two or three maxima near to 'c' in the same girdle. This girdle may be due to the folding process, and the forming of the main maxima near to 'c' to the stress as well as to the shear s_2.

An alternative explanation of this type of quartz orientation may be the following: The maximum at 'c' has been formed before the folding movement under stress, and its elongation in the 'ac'-girdle later on in connection with folding.

The quartz orientation of the smaller lenses around the northern part of Simsiö indicates shearing movement to have taken place in them, but the quartzite of the Simsiö hill has preserved that orientation which it received in the folding. Simsiö forms the central part of the migmatite fold, while the strike of the surrounding small lenses coincides with that of the migmatites. This fact may be an explanation of the forming and preservation of the orientation of the Simsiö quartzite.

The mode of the Simsiö tectonics with their vertical 'b' shows an approximation to the »Schlingentektonik» described by Schmidegg (1936) from the Central Alps of the Tyrol.

The orientation of the Simsiö quartzite can be compared with the orientation of a quartzite from Kurikkavaara, Kainuu district. Väyrynen (1924, p. 397, 1928, p. 27) has described this rock and with a gypsum plate made the observation that the vertical axes of the quartz grains are »perpendicular» to the schistosity. I have made a petrofabric analysis from this rock (D.Ka. 1, Pl. VIII). This diagram shows a well developed rhombic symmetry, representing maxima in the 'ac'-zone near to 'c' and in 'bc'-zone nearer to 'b'.

Megascopically this rock is a light-coloured and distinctly schistose quartzite of Jatulian type, being rich in sericite. Sericite occurs between larger and smaller quartzite pebbles which are plaited in thin sheets. In thin section the separate quartz grains of these plaited pebbles show a similar plaiting. Jointing surfaces are visible as rows of inclusions passing through the whole section. The direction of this jointing is marked by S in the diagram. s_1, s_2 and s_3 shear surfaces are visible as rows of inclusions and in the arrangement and shapes of the grains. Stress has evidently acted in the direction of 'c' and caused several shear surfaces. Prism planes of the quartz grains have acted as gliding planes. The orientation figure on the 'ab'-plane shows an elongation in the direction of 'b'.

In the case of Simsiö one or two maxima near to c appear and the shearing movement s_2 has acted together with stress. The vector field in the Kainuu quartzite is not so complicated as in the Simsiö area. The great number of the shear surfaces is apparent, but probably the same stress perpendicular to 'c' has caused them all. In Simsiö stress and shearing movement have acted together in such directions that they have caused only one or two maxima.

Hentschel (1937) has discussed the formation of the boudinages and — in accordance with Wegmann and Corin — he regards them as having been formed by the plastic country rock having filled the clefts which are formed by tension in the more resistant layers of the rock. The occurrence of the boudinages in the Simsiö quartzite thus affords evidence of the greater plasticity of the quartzite, as compared with diopside and rhodonite. A petrofabric analysis of the quartz from the cleft infilling is shown in D.S. la from point 1 on Map III. The general directions of 'a', 'b' and 'c' are marked in the diagram. 'b' stands vertical. The 'ac'-girdle is well developed and indicates a rotation — caused by a plastic flow — around 'b'. The position of the main maximum coincides with the direction of s_2. Another maximum — weaker occupied — lies symmetrically about 'c' and is evidently due to s_1. Thus the orientation at these points shows traces from the plastic flow as well as from the two general shears of the Simsiö area.

Conclusions. The petrofabric of the Simsiö area is characterized by the following features:

1. The quartz grains have not rotated as a whole.

2. Stress has acted in an E.-W. direction and has caused two plaiting shears, s_1 and s_2.

3. Shear has acted in a N.W.-S.E. direction, which is the direction of the other plaiting shear, viz. s_2.

The consequences of 1 and 2 are as follows:

a) Trener α-rule appears in that part of Simsiö where the stress seems to have been the main component of the vector field;

b) Böhm striations appear in the same part of the area;

and of 3):

the inclined positions of the maxima at 'c'.

Chiefly the Trener α-rule in the Simsiö area is not caused by the gliding parallel to the basal planes of the quartz grains. An evidence of this is visible in 4 a, where the Böhm striations are strongest and in which the basal pinacoid is arranged parallel to s_2 and not parallel to the schistosity. In accordance herewith, the stress ought to cause two maxima symmetrically about 'c', were the basal pinacoids to arrange themselves parallel to the plaiting shears s_1 and s_2 — in the same way as if the prism planes were to do so. Now, this is not the case in Simsiö. Here the rhombohedral faces are parallel to s_1 and s_2 at those points, where the Trener α-rule is most perfectly developed. At some points s_2 has been dominant and has caused orientation according to the prism rule (4 c, 5) and in one case, 4 a, the basal pinacoid has acted as gliding plane. The explanation of the occurrence of the Trener α-rule is to be found from the latter instance. The mechanics of the orientation in point 4 a have probably been as follows: The stress has caused two maxima near to 'c'. The main part of the quartz grains thus had a favoured position before the shearing movement, having their basal planes almost perpendicular to the plane of s_2. When s_2 has begun to act, it has caused gliding parallel to the basal plane, as visible from the Böhm striations. Part of the grains had not their basal planes parallel to s_2; in these cases Böhm striations appear in an inclined position and the breaking of the crystal lattice is visible in the cataclastic structure.

These quartz grains have undergone an intragranular deformation process in which the complete orientation of the rock with the c-axis perpendicular to s_2 — a new 'ab'-plane — is caused. They have »turned their» front parallel to s_2. Consequently, the last orientation process, which causes the complete orientation according to the Trener α-rule, demands a shearing movement in the favoured direction. According to the above, the orientation c perpendicular to the schistosity could be caused in two different ways: 1) By plaiting, and gliding parallel to the 'ab'-plane. 2) By plaiting, in which case the rhombohedral faces act as gliding planes.

Taking into consideration also the Kainuu quartzite, the relations between plaiting and Trener α-rule are as follows:

1. Trener α-rule may have been caused by plaiting (a), but also by other means (b).

2. Plaiting may cause orientation according to Trener α-rule (a), but it may cause also other types of orientation (b).

These two cases are characterized by the following features:

Case 1. a. Two plaiting shears occur. Rhombohedral faces occur as gliding planes. Two series of Böhm striations parallel to the rhombohedral faces may be visible.

b. One shear is dominant. Basal pinacoids are parallel to it and have acted as gliding planes. Böhm striations appear parallel to the basal plane.

Case 2. a. Similar to 1. a.

b. In the simplest case (two plaiting shears), two maxima occur symmetrically about 'c'. Prism planes or basal pinacoids may act as gliding planes. More complicated types of orientation may occur in the presence of several shear surfaces.

Sander (1915) has investigated the Trener α-rule in the old crystalline rocks and the »Schieferhülle» of the Alps, in the granulites from Saxony and in the »hälleflinte» from Sweden and has discussed a mechanical orientation rule in connection therewith.

Probably the type of prevailing deformation depends also upon the temperature, as the properties of the elasticity vary with the latter. (Sonder 1933, p. 482.)

2. VITTINKI.

The quartzite area of Vittinki (No. 2 on Map I) was described by Saksela (Saxén 1925). A geological map (fig. 13) shows the rocks of this district. Biotite-plagioclase-gneiss is of the common type

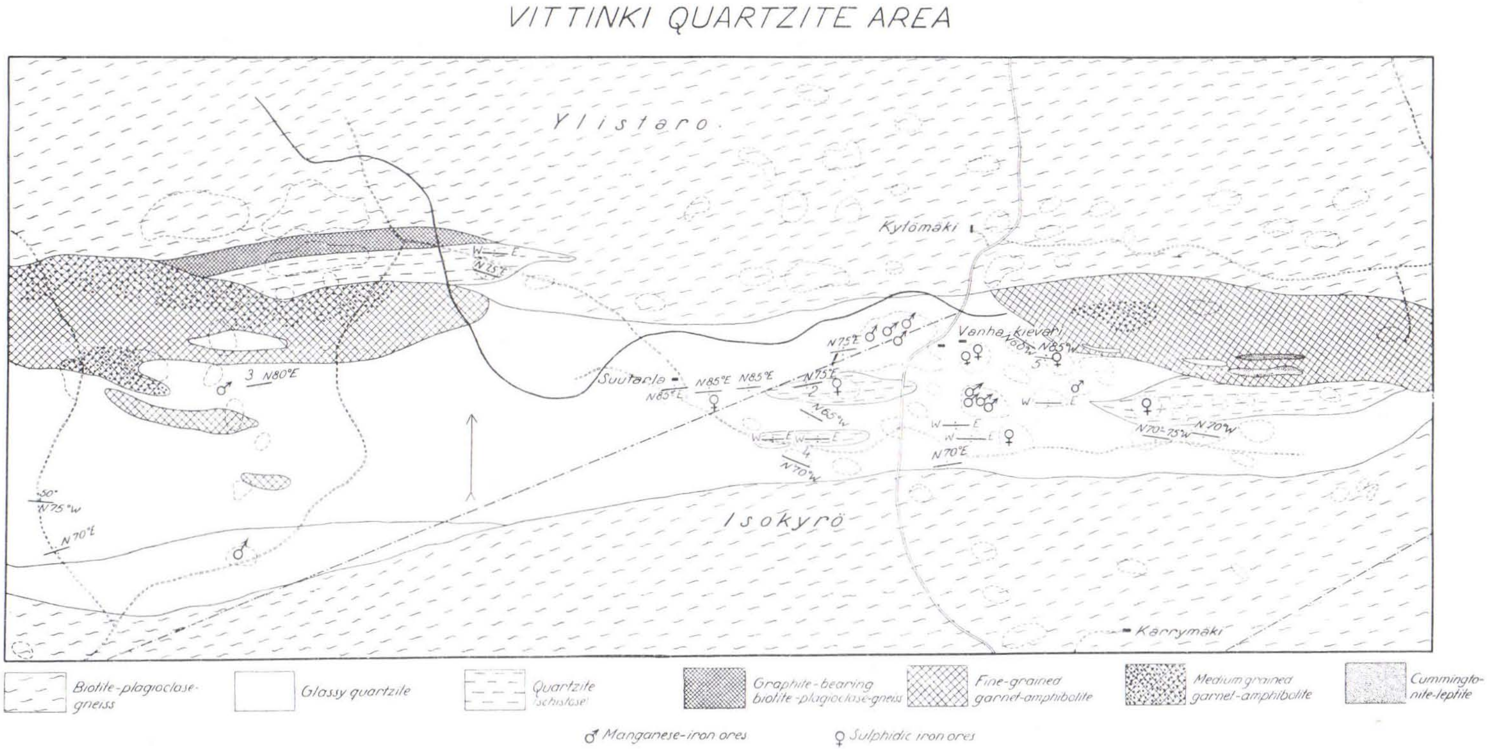


Fig. 13. Geological map of the Vittinki area mainly according to Saksela. Scale 1:25 000

described by Mäkinen (1916) and has a well developed schistosity. Quartz, biotite, and plagioclase are the main components, but occasionally muscovite, sillimanite and microcline occur together with them. Graphite is found in small amounts near Suutarla. The occurrence of minerals containing alumina has been discussed by Saksela in connection with the general problem of the origin of the gneisses.

Cummingtonite-leptite is schistose and consists of quartz, plagioclase (An_{20}), cummingtonite, and biotite. Garnet and magnetite occur as minor components.

Amphibolite appears as coarse-grained and medium-grained varieties. The main components are plagioclase (An_{50}) and green hornblende. Biotite, ilmenite, garnet and a small amount of quartz are found as minor components.

Two types of quartzite are common in Vittinki. The glassy variety prevails and in places it resembles the Simsiö quartzite, for instance in the western part of the area, where only a few outcrops were found. It is a coarse-grained variety, containing only occasionally scales of graphite; the colour is bluish. Iron-ores occur as local impregnations in it. In the central part of the area, near to the main road, the colour of the glassy type is more gray or dark and alternates with a schistose variety. Here the accumulations of iron and manganese ores occur more abundantly, as shown on the map. The schistose variety contains graphite and mica, mainly muscovite, more rarely biotite. It is usually rusty, because it contains sulphidic iron ores.

The petrology of the district has been described by Saksela. Iron-manganese ores are typical of this quartzite area and a great number of manganese-bearing minerals were found, viz. rhodonite, tephroite, knebelite, alabandite, rhodochrosite, spessartite, and vittinkite. Some iron-rich minerals, especially iron hypersthene, and grünerite, are characteristic of the Vittinki quartzite, and siderite is found in trifling quantities, but calcium-bearing minerals are very rare; only a little apatite and calcite were found. In this respect the chemical character of the Vittinki quartzite shows a marked difference to that of the Simsiö quartzites. A comparison of the rhodonites from Simsiö and Vittinki was presented in an earlier paper (Hietanen 1936).

Grünerite occurs as a light yellowish-brown and a dark brown variety. The yellowish-brown type is fine-grained. The refractive indices according to Saksela are $\beta Na = 1.695$, $\gamma Na = 1.678$ and $c{:}\gamma = 16°$ An analysis made by Dr. Naima Sahlbom is quoted overleaf.

Table X.

Grünerite, Vittinki.

	%	Mol.	
SiO_2	51.79	0.8589	
Al_2O_3	0.00		
Fe_2O_3	0.76	0.0048	
FeO	31.91	0.4441	0.7644
MnO	0.90	0.0127	
MgO	9.08	0.2252	
CaO	4.62	0.0824	
Na_2O	0.03		
K_2O			
TiO_2	0.00		
H_2O+	0.68		
	99.77		

This grünerite is richer in magnesia than the grünerite from Nurmo described below.

The quantity of iron ores is considerably larger than in Simsiö. The ores occur mainly in the middle part of the area, where also a great number of old prospecting quarries are situated.

The mode of the ore occurrence is similar to that in Simsiö. Both manganese minerals and iron ores have accumulated, but in different localities. Saksela distinguishes three types of iron ores:

Type I: Fine- and medium-grained pyrite occurs as narrow beds in fine-grained, schistose quartzite. The most eastern occurrence of ores belongs to this type.

Type II: Coarse-grained pyrite and pyrrhotite occur as accumulations in the glassy quartzite. The ore percentage is inconsiderable. This type prevails to the east and south-east of the farm Vanha Kievari.

Type III: The ores, mainly pyrrhotite, enclose smaller or larger pieces of quartzite (breccia structure). This type is found nearest to Vanha Kievari and is the richest of the ore accumulations.

Among the manganese minerals rhodonite occurs most abundantly as lenses and beds in the quartzite, and usually together with magnetite. Both ores are, however, sharply distinguished from each other. The accessory minerals of the Vittinki quartzite also contain iron oxide or manganese, but not together. Knebelite is the only exception, consisting of the iron-manganese silicate, but it is very rare in Vittinki. In this respect we see again a difference between

Simsiö and Vittinki. In Simsiö the iron oxides and manganese are generally present as components of the same minerals, viz., of the rhodonites and pyroxmangites.

The origin of the iron-manganese ores is explained by Saksela in the same manner as the origin of the ores in Macskamezö and India (see p. 29).

The rock at point 5 (fig. 26) is fine-grained and distinctly schistose, containing abundant ore grains and some grünerite, the orientation of which indicates the dip of 'b' in the 'ab'-plane to be 40° E. The strike of 'ab' is N. 85° W. and the dip vertical. D.V. 5 (Pl. IX) shows a petrofabric analysis of this rock. The main maximum is situated at 'a' and it is elongated in the 'ac'-girdle. Weak maxima occur at 'c' and in the locus of Sander's maximum III and IV. The girdle in the 'ac'-zone is perpendicular to the plane of schistosity and it has the tectonic axis 'B' as rotation axis 'b'. Schmidt (1925) has described this type of orientation in the »Mugl gneiss» of the Austrian Alps. He has explained the main maximum at 'a' to be formed by gliding parallel to 'a'. The prism planes have acted as translation surfaces in the quartz lattices and [0001] as a gliding direction.

The elongation of the main maximum as well as the distribution of the poles in the 'ac'-girdle are due to a rotational strain (Sander 1930, Fairbairn 1937). The maximum at 'a' is the locus of maximum shear strain and the rotational strain causes the scattering of the poles.

This diagram shows that there is a tendency to form an inclined girdle in the zone of maxima I and IV. In the folloving diagrams this girdle is also represented and shows an improved development.

D.V. 1. shows a petrofabric analysis of the quartzite from point 1 in fig. 1. The quartzite is here dark gray and medium-grained. Some quartz grains show a well elongated shape in the sections perpendicular to the plane of schistosity. The strain shadows of these are mainly perpendicular to the schistosity, indicating that they belong to the maxima in the 'ac'-girdle. Instead of maximum I, the maxima II are represented, one of them being the main maximum. This division of maximum I into two separate maxima may be supposed to be due to the same rotational strain which as we see has caused the elongation of maximum I in D.V. 5. The maximum near 'c' is lightly occupied and elongated in the 'bc'-girdle. This girdle indicates the action of a crossed strain which has caused rotation around 'a'. The maximum at 'c' may be due to a plastic deformation, as in the case of Simsiö (D.S. 4 a). The Böhm striations are visible in this quartzite mainly in the larger grains and they appear parallel to the basal plane and also in the inclined positions. In several grains two series of them are found. The angle between them corresponds to the angle between the rhombohedral faces $(10\bar{1}1)$ and $(1\bar{1}01)$, which consequently have acted as gliding planes during the deformation.

Several gliding planes are visible in the external structure of the quartz grains. According to the directions of these planes and of the Böhm striations the mechanics of the orientation in the quartzite V. 1 are as follows. Part of the grains have been orientated with their prism planes parallel to the shear surfaces, but another part show a tendency to orientate their basal planes or rhombohedral faces parallel to these planes; and just in these grains the Böhm striations appear. They belong mainly to the larger grains. Consequently in this case both types of deformation have been in action. Gliding along the prism planes as well as the gliding parallel to the basal pinacoid is established by the shear surfaces and the Böhm striations. The friction of the larger grains in intergranular rotation has evidently been greater than that of the smaller ones and therefore they have undergone intragranular deformation. In some grains a deformation like that described in the quartzite of Selkie, Kontiolahti (p. 34), is visible. The angle between maxima II in the diagram V. 1 is about 50°, which corresponds to the angle $(0001) \wedge (10\bar{1}1) = 51^\circ 47^{1}/_{6}{}'$. According to this, those grains the poles of which are comprised in maximum II may have their $(10\bar{1}1)$-faces parallel to the shear surface which passes another of the maxima in II.

Thus the same shear which has formed one of maxima II might have caused the Böhm striations in the grains belonging to another maximum II. The Böhm striations appear mainly in those grains of which the poles are comprised in the maximum at 'c'. In these grains Böhm striations appear parallel to the rhombohedral crystal faces, as well as parallel to the basal planes.

D.V. 2. The quartzite is medium-grained and mainly even-grained. The colour is light gray. Magnetite and some grünerite occur as accessories. 'b' is not visible. The result of a petrofabric analysis shows two girdles. The diagrams of neighbouring points permit the determination of these girdles as 'ac'- and 'bc'-girdles. The main maximum is probably maximum I, and the maxima in the 'bc'-zone are maxima III, which are represented also in D.V. 1.

D.V. 3. Well developed shear surfaces intersecting along 'b', which is also megascopically visible, are characteristic of the quartzite from point 3. The grains show an elongation parallel to 'b'. No

Böhm striations appear in this rock. Maxima near to 'a' and the 'bc'-zone are represented. The minima of axes appear at 'c', dividing the 'ac'-girdle into two separate parts. An inclined girdle comprising I and III is also occupied. The shear surfaces visible in a section under the microscope are marked in the diagram. The 'ab'-plane is the best developed of these and is visible also megascopically The strong maxima in III are apparently formed so that the $(10\bar{1}1)$-faces have been orientated parallel to this shear surface and the glide direction $[\bar{2}1\bar{1}0]$ has been parallel to 'a'. The distribution of maxima II is due to shears s_2 and s_3.

D.V. 4. The quartzite from point 4 is light-coloured and fine-grained. Magnetite occurs as an accessory. The diagram shows one strong girdle and some maxima in an inclined girdle of the zone comprising I and III. The maximum at 'a' has been divided into four separate maxima, two of which are the main maxima in the diagram. The forming of the girdle and the dividing of the maxima can be explained in the same manner as before. In this case we have only an inclined position of the girdles according to the 'b'-axis. This inclination may be caused by the crossed strain which has been in action also at other points, as seen in the common occurrence of maxima in the 'bc'-girdle. Another explanation is that the maxima form two small girdles with 'b' as rotation axis. The formation of the maxima IV and III is the same as before, and the rotation around 'b' has caused two small girdles.

In all diagrams the gliding parallel to 'a' appears to be the most characteristic mode of deformation. This direction in the Vittinki quartzite area lies in a vertical plane, the direction of which is E.-W. The dip of 'a' in this plane varies from 20° to 55° W. This direction has consequently acted as the main direction of differential movements.

3. NURMO.

The quartzite area of Nurmo is marked as number 3 on Map I. Fig. 14 shows a sketch map of this district. The strike is mostly N. 25°—45° W. but arches in the S. E. and N. W. parts of the lens to N. 70—80° W. The folding axis stands vertical, but occasionally deviates from this direction. The phyllites are fine-grained, well-foliated types, and, in contrast to the Simsiö area, they are not rusty. Their colour is light gray and they occur, besides on both sides of the quartzite, as a continuation to that part of the quartzite which is fine-grained and has a well developed schistosity. The amphibolites are megascopically quite normal. The medium-grained type prevails. Hornblende occurs as needles and is orientated along the schistosity. A very coarse-grained variety, however, is found in some outcrops. The grain-size averages from 5 to 15 mm. A great amount of rust indicates a content of sulphidic iron ores. These rocks are situated in the same zone as the ore-bearing quartzite to the S. E. of this place.

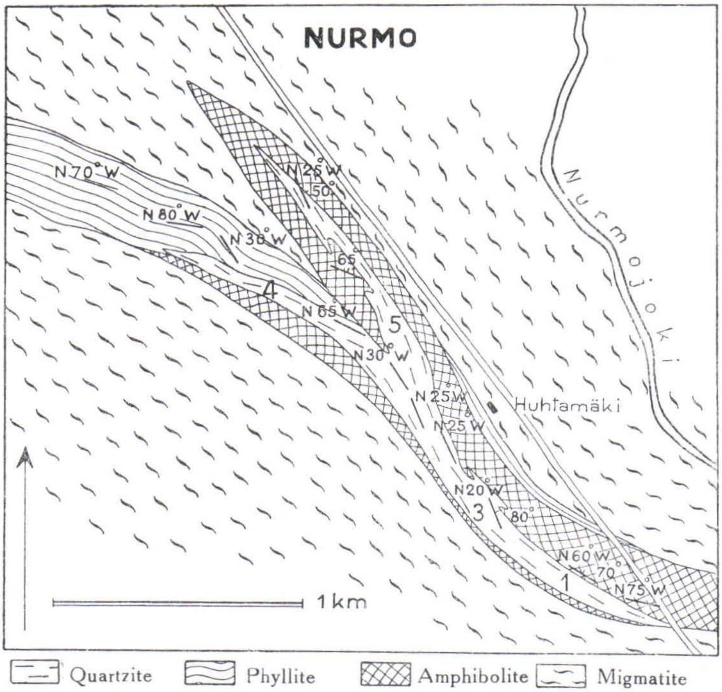


Fig. 14. The quartzite area of Nurmo.

Three types of quartzite are found here: 1. The north-eastern part of the area, point 5, consists of a very coarse-grained, glassy variety, which resembles the Simsiö quartzite in its bright blue colour. This type consists of almost pure quartz, and only a little graphite and a few pyrite grains were found in it. 2. The quartzite on the south-western side, point 3, is fine or medium-grained and is impregnated with ores. The quartz of this type has a well developed lattice orientation as described later. Grünerite appears as a minor component in this rock. 3. In the southern part of the area, point 1, the glassy variety grades over into a more fine-grained, light-coloured variety, showing under the microscope a clastic structure, the cement between the rounded quartz grains consisting of long needles of grünerite (fig. 15). This part of the quartzite lens evidently shows a lower degree of metamorphism than the other quartzite areas in Southern Ostrobothnia. From the advanced metamorphic differentiation which resulted in the accumulation of the diopside and the manganese minerals it may be suggested that the metamorphism in the quartzites of Simsiö and Vittinki has taken place at fairly high temperatures. The grünerite quartzite of Nurmo is in this respect one degree lower metamorphic, as the crystals of grünerite are here scattered between the quartz-grains and probably lie in the positions where they originated at the expense of the primary cement. A petrofabric analysis made from this rock shows that the quartz is quite un-orientated, but the grünerite, which occurs very abundantly in this rock, shows a fairly perfect orientation, with its axis c along the tectonical axis 'b' and (100) parallel to the schistosity.

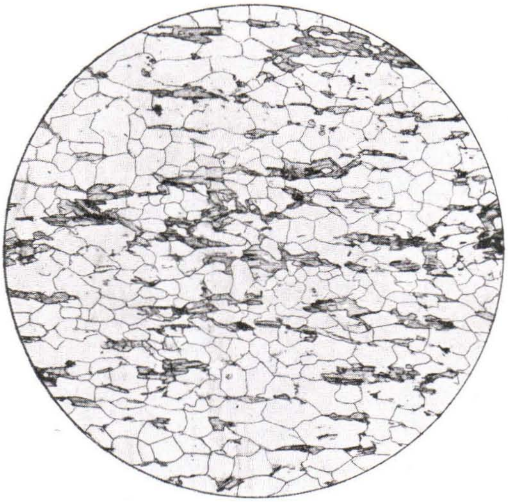


Fig. 15. Grünerite-quartzite of Nurmo.
Magn. 9 diam.

In the western part of the area the quartzite is medium-grained and light coloured as at places in the Simsiö area. Ore minerals, magnetite and pyrrhotite, occur abundantly in a narrow zone in the most western part of the quartzite lens.

As mentioned, the medium-grained, almost glassy variety (2) of point 3 shows an optic orientation. A result of petrofabric analysis is shown in D.N. 3 (Pl. IX). A well developed girdle consists of four separate maxima and is situated in an inclined position. The minimum of axes at 'c' divides the girdle into two separate parts. The comparison of this diagram with D.L. 30 indicates a similar deformation. Axis 'b', of that rotation which has caused the formation of the girdle, deviates about 30° from 'b'. The elongation and dividing of the maxima near to 'c' are probably due to a rotation around 'b'.

In a petrological respect the grünerite is the most interesting mineral of the Nurmo quartzite, being almost the only accessory constituent. Its colour is yellowish-brown. In the separation by means of Clerici solution its specific gravity was 3.452—3.441. The refractive index γ measured by immersion is 1.702, γ—α was measured by means of Berek compensator and it shows a value $\gamma - \alpha = 0.030$. The optic axial angle is measured in thin section by means of the Universal stage as follows $+2\,V = 95°$. $\gamma \wedge c = 15°$. According to these determinations the refractive indices are $\alpha = 1.678$, $\beta = 1.684$, $\gamma = 1.708$.

An analysis of this mineral made by Miss Elsa Ståhlberg is as follows:

Table XI.

Grünerite, Nurmo.

	%	Mol.	
SiO_2	48.96	0.8119	
TiO_2	0.00		
Al_2O_3	0.00		
Fe_2O_3	2.92	0.0183	
FeO	38.16	0.5311	0.7000
MnO	0.12	0.0017	
MgO	5.53	0.1372	
CaO	1.68	0.0300	
Na_2O	0.13	0.0021	
K_2O	0.02	0.0002	
H_2O+	2.42	0.1343	
H_2O-	0.08		
F	0.00		
	100.02		

The amount of calcium is smaller than in the Vittinki grünerite and indicates that the Nurmo mineral is a very pure member of the grünerite-cummingtonite series. The ratio [FeO]: [MgO] is 4.2 according to the refractive indices and the diagram of Winchell. The same ratio from the analysis is 4.18, when MnO and Fe_2O_3 as FeO have been added to FeO.

The precise ratio is seen from the mol. per cent: (Table XII.)

Table XII.

Ratio [FeO]:[MgO] and refractive index γ in the grünerites of Nurmo and Vittinki.

	Nurmo	Vittinki
$FeSiO_3$	80.70 mol. %	67.2 mol. %
$MgSiO_3$	19.30 » »	32.8 » »
γ	1.708 » »	1.695 » »

The corresponding amounts in mol. per cent in the grünerite of Vittinki according to Saksela are shown in the same table.

Thus the grünerite of Nurmo is richer in iron than the grünerites of Simsiö and Vittinki. The amounts of other accessory components are negligible. The quartzite of Nurmo may be regarded as a pure grünerite quartzite and as the variety richest in iron silicates among the quartzites of Ostrobothnia.

An analysis made by Miss Elsa Ståhlberg shows the following composition:

Table XIII.

Quartzite, Nurmo.

	%	Mode	%
SiO_2	88.60		
Al_2O_3	0.25		
Fe_2O_3	0.92		
FeO	7.92	Quartz	77.5
MnO	0.04	Grünerite	22.6
MgO	1.25		100.1
CaO	0.72		
Na_2O	0.13		
K_2O	0.04		
TiO_2	0.01		
P_2O_5	0.00		
H_2O+	0.54		
H_2O-	0.14		
	100.55		

The common occurrence of grünerite in the quartzites of South Ostrobothnia indicates them to have been deposited and recrystallized under similar conditions. The similarity between these is still more accentuated by the circumstance that no grünerite has been met with in any other quartzite area in Finland. The distinction between the iron-bearing silicates of the Ostrobothnian quartzites also seems to be indicated by the same mineral. The quartzite of Nurmo contains only grünerite, and this mineral is here richest in iron. In Simsiö the grünerite occurs in small amounts and always in connection with iron-rich pyroxmangites. The Simsiö grünerite has not been analyzed, but its occurrence together with manganese-bearing minerals gives some hints of a content of manganese. In Vittinki the quartzite is rich in iron oxides, but generally these have not reacted with silica, and also in the grünerite from Vittinki the content of iron is lower than in the grünerites of Nurmo and Simsiö.

4. ORISMALA.

To the north-west from Vittinki, about three km south of Orismala, we meet with a small quartzite area (No. 4 on Map I). The quartzite occurs here as a narrow long lens between zones of amphibolite. The amphibolite is a medium-grained, foliated variety and it is surrounded by migmatites.

The quartzite is granoblastic and medium-grained of a gray colour. It contains narrow beds and grains of iron-rich amphibole and diopside and a smaller amount of graphite. Amphibole occurs very abundantly as long needles parallel to the schistosity.

Both minerals, amphibole and diopside, have been separated and analyzed by Mr. J. J. Carlberg. They show the following compositions:

Table XIV.

Iron-rich amphibole, Orismala.

	%	Mol.	
SiO_2	55.44	0.9194	
Al_2O_3	0.10	0.0010	
Fe_2O_3	0.96	0.0060	
FeO	23.64	0.5863	0.9656
MnO	0.21	0.0030	
MgO	8.36	0.2073	
CaO	9.48	0.1690	
Na_2O	0.65	0.0105	
K_2O	0.01	0.0001	
H_2O+	0.88	0.0489	
H_2O-	0.02		
	99.75		

This amphibolite is rich in iron showing an approximation to the grünerite of Vittinki. The amount of calcium, however, is still larger, indicating a member between the grünerite and ferrotremolite series. Its mineralogy and occurrence together with diopside will be discussed by Mr. J. J. Carlberg in a forthcoming paper.

Table XV.

Diopside, Orismala.

	%	Mol.	
SiO_2	50.86	0.8435	
Al_2O_3	0.00		
Fe_2O_3	1.75	0.0110	
FeO	16.04	0.2232	0.8305
MnO	0.18	0.0025	
MgO	8.34	0.2069	
CaO	22.32	0.3979	
Na_2O	0.00		
K_2O	0.00		
H_2O+	0.31		
H_2O-	0.02		
	99.82		

An analysis of the quartzite by Miss Elsa Ståhlberg indicates the Orismala quartzite to have the following composition:

Table XVI.

Quartzite, Orismala,

	%	Mode	%
SiO_2	84.72		
Al_2O_3	0.43		
Fe_2O_3	0.48	Quartz	71.5
FeO	5.15	Amphibole	14.1
MnO	0.05	Diopside	13.5
MgO	2.04	Graphite	0.6
CaO	4.45		99.7
Na_2O	0.17		
K_2O	0.04		
TiO_2	<0.01		
P_2O^1	0.00		
H_2O+	1.44		
H_2O-	0.12		
C	0.60		
	99.69		

This quartzite contains besides iron and magnesium also a considerable amount of calcium, which mainly exists as a component of diopside. The mineral composition indicates the Orismala quartzite as representing a variety between the diopside quartzite of Simsiö and the grünerite quartzite of Nurmo.

Graphite appears as large scales parallel to the schistosity, as was the case also in the Simsiö-quartzite. This mode of occurrence seems to be characteristic of the quartzites of Ostrobothnia and indicates a great degree of recrystallization.

The strike of the quartzite is E.-W. and the dip 80° S. The direction of the linear structure is 60° E. One petrofabric analysis made of this quartzite area is D. O. 1 on Pl. IX. It shows a one-girdle figure which is general in the narrow lenses of quartzites in Ostrobothnia. The position of this girdle is almost horizontal. The main maximum lies asymmetrically near to 'a'. A light occupation of another girdle, which stands vertically, may belong to an earlier deformation. The axis of this girdle lies horizontally almost parallel to the present main maximum. An alternative explanation to the formation of the vertical girdle is the action of a crossed strain.

5. LAIHIA.

In the parish of Laihia (No. 5 on Map I) Professor Laitakari has found a small quartzite occurrence. As is usual in South Ostrobothnia, the quartzite is here surrounded by amphibolites. Fig. 16 shows a sketch map of this district. The amphibolites are fine-grained, well foliated and join with migmatites. At the southern part a biotite-granite appears in the amphibolite as narrow bands parallel to the schistosity. The quartzite of the larger lens shows a close approxima-

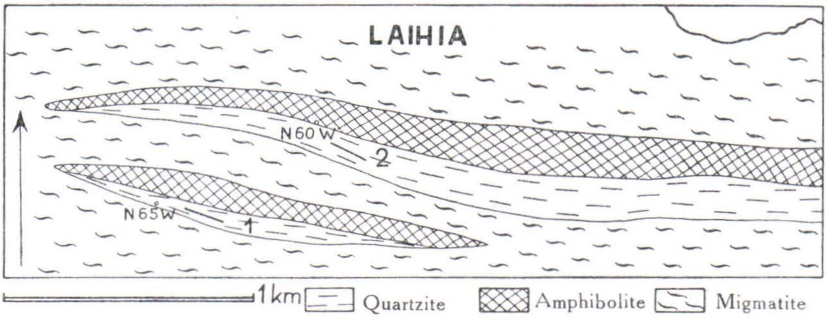


Fig. 16. The quartzite areas of Laihia.

tion to the glassy type of the Simsiö quartzite. It is coarse-grained, consisting of a nearly pure quartz-rock, which contains only a few graphite scales. The colour is bluish or pale. An ore accumulation is situated on the western side of the main road (point 2). The rock of the smaller lens, point 1, consists of a medium-grained, foliated quartzite which contains a small amount of grünerite, magnetite, apatite and graphite, all arranged parallel to the schistosity. An analysis of this quartzite made by Miss Elsa Ståhlberg shows the following result:

Table XVII.

Quartzite, Laihia.

	%	Mode	%
SiO_2	83.90		
Al_2O_3	0.00		
Fe_2O_3	9.96		
FeO	5.83	Quartz	82.1
MnO	0.09	Magnetite	15.3
MgO	0.11	Grünerite	3.0
CaO	0.12		100.4
Na_2O	0.09		
K_2O	0.13		
TiO_2	0.03		
P_2O_5	0.00		
H_2O+	0.12		
H_2O-	0.00		
	100.38		

Another accumulation of magnetite and pyrrhotite occurs in this part of the area. The type resembles the fine-grained glassy quartzite of Vittinki with its gray colour; small magnetite grains are abundantly present in places. The strike is N. 60° W. and the dip 60° S. S. W. The plane of 'ab' stands vertical.

Part of the quartz grains are well flattened and have the shape of narrow sheets arranged in long lines or rows, like the quartz of many granulites of Finnish Lapland. The quartz grains of these lines show an orientation according to the same rule as the smaller quartz grains. D. L. 2 (Pl. IX) shows the result of a petrofabric analysis made from this rock. Two maxima II and one of maxima IV are represented in this diagram. There are two alternative ways of looking for an explanation of same. In this respect we can follow the ideas of Sander or Schmidt. An explanation of the formation of maxima II according to Schmidt is as follows; 'ab' is a gliding plane and the crystal faces $(2\bar{1}\bar{1}2)$ or $(11\bar{2}2)$ arrange themselves parallel to it. The existence of one maximum IV indicates that its formation belongs to another shear. The inclined girdle, in which this maximum is situated, indicates another axis 'b_1'. This direction is seen in the section parallel to the 'ab'-plane as a direction in which some quartz-grains show an elongation. This 'b_1' is probably the axis of an earlier rotation and the shear parallel to the 'ab'-plane has taken place later. This shear has favoured the preservation of maximum IV in the earlier girdle, as the planes $(10\bar{1}1)$ of the crystals, of the poles of which this maximum is comprised, have been parallel to the 'ab'-plane.

Sander favours the idea of the prism surfaces as gliding planes and several shear surfaces. According to his point of view three main shears caused the three maxima, each of them demanding a shear surface. The positions of the maxima determine the gliding directions in these planes. The formation of the inclined girdle in any case demands another 'b_1', and a rotation around it as well as a rotation around 'b'.

This mode of the orientation can be compared to that »B oblique B'» tectonics which Ingerson (1936) has described in a muscovite-biotite schist from Niederthal, Tyrol.

The external structure of the quartz grains shows traces of shear surfaces, s_1, s_2 and s_3 (D.L. 1), of which s_1 is most clearly visible in the arrangement of some small quartz grains. But also the plane 'ab' might have been a gliding plane as well as s_1 and s_2. The formation of the maxima II may therefore be due to a gliding along 'ab' and orientation of the rhombohedral crystal faces parallel to this plane, or to the shears s_1 and s_2. One can also assume that both orientation rules have been in action. The well-developed shear surface s_3 gives evidence that the gliding along prism surfaces has been dominant during the formation of maximum IV.

The quartzite areas of South Ostrobothnia occur in the same west-easterly zone and are surrounded by amphibolites. They represent the oldest rocks in the Svecofennidic mountain chain of Ostrobothnia. The traces from two folding series are visible in the petrofabrics of several quartzite areas, as for instance in the Orismala quartzite, where the dominant orientation, probably belonging to the later folding process, is a horizontal girdle but traces from the former vertical girdle are clearly visible. The »B oblique B'» tectonics of Laihia and Vittinki quartzites give evidence of the same fact. The Simsiö quartzite has got its orientation mainly in this later folding. The folding around the vertical B has been more intensive here than in other parts of this zone, in which the quartzite areas are situated.

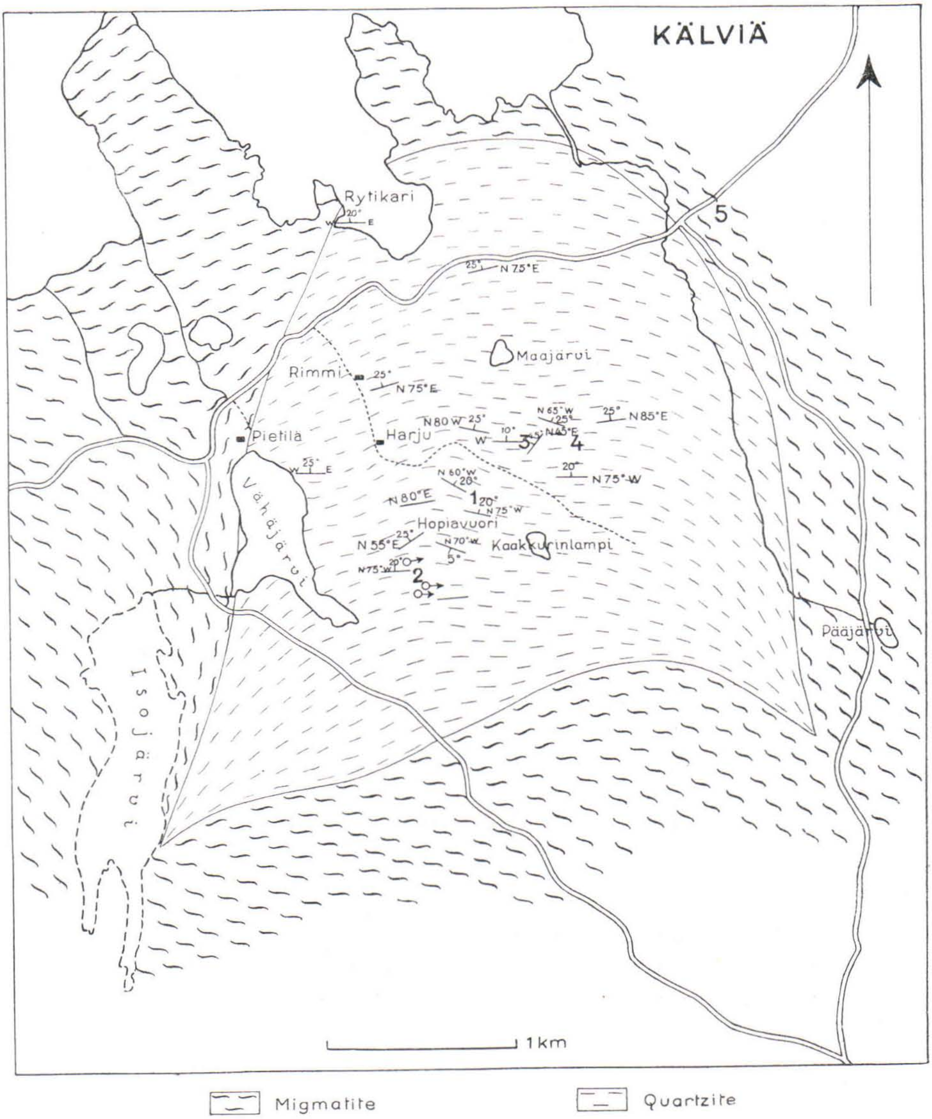


Fig. 17. The Kälviä quartzite area. Contours and surroundings according to Saksela.

6. KÄLVIÄ, CENTRAL OSTROBOTHNIA.

The quartzite area in Kälviä (No. 6 on Map I) comprises one larger outcrop Hopiavuori and several smaller outcrops around it, as seen from the strike marks in fig. 17. The quartzite found in this district in Central Ostrobothnia differs in many respects from the quartzite lenses in South Ostrobothnia. Amphibolites and phyllites, which are general in connection with the quartzites in South Ostrobothnia, are not found in Kälviä. The quartzite rocks are bounded by migmatites on every side of the area. The schistosity is here nearly horizontal, or the dip is from 10° to 25° N. or N. W.

The geological position of this quartzite area with its almost horizontal schistosity and introduced granite masses shows a resemblance to the Gaustafjell region, Norway, described by Wyckoff (1934).

The surrounding migmatites are of the general character described by Mäkinen (1916) and Saksela (1932, 1933). Saksela (1932) has also discussed the tectonics of this district.

The quartzite is fine-grained and light-coloured and looks megascopically clastic. Under the microscope, however, it shows a granoblastic structure. The strain shadows in quartz grains are very weak or absent.

The low temperature metamorphism is apparent from the mineral composition. Among the accessory components clinozoisite is most characteristic. Occasionally it occurs very abundantly and lies between the quartz grains. The refractive indices were measured by immersion as follows: α (min.) = 1.670; β = 1.674—1.681; γ (max.) = 1.691; γ—α about 0.013 and 2 V = 31°—55°. An analysis made by Miss Elsa Ståhlberg shows the following composition:

Table XVIII.

Clinozoisite, Hopiavuori, Kälviä.

	%	Mol.
SiO_2	40.36	0.6693
TiO_2	0.09	0.0011
Al_2O_3	30.67	0.3000
Fe_2O_3	0.61	0.0038
FeO	1.77	0.0246
MgO	0.74	0.0184
CaO	22.62	0.4328
H_2O+	3.50	
H_2O-	0.00	
	100.36	

Zoizite	91.3	mol. %
Pistacite	8.7	» »

Spec. gravity 3.230—3.215

The clinozoisite-bearing variety of quartzite from Kälviä has been analyzed by Miss Elsa Ståhlberg and shows the following composition:

Table XIX.

Clinozoisite-quartzite, Hopiavuori, Kälviä.

	%
SiO_2	68.84
Al_2O_3	13.28
Fe_2O_3	1.33
FeO	1.19
MnO	0.25
MgO	0.59
CaO	4.79
Na_2O	1.99
K_2O	1.28
TiO_2	0.45
FeS	2.61
FeS_2	2.55
MoS	0.01
CuS	0.02
H_2O+	1.24
H_2O-	0.24
	100.65

Mode	%
Quartz	42.6
Plagioclase (An_{34})	22.6
Microcline	7.6
Clinozoisite (Pi_9)	14.7
Chlorite	4.6
Sphene	1.1
Magnetite	1.5
Pyrrhotite	2.6
Pyrite	2.5
Water	0.6
	100.5

Another mineral rich in alumina is plagioclase (34 % An), which appears as grains together with quartz and occasionally gives an arkosic character to the rock. Microcline has partly altered into sericite.

Biotite is a general minor component. In the north-eastern part of Hopiavuori (point 1) it occurs very abundantly in the arkosic quartzite. It is orientated parallel to the schistosity, so that the rock here appears to be gneissose. The amount of biotite decreases gradually in the south-westerly direction and the rock passes over into a light-coloured, blastopsammitic sandstone-like variety which prevails in the whole area. The biotite occurring in this variety is light-coloured. The colour indicates a high content of magnesia in the chemical composition. Muscovite is a general component but appears only in small amounts.

Ore minerals are found as accumulations in the middle part of the area, point 2, especially in the southern part of Hopiavuori and near Pietilä farm. Pyrrhotite is most common, but the accumulations in which prospecting has been carried on have proved very poor also in this ore. Pyrite occurs as grains and as well-developed crystals which show mainly octahedral and cubic crystal forms.

The only similarity between the Kälviä quartzite and the quartzites of South Ostrobothnia is the occurrence of ore minerals in same.

Titanite and rutile are found in small amounts. No petrofabric orientation of quartz can be found in the quartzite of Kälviä by means of a gypsum plate. This area is interesting in respect of the problem of granitization.

The granite which has penetrated the whole quartzite area is of a coarse-grained, pegmatitic type, containing muscovite and occasionally long prisms of tourmaline. The granite can be seen either as smaller and larger masses in quartzite, or it may have penetrated between the schists. The contact between the granite and quartzite may be gradual or sharp. The schistosity has usually its original direction near to the contact or shows a weak curving, as seen in fig. 18. The schist planes of the quartzite show a downward curve in the contact zone. In another place, where the granite also occurs as a band in the quartzite, they show an upward curve.

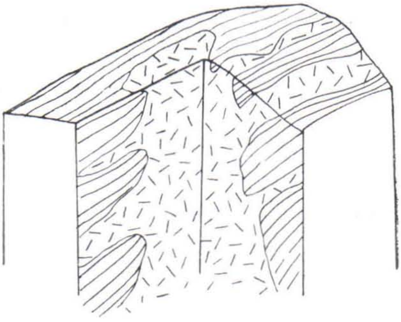


Fig. 18. Granite masses and veins in the quartzite of Kälviä. About $^1/_{100}$ of nat. size.

In both cases the quartzite has preserved its original nearly clastic structure near the contact zone, being sandstone-li and containing its original feldspar as grains between the quartz grains. In many places the granite seems to occur as small lenses in the quartzite, but really it is lying as bands parallel to the horizontal schistosity. Erosion has brought it to the surface of the rock only in part, and other points are still covered with quartzitic schist. Generally the granite masses range from 2 to 10 m in diameter. The breadth of the beds is variable, usually ranging from 20 cm to 2 m.

B. SVECOFENNIDIC QUARTZITE AREAS IN SOUTH FINLAND.

7. TIIRISMAA.

The quartzite area of Tiirismaa (No. 7 on Map I) has been recently investigated and described by Eskola and Nieminen (1938) from

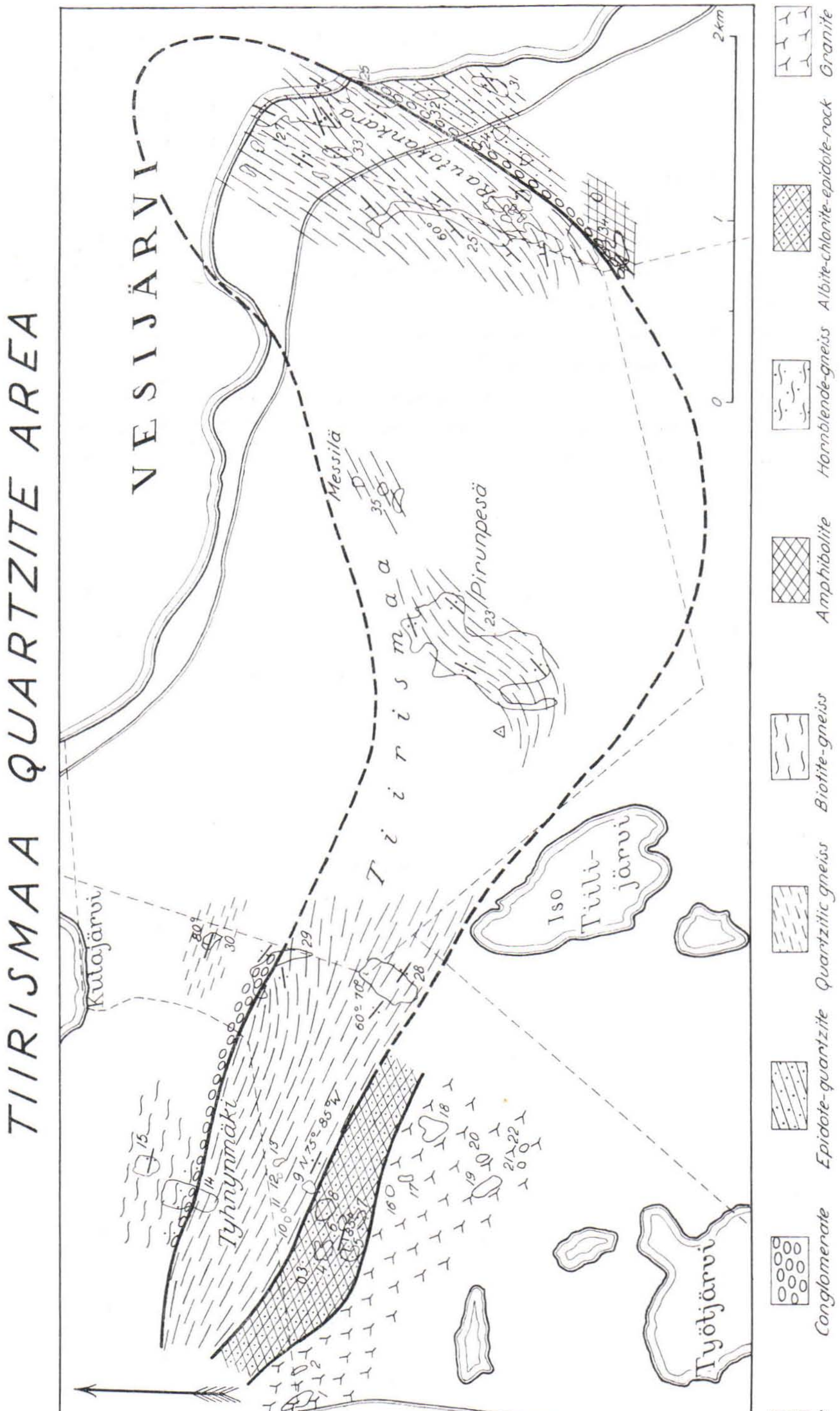


Fig. 19. According to Eskola and Nieminen.

petrological and geological points of view. This quartzite area represents the horizontal section of a lens standing almost vertical. The geological map (fig. 19) shows the rocks of Tiirismaa and the surrounding area. Conglomerates occur in Tyhnynmäki at the west end of the northern boundary of the quartzite, and in Rautakankara, at the south-eastern contact of the same quartzite area. As the conglomerates contain pebbles of the Tiirismaa quartzites at both contacts, they must belong to the same stratigraphical horizon originally deposited directly upon the quartzite. This fact seems to indicate a complicated tectonical folding around an axis which now stands in an almost vertical position. Most parts of the Tiirismaa area consist of sillimanite-quartzite which is reddish in colour owing to pigmentary hematite. The sillimanite quartzite has the following composition (Eskola and Nieminen 1938. The mode was calculated by me).

Table XX.

Sillimanite-quartzite, Pirunpesä, Tiirismaa.

	%
SiO_2	94.52
Al_2O_3	2.38
Fe_2O_3	0.84
FeO	0.58
MnO	0.05
MgO	0.04
CaO	0.00
Na_2O	0.16
K_2O	0.08
TiO_2	0.01
H_2O+	1.15
$H_2O—$	0.21
	100.02

Mode	%
Quartz	83.3
Sillimanite	11.4
Sericite	2.6
Magnetite + Hematite	1.5
Water	1.2
	100.0

The composition of an epidote-quartzite from Rautakankara, belonging to an outer mantle lying stratigraphically upon the conglomerate is according to Eskola and Nieminen as follows:

Table XXI.

Epidote-quartzite, Rautakankara, Lahti.

	%
SiO_2	65.64
Al_2O_3	13.14
Fe_2O_3	5.04
FeO	1.08
MnO	0.08
MgO	2.27
CaO	8.44
Na_2O	0.37
K_2O	0.98
TiO_2	0.85
H_2O+	2.02
H_2O-	0.28
	100.19

Mode	%
Quartz	44.2
Epidote (Pi_{12})	33.2
Sericite	11.3
Chlorite	6.4
Magnetite	2.8
Sphene	2.0
Water	0.3
	100.2

A comparison of the clinozoisite quartzite from Kälviä (p. 65)with this epidote-quartzite of Tiirismaa shows an approximation between the two in chemical composition. Mineralogically the Kälviä quartzite differs mainly in such respect that feldspars are abundantly present and that the Ca-Al-mineral contains more zoisite component. The plagioclase in the epidote-quartzite of Tiirismaa may have changed into sericite and epidote, and the orthoclase into sericite.

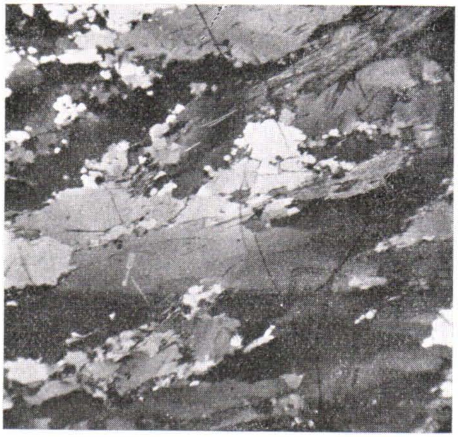


Fig. 20. Sillimanite quartzite of Tiirismaa. Magn. 18 diam.

The point of the D.Ti. 1 (Pl. IX) is the southernmost part of the Pirunpesä outcrop in the middle of Tiirismaa (S.W. of point 23). The coarse-grained rock contains fibrous sillimanite which appears mainly between the quartz grains (Fig. 20). Between large grains with fringed boundaries there occur smaller grains, probably of a parakinematic crystallization, as the large grains show strain shadows, but not these smaller ones. D.Ti. 1 shows the result of a petrofabric analysis of this rock. The maxima are situated in two girdles which lie in positions asymmetrical to the coordinates of the rock. In each girdle there occurs one main maximum, and the angle between the maxima of the two girdles is about 70°. Sander (1930, D. 39, 43 and 45) has described and explained similar orientations from granulites. In these cases the rocks have undergone pre-crystallization deformation. With their strong strain shadows the quartz grains of Tiirismaa show a post-crystallization deformation. Shear joints nearly parallel to the girdle of minima of axes are distinctly visible in thin section. Sander has described similar traces of differential movements and compared the deformation of this type to the deformation of calcite. This comparison indicates the gliding to have taken place along the rhombohedral faces. In the quartzite of Tiirismaa the shear surface forms an angle of 43° with the 'ab'-plane and indicates the movements in the rock in point 1 as having taken place in a vertical plane standing in a south-northerly position. Another explanation is similar to that given in connection with the following diagram.

D.Ti. 23. This outcrop is situated in the central part of the quartzite area and its character is the same as that of the rock in point 1. The diagram shows a small girdle around 'a' and some weak maxima in the 'bc'-zone. The main maximum is near to 'a' and in the same zone as maxima III in the 'bc'-zone. In this case the explanation which Sander has presented alternatively with the explanation of D.Ti. 1, seems to be applicable, viz., that the prism planes have acted as gliding planes and that the main maximum in 'a' has been divided into several separate maxima by the oscillation of the 'a'-axis.

D.Ti. 4. The rock at point 4 — north of point 23 on the map — is similar to the former. The diagram shows a small-girdle figure, the centre of which is in the 'ac'-zone. Three series of healed shear joints are visible; one is parallel to 'ac' and the others are on each side of it. They seem to indicate that the direction of gliding is the centre of the small girdle and that the girdle has been formed by oscillation, as was the case with D.Ti. 23.

All these diagrams are made from the quartzite of the central part of the area where the strike is about N. 15°-40° E. and the dip nearly vertical. D.Ti. 1 is nearly parallel to the 'ac'-plane and shows occupation in two small girdles. Shear joints in the section form an angle of nearly 40° with the 'ab'-plane. D.Ti. 4 was made parallel to the 'ab'-plane. The centre of the small girdle differs about 40° from 'a'. Two series of shear joints are visible, forming an angle of 10° or 15° with the 'ac'-plane. D.Ti. 23 shows a small girdle, the centre of which differs about 20° from 'a'. The position of the main maximum is in the 'ab'-plane and about 20° from the 'ac'-plane. In all these diagrams the angle between 'a' and the centre of the small girdle varies from 20° to 40°. The variations in this direction may be partly local and partly due to the errors in measuring, as all three diagrams were drawn parallel to different planes. The average direction of points 1 and 4 is nearly parallel to the 'ac'-plane and differs about 40° from 'a'. In the field this direction is S.-N. which consequently is the average direction of differential movements. The map (fig. 19) shows that the schists stand here in a vertical position making an 'S'-shaped fold. At point 23 the centre of the small girdle lies nearest to 'a', differing 20° from it. The strike is N. 15° E. and consequently the direction in question is N. 5° W.

Abundant sillimanite occurs at both ends of the quartzite area, mainly as bunches of needles between the quartz-grains and also as inclusions in them. Magnetite is another common minor constituent. Diagrams show mainly two girdles in asymmetrical positions.

D.Ti. 10, Tyhnynmäki. The point in which the girdles intersect is only weakly occupied. Healed shear joints passing this point are visible as rows of inclusions of ore minerals or of other minerals the character of which could not be determined. In the field the strike of this direction is N. 30° W. and the dip 25° N. N. W.

D.Ti. 9, Tyhnynmäki. The intersection point of the two girdles is in the 'ab'-plane. In the field the direction of it is N. 75° W. In this plane the dip of the intersection direction is 50° W. N. W.

D.Ti. 29, Tiirismaa. does not show any distinct girdles. The main maximum is in 'a', with another strong maximum at a distance of about 30° from 'c'. The direction of 'a' is N. 75° W. and the maximum at 'a' may indicate the direction of gliding. The rock at point 6 — near to the conglomerate of the northern zone — consists of quartz, plagioclase (75 % An), diopside, titanite, magnetite and mica.

At the eastern end of the quartzite area, D.Ti. 17, north of point 25, shows a quartz orientation similar to that of D.Ti. 10. The direction of movement is here indicated by the intersection point of the two girdles as also appears from the healed shear joints. The strike of this direction is N. 25° W. and its dip about 20° S. S. E. In D.Ti. 13, south from point 25, this direction is parallel to the horizontal plane and its strike is N. 25° E. Consequently the directions of movements oscillate here around the S.-N. direction.

D.Ti. 27 shows two somewhat confused small girdles in the same positions as D.Ti. 1 and further one strongly occupied maximum. As the strike here is N. 65° E. a comparison with D.Ti. 1 gives the movement direction N. 25° E. The distribution of the maxima may be due to the oscillation of this direction of movement.

The orientation of poles in two girdles has been thoroughly investigated (Sander 1932, Sahama 1936, Closs 1935, Osborne 1935, 1936) and in all cases the direction in which the girdles intersect has been established as having acted as the direction of differential movements. The triclinic symmetry of the diagrams indicates that the movements have taken place later than the general folding. Several other circumstances in the Tiirismaa area afford evidence to the same effect. In the quartzite these traces of movements appear as granulation of the grain boundaries. The later deformation has not been able to change completely the external shapes of the grains. Some small grains have recrystallized on their boundaries and the large grains have been re-deformed in their lattice structure.

The mineral composition of the surrounding rocks shows traces of the post-crystallization deformation. Greenschists occur here instead of amphibolites, which are common as the country rocks of the quartzites in Ostrobothnia. The alteration of amphibolites to greenschists may have been caused during the latest period of the deformation process, the traces of which are seen in the lattice orientation of quartz.

Thus the orientation of the quartz seems to have been caused by a later period of deformation, whereas the complicated folding of the area has been brought about during an earlier period. These two periods were assumed by Eskola from the petrological study of this area and the petrofabrics of the quartzite support his views. In the central part of the area the direction of the differential movement has been N.-S. At both ends one shear is parallel to the schistosity (D. Ti. 9, 29, 13 and 27) while the other shear forms an angle of about 50° with it. This shear is indicated by D. Ti. 10 and 17.

8. TYTÄRSAARI.

The island Tytärsaari (No. 8 on Map I) is situated in the middle of the Gulf of Finland about 65 km south of the town of Kotka. The longest diameter of this small island ranges about 3.5 km. The quartzite rocks are situated in the north-western part of the island. The eastern shore is covered by dunes, and a zone of gravel extends through the island from south to north. The highest hill (east of point 6 on the sketch map in fig. 21) consists of a reddish, coarse- or medium-grained granite. The quartzite is light-coloured, reddish or bluish, and coarse-grained. The strike is visible only at a few places. Sparse sillimanite and magnetite grains occur as accessories. Strain shadows are weak and the structure is crystalloblastic. Three petrofabric analyses were made and they all show two girdle figures (D.T. 4, 6 and 15, Pl. IX and X). The main maximum is situated in the intersecting point of the girdles. Shear joints are visible in sections passing through the rock.

Fig. 21 Tectonical sketch of the quartzite area of Tytärsaari. Scale 1:30,000

D.T. 4. The strike is scarcely visible. The main maximum is strong. Several small maxima occur in two girdles which form an angle of about 90°. The position of the main maximum corresponds in the field to a direction, the strike of which is E.-W. and the dip 20° W. This direction has been the direction of the main shear. At point 15 the same direction is: strike N. 50° E. and dip 25° N. E., and at point 6: strike N. 30° E., dip 10° N. N. E. In D.T. 6. 'b' and 'c' are also strongly occupied and an inclined girdle passing 'b' appears. The direction of the differential movements ha been on an average N. 60° E. It has been caused by the folding process, and thus in Tytärsaari the orientation process is contemporaneous with the folding. Fig. 21 shows a sketch map illustrating the assumed folding process. The directions of shearing movements are marked by the symbol of folding axes.

9. TAALIKKALA AND ANTAMOINEN.

Within the rapakivi granite near Lappeenranta we meet with a lens consisting of Archaean rocks, mainly coarse-porphyritic biotite-granites and metabasalts. In the contact zone of these there are two small quartzite lenses (No. 9 on Map I). The area has been described by Hackman (1934). In the contact zone of the biotite-granite and the quartzite narrow lenses consisting of migmatitic gneiss are found north of the quartzite areas. This gneiss grades over into quartzite and according to Hackman it has been mylonitized to a certain extent.

The quartzite shows megascopically mainly a clastic structure and a gray or reddish colour. In Antamoinen, east of the main road, a high rocky hill consisting of a glassy variety is found. The clastic quartzite contains a considerable amount of feldspar and epidote. Muscovite, chlorite, brown-coloured biotite, a little zircon and corundum (!) occur as minor constituents. The feldspar, mainly consisting of microcline, appears as a cementing mineral between rounded quartz grains. Plagioclase has altered into epidote and sericite, which now are seen partly as recrystallized grains and partly also as aggregates having the external shapes of feldspar grains.

The glassy variety of quartzite shows a granoblastic structure and it occasionally contains epidote in abundance as groups of grains situated between quartz grains. Other minor constituents are scarcely found in this type.

No diagram has been made, as no orientation could be determined by means of a gypsum plate.

10. KUPARSAARI, ANTREA.

The fourth small quartzite area in South Finland is situated in Kuparsaari, Antrea (No. 10 on Map I). This quartzite is an excellent example of blastopsammitic wollastonite-quartzites. The quartzite rock occurs in connection with limestones and in the contact zone (fig. 22) quartz and lime have reacted, forming wollastonite. No petrofabric analysis has been made of this rock. It was taken up in this paper for comparison with the other quartzites in a petrochemical respect.

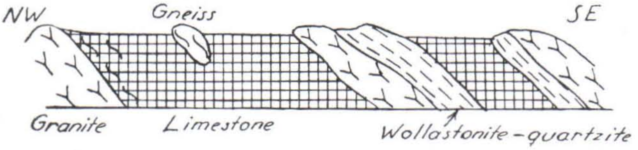


Fig. 22. Wollastonite-quartzite of Kuparsaari according to Eskola (1919). Profile. Stale 1:1,500.

A chemical analysis by Miss Elsa Ståhlberg shows the result quoted in Table XXII.

This quartzite contains, besides wollastonite, feldspars and diopside as accessories. The small amounts of magnesium and iron indicate a very pure member of those quartzites in which calcite has originally been present as cement material.

Table XXII.

Wollastonite quartzite, Kuparsaari, Antrea.

	%
SiO_2	77.90
Al_2O_3	5.17
Fe_2O_3	0.44
FeO	0.76
MnO	0.03
MgO	0.26
CaO	10.04
Na_2O	1.29
Na_2O	1.29
K_2O	2.66
TiO_2	0.18
P_2O_5	0.04
H_2O+	1.00
H_2O-	0.16
	99.93

Mode	%
Quartz	48.5
Microcline	15.7
Plagioclase (An_{10})	11.5
Wollastonite	18.5
Diopside	3.4
Magnetite	0.6
Apatite	0.1
Sphene	0.4
Water	1.2
	99.9

II. KARELIDIC QUARTZITE AREAS.

A. QUARTZITE AREAS OF WESTERN LAPLAND.

11. OLOSTUNTURI AND JUNKIROVA, MUONIO.

In Western Lapland we meet with numerous extensive quartzite areas forming parts of the Karelidic zone. The new geological map of this district (Muonio sheet B 7) as well as the continuation sheets of Sodankylä and Tuntsajoki have been made by Mikkola (1936, 1937). The quartzite areas lie mainly in a N.-S. direction and their strike as well as the strike of the surrounding rocks is also mainly N.-S. The dip — usually in an easterly direction — is slight. Only three limited occurrences of these areas are discussed in this paper. These three areas are Olostunturi with Junkirova in Muonio (No. 11). Rautakero in Ounastunturi (No. 12), and Jyppyrä in Enontekiö (No. 13).

The quartzite area investigated in Muonio comprises two hills, the larger one, Olostunturi and, east of it, the smaller Junkirova. They are — according to Mikkola — outcrops of one and the same quartzite lens, its length being about six kilometers while it arches from north-east to south-east as shown on the sketch map in fig. 23. The quartzite rocks are surrounded by quartzitic and leptitic gneisses which are veined by granites and contain sillimanite.

Granites also penetrate the quartzite area. They occur as stocks and bands mainly in the coarse-grained quartzite. The diameter of the masses is variable, the largest having a length of about 250 m. In the middle of the area we meet with a narrow zone of medium-grained biotite-gneiss of a gray colour.

The granites are coarse-grained, pegmatitic varieties. Their colour is mainly reddish from abundant red microcline, which also in microscopical examination proved to be the main component of this rock. Plagioclase is found in small amounts and has mainly the composition of An_{20}. Muscovite is most common among the minor components, but biotite also appears. There are frequent gradual transitions from quartzite to granite, and feldspars occur commonly as grains in the quartzites. Occasionally these grains show an arrangement in rows parallel to the schistosity. Clusters of grains may in places be observed among them. These grains of feldspar mainly consist of microcline showing a lattice structure. They are more idiomorphic than the quartz grains and are well preserved, in contrast to plagioclase, which has abundant inclusions of sericite, being sometimes entirely altered into this mineral.

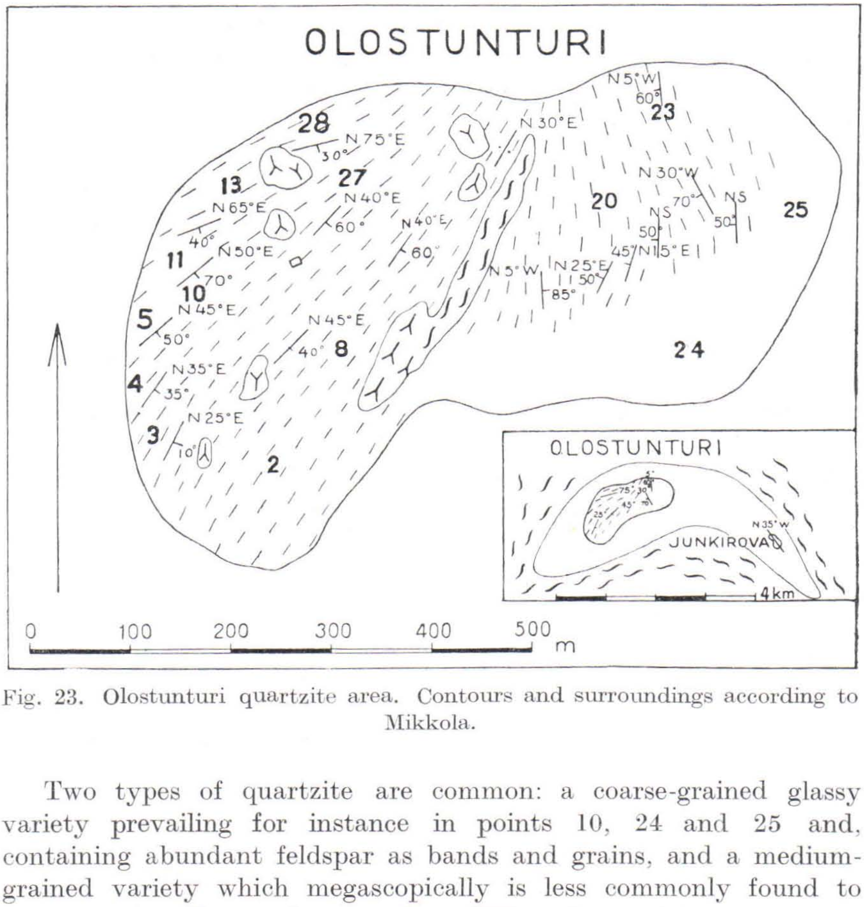


Fig. 23. Olostunturi quartzite area. Contours and surroundings according to Mikkola.

Two types of quartzite are common: a coarse-grained glassy variety prevailing for instance in points 10, 24 and 25 and, containing abundant feldspar as bands and grains, and a medium-grained variety which megascopically is less commonly found to contain microcline as large grains. Sillimanite, sericite, muscovite, magnetite, diopside, biotite, chlorite, sphene and apatite are met with among the accessories. Sillimanite occasionally occurs in abundance (for instance in localities 5, 11, and 28, fig. 23) as needles and bunches between the quartz grains. On the western slope of Olostunturi (points 5 and 11 on the map, fig. 23) sillimanite occurs in a zone which is lying parallel to the schistosity. The dip is here from 50° to 70° S. E. and a lamination parallel to the schistosity is distinctly visible. The occurrence of sillimanite in the same zone may indicate this schistosity to be parallel to an original bedding. Before metamorphism the zone rich in sillimanite possibly contained more clay than the other horizons. Should this have been the case, the arrangement of feldspar grains in rows, as just described, may also be due to the original bedding, and the origin of the feldspar in the quartzite may be sedimentary, even though some recrystallization and clustering together of the grains may have occurred. Where granite occurs as large masses it seems, however, to have been injected. Near to these masses smaller groups of feldspar are common and it is more difficult to explain their origin, as well as that of the granite occurring in small bands parallel to the schistosity. The irregular bands of granite alternate with quartzite in localities 4, 5, and 13. The breadth of the bands is about 1 cm. Megascopically this granite seems to belong to the same type as the granite of the large masses, being, however, medium-grained. The mica, mainly muscovite, is present only in small amounts. The scattered occurrence of feldspar grains suggests that the original sand has been arkosic, as in Kälviä and Taalikkala. In contrast to these occurrences, however, the mutual relations between quartz and feldspar are different. In Taalikkala the grains of quartzite are rounded, as they are in sandstones, and the feldspar occurs as a cement mineral between them. The quartz has kept its rounded shape. The low temperature metamorphism has not been able to recrystallize it, but the feldspar grains have lost their shapes. In the quartzite of the Olostunturi area the feldspar is more idiomorphic than the quartz, as is generally the case in igneous rocks. During the metamorphism a complete recrystallization has taken place and in this recrystallization the feldspar has produced more idiomorphic shapes than the quartz. The granoblastic structure of the Kälviä quartzite indicates conditions about midway between these.

Dr. Mikkola, according to his personal communication, has found on Olostunturi varieties rich in calcium-bearing minerals, viz. clinozoisite, epidote, or diopside. These rocks lie as zones among the quartzites of other types, probably in the same way as does the sillimanite quartzite. The cement of the original sandstones has in this case been marly.

The small outcrop of Junkirova consists of the same coarse-grained or medium-grained quartzite as at Olostunturi. Feldspar grains are common also here (fig. 24) and two larger masses of granite occur in the central part of the outcrop. The feldspar is mainly microcline, and muscovite; biotite, chlorite, diopside and magnetite occur as accessories.

The quartz grains in the section parallel to the horizontal plane and perpendicular to the schistosity show an elongation in the direction of their c-axes, which lie in the plane of schistosity as shown in D. M. 1 (Pl. X.) This diagram shows one sharp maximum in the plane of schistosity. Another section parallel to the schistosity shows four distinct directions in which the grains are elongated and which seem to indicate movements. Two of these shear surfaces (s_1 and s_2 in D. M. 1) are better developed. The other two are situated perpendicular to the plane of schistosity. The direction of elongation nearly coincides with s_3, which plane in the field investigation proved to be the 'ab'-plane. The absence or scarcity of mica makes a precise determination of 'b' impossible.

Fig. 24. Feldspar grains in the quartzite of Junkirova. Magn. 18 diam.

D. M. 23. The quartzite at point 23 is medium-grained. Microcline, plagioclase (20 % An) muscovite, sericite, biotite and magnetite occur as accessory minerals. D.M. 23 shows two maxima in the 'ab'-zone. The second of these is divided into two smaller maxima. The quartz grains are elongated in the direction of their vertical axis and show strong strain shadows. The direction of the vertical axis is parallel to the 'ab'-zone and the direction of gliding may have taken two different ways in this plane if [0001] has been a glide direction. Another explanation seems, however, to be more probable in this case, viz., that $(10\bar{1}0)$ is parallel to 'ab' and $[\bar{2}1\bar{1}3]$ is the glide direction and parallel with 'a'. The angle between the maxima and 'a' is about 53°, which corresponds well to the angle between $[\bar{2}1\bar{1}3]$ and [0001]. In fig. 17, Pl. VIII the points of these maxima are marked as number VII. One of them is better developed than the other and it may be that the maximum of D.M. 1 is formed so that only one of maxima VII is represented.

In this case, namely, a section parallel to the 'ab'-plane shows the directions 'a' and 'b' in the external shapes of quartz grains, The angle between $[\bar{2}1\bar{1}3]$ and $(0\bar{1}11)$ is nearly 90° and, if $[\bar{2}1\bar{1}3]$ is parallel with 'a' and (0001) parallel with the 'ab'-plane, the face $(0\bar{1}11)$ of the unit rhombohedron must be nearly parallel with 'b'. From the shapes of the quartz grains this seems to be the case, as several grains have a quadrangular form. A couple of sides coincide with the direction of 'b' and another with that of 'a'. The direction of the strain shadows and the vertical axis is nearly parallel to the diameter of the quadrangle which bisects the obtuse angle. In a section perpendicular to the plane of schistosity the quartz grains show an elongation parallel to the 'ab'-plane.

Similar mechanics of orientation can be assumed in the case of D.M. 23. Two maxima appear, as there is one degree of freedom. The division of the other maximum may be a fortuitous circumstance. It is, however, seen also in D. M. 10 which shows the same type of orientation.

D.M. 10. The rock at point 10 is coarse-grained. Microcline, plagioclase (20 % An) and muscovite occur as accessories. Strain shadows in the quartz grains are scarcely visible. The petrofabric analysis shows an orientation of two maxima, which probably correspond to the maxima of D.M. 23. A determination of 'a' and 'b' has not been possible in this glassy quartzite.

D.M. 25. The properties of this quartzite are the same as those of the former. Sphene and magnetite occur among other accessories. The plagioclase has abundant inclusions of sericite, as is usual in the quartzites of Western Lapland. The diagram shows two main maxima, the explanation of which may be the same as in the case of D.M. 23. The directions of 'a' and 'b' could not be determined.

D.M. 4. The quartzite at point 4 shows narrow granite veins. The quartzite contains abundant sillimanite as long needles mainly parallel to 'b'. They appear as bunches between quartz grains and also as inclusions. The other accessories are scarce; only small amounts of microcline, plagioclase (20 % An), magnetite, muscovite and sphene are found. The bedding is nearly horizontal and the stretch N. 25° E. The main maximum in D.M. 4 is situated at 'b' and two other maxima in the 'ac'-girdle on both sides of 'a'. The 'bc'-girdle is partly occupied, indicating some action of a crossed strain. Schmidt (1925) has described tectonites with an 'ab'-girdle from Greiner Scholle and Val Piora and has explained the formation of the maximum in 'b' as follows: The direction of the gliding has been the direction of 'a' and it has taken place in the prism planes parallel to $[2\bar{1}\bar{1}0]$. In D.M. 4 there are no gliding surfaces visible under the microscope. The grain boundaries are fringed and the dimensions of the quartz grains are nearly similar in all directions. Strain shadows are strong and ruptural and may indicate that the gliding during the deformation has taken place along the prism faces. The maximum at 'a' is divided into three separate maxima. One of them is situated in the 'ab'-zone and the other two are in asymmetrical positions about 'ac'. Each of these two maxima is in the same great circle as the maxima in the 'bc'-girdle. Possibly the shearing strain which has caused the maxima of the 'bc'-zone has also caused the dividing of the maximum at 'a'.

D.M. 20. The minor constituents are microcline, plagioclase (23 % An), muscovite, sericite, diopside, biotite, chlorite, sphene and magnetite. The rock is medium-grained and the feldspar grains, as usual, have arranged themselves in rows parallel to the bedding plane.

In the diagram the 'ab'-girdle is well developed and comprises several separate maxima. The main maximum is at the point of maximum VII. The maxima at 'a', 'b' and at the point symmetrical with III, with respect to 'ac', are represented. The forming of this diagram can be explained according to Schmidt's ideas as follows: 'a' is the glide direction, the maximum at 'b' is explained as in the case of D.M. 4. The maximum at 'a' is due to a gliding along the prism faces with the vertical axis as a glide direction. The maxima VII are formed by gliding parallel to prism faces $(10\bar{1}0)$ and with $[2\bar{1}\bar{1}3]$ as glide direction. In accordance herewith one might expect both maxima VII to be similar in occupation, but now one of them is much stronger than the other. An application of Sander's mode of treatment would result in the following interpretation: Prism faces have acted as gliding planes and the separate maxima have been formed by »Mehrscharige Gleitung». In such case the shear surface passing the main maximum VII would have been the surface of maximum shear.

D.M. 8. Microcline, plagioclase (23 % An), muscovite, sericite, biotite, chlorite, diopside, sphene, magnetite and apatite occur as accessory minerals in this medium-grained quartzite. The result of the petrofabric analysis, D.M. 8, shows a main maximum in the 'ab'-zone and some maxima in a girdle perpendicular to the bedding and schistosity plane. 'b' is not visible, but the maxima probably correspond to the maxima of D.M. 4, so that the main maximum is at 'b' and the maxima in the central part of the diagram are near 'a'. 'c' is also occupied in both diagrams. According to this, the explanation of D.M. 8 is the same as in the case of D.M. 4.

D.M. 28. The quartzite at point 28 belongs to the same zone as the rock at point 4 and it is also rich in sillimanite. The other minor constituents are microcline, plagioclase (20 % An) muscovite and magnetite. In D.M. 28 the main maximum is situated in the 'ac'-zone near to 'a'. Some maxima in the 'bc'-girdle appear as in D.M. 4. The close approximation to this diagram indicates a similar orientation process.

All diagrams indicate 'a' to have acted as the direction of differential movements, as is common in the normal tectonites. Two types of orientation can be distinguished, viz., the girdle figures and those with separate maxima. One of the girdles is in the 'ab'-zone and the separate maxima appear in the same zone, where this zone has been developed. Consequently the orientation of the Olostunturi quartzite is characterized by the location of the maxima with respect to 'ab' and 'a'. Maxima I, VI and VII are most common and in all these cases the prism planes are parallel to 'ab', the glide direction being different. Maximum I is due to the gliding along [0001], VI to $[2\bar{1}\bar{1}0]$ and VII to $[2\bar{1}\bar{1}3]$. In this case the mode of Schmidt's explanation seems to be most acceptable, all directions of closest packing in the lattice of the quartz being represented. Among the possible gliding planes only the prism planes have been in action during the last period of deformation. In the former period plastic deformation has caused Böhm striations in some quartz grains of the glassy quartzites. Fig. 14 a, b (Pl. VII) shows such a grain and the map of axes made from it. Relict Böhm striations are visible, forming an angle of from 0 to 10° with the basal plane. The breaking into needles is visible as strong ruptures. In another grain (fig. 15 a, b Pl. VII) the gliding along prism faces has been more dominant, but also in this case Böhm striations appear in one part of the quartz grain. In both grains the gliding along prism faces seems to have taken place parallel to $[2\bar{1}\bar{1}0]$, as indicated by the Böhm striations parallel to the basal plane.

The direction of 'a' in the field varies with the strike and dip, being evidently connected with the general folding process. 'b' is mainly horizontal or deviates from it about from 0° to 45°. Thus the direction of 'a' in the 'ab'-plane is almost vertical. The folding movement has been complicated and the direction of 'b' varies in considerable amount, as is visible from the strike and dip in the sketch map (fig. 23). The type of the tectonics is alpinic and the orientation of the quartz has taken place contemporaneously with the folding. However, traces of a stronger shear movement are visible in some diagrams, as for instance in D.M. 1 and in D.M. 23, in which one of the maxima VII was a main maximum. This direction in the field is N. 30° W. in Junkirova and N. 10° W. in Olostunturi.

12. RAUTAKERO, OUNASTUNTURI.

The outcrops are situated on the north-western slope of the hill Rautakero (No. 12 on Map I) belonging to the highlands of Ounastunturi. Quartzite in the upper part of the slope shows megascopically a clastic structure, as usual in Ounastunturi; but in the lower part we meet with a quartzite which megascopically shows an approximation to the glassy feldspar-bearing variety of Olostunturi, and the rock in the middle of the slope resembles the fine-grained type of the Olostunturi quartzite. The glassy type is coarse or medium-grained and contains feldspar grains. On the surface of the rock these grains are seen evenly distributed and mainly arranged in rows parallel to the schistosity, as was occasionally the case in the quartzite of Olostunturi. Stocks of coarse-grained red-coloured granite occur, but they are few in number and small. Their length varies commonly from 20 cm to 100 cm and their breadth from 5 cm to 50 cm. Some larger masses are also seen here.

The outcrops of the hill Välivaara, situated north of Rautakero, consist of the same aplitic, pegmatitic granite and the hills in a northerly as well as a southerly direction from this locality consist of quartzites which show no orientation and which therefore were not closely examined.

The planes of schistosity on Rautakero are nearly horizontal or dipping up to 20° E. The direction of 'b' is N. 35° E. D.R. 1. shows a well developed orientation of one strong maximum in the 'ab'-zone. This maximum deviates 35° from the direction of 'a'. The directions of the vertical axes of quartz grains consequently lie in the W.-E. direction of the horizontal plane. Quartz grains are recrystallized with fringed boundaries, and they show strong strain shadows. Ruptures parallel to the vertical axis are many and sharp, indicating that gliding also here has taken place parallel to the vertical axis. According to this the direction of shearing movements have been W.-E.

13. JYPPYRÄ, HETTA.

The small quartzite area upon the hill Jyppyrä (No. 13 on Map I) in the village of Hetta, Enontekiö, comprises one larger and a few smaller outcrops. Quartzite is present as small lenses enclosed in granite which has also penetrated the quartzite rocks, so that pure quartzite can be found only in a few places, as shown on the map, fig. 25. The surrounding rocks consist of quartzitic gneisses. In a

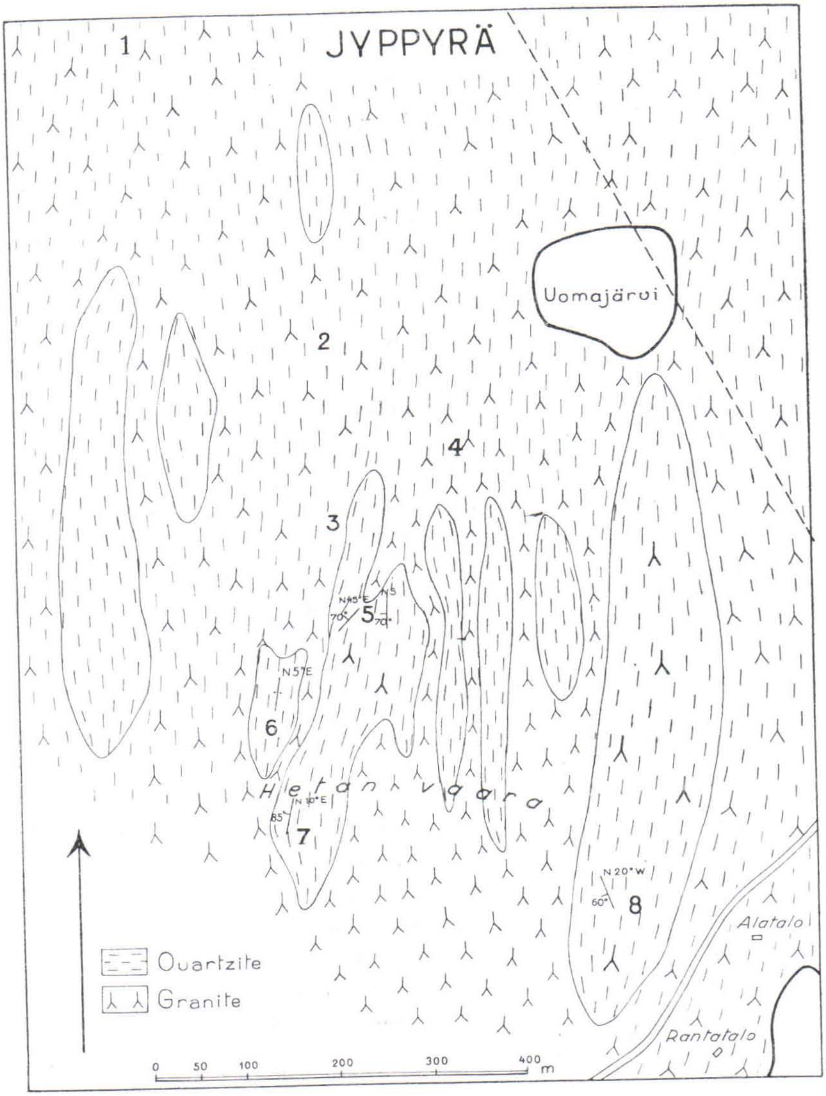


Fig. 25. Quartzite area of Jyppyrä, Hetta.

north-easterly direction we meet with slightly gneissose »Hetta granite» and in the north-west granitic gneisses. The granites upon Jyppyrä are mainly gneissose, containing abundant biotite. Aplitic or pegmatitic granite occurs in masses in the quartzite, which contains also grains of feldspar, mainly microcline, as in the quartzites of Muonio and Rautakero.

The quartzite is coarse- or medium-grained and light-coloured. The strike varies from N. 20° W. to N. 10° E.; the dip is mainly 80° W. and the direction of the linear structure ranges from 35° S. to 70° S.

The common minor constituents in the quartzite of Jyppyrä are microcline, plagioclase (An_{25}), muscovite, magnetite, biotite, and sphene. Microcline is also here more idiomorphic than quartz, occurring as inclusions in larger quartz grains and also between them (fig. 26).

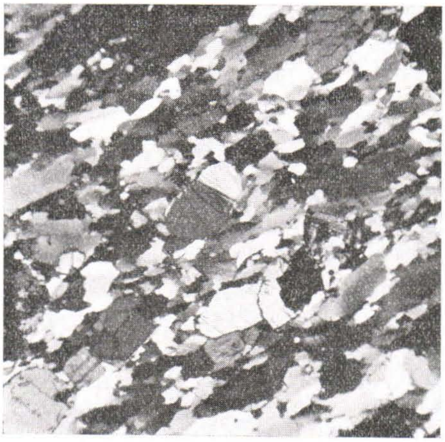


Fig. 26. Feldspar-bearing quartzite of Jyppyrä. Magn. 18 diam.

D.J. 5 (Pl. X). The quartzite at this point is coarse-grained and light-coloured, containing microcline, plagioclase (15 % An), biotite, magnetite, and muscovite as accessories. The quartz grains are elongated parallel to 'b' and their ruptural strain shadows, forming an angle of about 45° with 'b', are very marked. The shear has evidently taken place in this direction, the prism faces having acted as gliding planes and the vertical axis as glide direction. As a result of this deformation the diagram shows one strong maximum in IV.

D.J. 6. The megascopical structure and the minor constituents of this rock are the same as those of point 5. The diagram shows a girdle in which the main maximum is situated near to 'a' and two smaller maxima in the same position as the maximum of D.J. 5. Part of another girdle perpendicular to the former is also visible. Together they form a figure of two girdles in a position asymmetric to axes 'a', 'b', and 'c'. The sharp maximum near to 'a' is formed by the gliding of the prism planes, as was the case in D.J. 5. Girdles which are lightly occupied indicate a rotation of the poles out of the maximum. The complete girdle is due to the main strain and the other one to a crossed strain which has evidently been weaker than the main strain.

D.J. 7. The minor constituents of this coarse-grained quartzite are microcline, plagioclase (15 % An), biotite, magnetite, muscovite, chlorite, and a few grains of clinozoisite. The main maximum is the same as in D.J. 5. Two weak maxima in the 'ac'-girdle and also the light occupation of a girdle near to the 'ab'-zone distinguish this diagram from D. J. 5. The type of deformation is the same, as the strong occupation of the main maximum indicates. The explanation of the formation of the weak girdles is the same as in the case of D.J. 6.

D.J. 8. The rock at this point contains the same accessory minerals as the quartzite at point 7, but the amount of clinozoisite is more considerable. The petrofabric analysis shows a similar result as in the case of D.J. 5, the maximum being situated, however, nearer to the 'ac'-zone and being more elongated in the horizontal plane. Some poles in the same zone indicate traces of a strain similar to that which has given rise to the girdle of D.J. 6.

The optic orientation of the quartzite of Jyppyrä is consequently characterized by one strong maximum in an asymmetric position. The external shape of the quartz grains gives evidence of a shear passing this maximum and the ruptural strain shadows parallel to this shear surface indicate that the prism surfaces have acted as gliding planes. The directions of the shearing movement at points 5, 7 and 8 are in the horizontal plane as follows: at point 5 N. 30° E., at point 7 N. 45° E., and at point 8 N. 20° E. D.J. 6. shows some shearing movement to have taken place in the direction N. 40° E. but the direction of the main shear is inclined 30° N. in a vertical plane, the direction of which is N.20° W. Possibly this variation in the direction of shear is due to the rotational strain which the girdle indicates to have been in action.

The direction of differential movements in Jyppyrä and in Rautakero has taken place in the horizontal plane. The triclinic symmetry of the diagrams indicates that the orientation process must belong to a period later than the general folding. Probably one strong »Durchbewegung» has caused it. The direction of this movement in Jyppyrä is about N. 35° E. and in Rautakero W.-E.

B. QUARTZITE AREAS OF KARELIA.

14. KIEHIMÄ.

The Kiehimä area, north of the east end of Lake Oulujärvi, was chosen for petrofabric study as a representative of the Karelidic Kainuu zone which the investigations of Väyrynen (1928) and Wegmann (1929) have already made well known for its interesting tectonics.

The extensive quartzite areas east of Lake Oulujärvi consist mainly of fine-grained crystalline quartzites which generally contain sericite or muscovite as minor constituents. Feldspar, tourmaline, and zircon occur occasionally. This district has been described by Wilkman (1931), and Wegmann has widely surveyed its tectonics in connection with his investigation of the Karelidic mountain-chain according to the methods and viewpoints of Alpine geology (Wegmann 1928, 1929 a, b). The axis of the folding lies mainly in a south-northerly direction, but generally it is not parallel to the horizontal plane. In the Kainuu district the tectonics are characterized by two depressions and two culminations, viz., the depressions of Oulujärvi and Kuolajärvi and the culminations of Nurmes and Puolanka. In the depressions the overthrust nappes come from the west into the quartzite zone, as for instance the Paltamo nappes. In the culminations the old gneissose granite is exposed in the topography. The folding has taken place from west to east and the quartzites are thus seen in zones parallel to the S.-N. direction. The original bedding is usually preserved in spite of folding and only in places which have been subjected to intensive shear does the quartzite show a well developed megascopical stretching along the folding axis 'b'. Thus for instance the quartzite on the south-western slope of the hill Pieni Leppimäki, Kiehimä (No. 14 on Map I) shows a structure which megascopically suggests rolling movements, the axis of which is N. 10° E. The oscillation of the axis is also seen in its local deviations from the general N.-S. direction. Consequently this oscillation of the axis has not taken place in one or another plane but it can be characterized only by the co-ordinates in three dimensions. The optic orientation of quartz seems to give good assistance in the elucidation of the character of the folding-movements and of the real direction of the axis 'b'. Thus the Karelidic mountain chain forms a perfect unity and it ought to be wholly investigated by the petrofabric methods at one and the same time. However, the absence of quartz orientation in many localities makes this kind of work more difficult and in some places impossible. It is only where the orientation can be found that such work may throw light on the matter. In the present investigation only a few diagrams have been made from those places where the quartz was found to show an orientation. Thus the present work may offer only some hints for the future thorough investigation of the Karelidic mountain structure by means of the petrofabrics. Diagrams were made from the districts Pieni Leppimäki and Mieslahti and both show a figure of one-girdle perpendicular to the axis 'b', as was to be expected in view of the general character of the folding movements of the Karelidic mountain chain (D. P. L. 1

and D.Mi. 1, Pl. X). This girdle Sander and Schmidt have found to be characteristic of those Alpine tectonites with which the quartzites now investigated are comparable. Both diagrams show, however, a tendency to form another girdle perpendicular to the former and parallel to the horizontal plane. In Pieni Leppimäki this girdle represents an 'ab'-girdle and in Mieslahti a 'bc'-girdle, as the bedding 's' in Pieni Leppimäki lies mainly horizontal, while in Mieslahti it stands nearly vertical. The districts belong to different zones and consequently to different parts of the large fold directed from S. to N. The Pieni Leppimäki quartzite is situated in a more westerly direction and belongs to the upper part of the folded complex. Now, as the crossed shear which has caused the maxima of the horizontal girdles, has been the same in both cases, it appears that this shear must have been later than the general folding movement.

These two instances, however, are not sufficient to enable one to draw definite conclusions concerning extensive quartzite areas. As mentioned above, more comprehensive investigations from the viewpoint of petrofabrics would be necessary.

The quartzite of Pieni Leppimäki is a light-coloured medium-grained variety and contains biotite, muscovite and tourmaline. The long biotite scales parallel to the axis of folding show another folding perpendicular to the same axis. The quartzite on the western slope of the same hill is light reddish, glassy and shows no bedding or megascopic orientation.

The quartzite of Mieslahti (No. 14 on Map I) is medium-grained and light-coloured. It contains only a little muscovite as a minor constituent. The granoblastic quartz grains show weak strain shadows. The small outcrops on the shore of the river Miesjoki consist of a well foliated type. The strike is N. 45° E. and the S-planes stand in a vertical position.

15. KOLI.

The tectonical position of Koli is seen on Map I (No. 15). In the tectonical longitudinal profile of Wegmann (1928) it is situated on the southern slope of the Nurmes culmination, the tectonical axis turning from N. to S. The local oscillation at Koli ranges from 40° S. to about 20° N. and again to 40° S. This rocky highland represents the northernmost end of the Jatulian quartzite zone of Karelia. The quartzite rests upon old gneissose granite, joining with it in northern, eastern and western directions. Consequently it represents a »bay» of the larger quartzite area south of Koli. Its tectonics are characterized by over-thrusting movements from west to east. The quartzite is mainly blastopsammitic with traces of a clastic structure as commonly seen in the quartzites of the Jatulian type. Kyanite and scarce sericite and magnetite are the common accessories.

An analysis of this quartzite has been made by Miss Elsa Ståhlberg and it shows the following result:

Table XXIII.

Kyanite-quartzite, Koli, Juuka.

	%
SiO_2	89.38
Al_2O_3	6.57
Fe_2O_3	1.56
FeO	0.50
MnO	0.01
MgO	0.00
CaO	0.06
Na_2O	0.05
K_2O	0.51
TiO_2	0.16
P_2O_5	0.00
H_2O+	1.18
H_2O-	0.14
	100.12

Mode	%
Quartz	84.2
Kyanite	7.8
Sericite	5.0
Magnetite	2.0
Water	1.0
	100.0

This analysis of the kyanite-quartzite of Koli can be compared with the analysis of the sillimanite-quartzite of Tiirismaa (p. 68). The chemical composition shows a close approximation but in the Tiirismaa quartzite the mineral of the formula Al_2SiO_5 exists in the stable form, while the same mineral in the Koli quartzite appears in a metastable form. So far as kyanite belongs to the stress minerals, this fact may indicate the different modes of deformation in these two quartzites, the Koli quartzite representing a type deformed in a greater degree under shearing stress.

In some places which have been subjected to shear a megascopical stretching is visible. So for instance north of Ukko-Koli an outcrop consists of the reddish, medium-grained quartzite, in which abundant kyanite occurs as accessory, showing a well developed arrangement with its longest dimensional axis parallel to the 'b' of the rock (fig. 27). The strike is here N. 25° E., the dip 65° W. and the stretch 52° S. S. W. Granulation of quartz grains is fairly perfect in this locality (fig. 27), indicating that some movements have acted upon the quartz grains after recrystallization. As mentioned above, the tectonics of Koli are characterized by an intensive oscillation of the 'b'-axis. At this point the direction of axis 'b' deviates to the largest extent from its horizontal position, indicating folding movements here to have been more intensive than in neighbouring localities. The petrofabric analysis of this quartzite (D. Ko. 2) shows a well developed rhombic symmetry. The main maxima are situated near to 'a' in an 'ab'-girdle. 'c' is lightly occupied, the maximum showing an elongation in the 'ac'-zone and to a smaller extent also in the 'bc'-zone. The maxima lying symmetrically near to 'b' are weakly occupied. A girdle perpendicular to 'c' indicates a rotation round 'c' which has probably caused also the distribution of quartz poles in three submaxima instead of one main maximum in 'a'. A similar exchange of the rotation axis was observed in the quartzite of Pieni Leppimäki, Kiehimä. In Mieslahti another 'b' was parallel to 'a', but in both cases this girdle was in the horizontal plane, indicating that the axis 'b_1' stands vertical. In the quartzite of Koli the direction of the rotation axis deviates from this direction about 25° (D.Ko. 2).

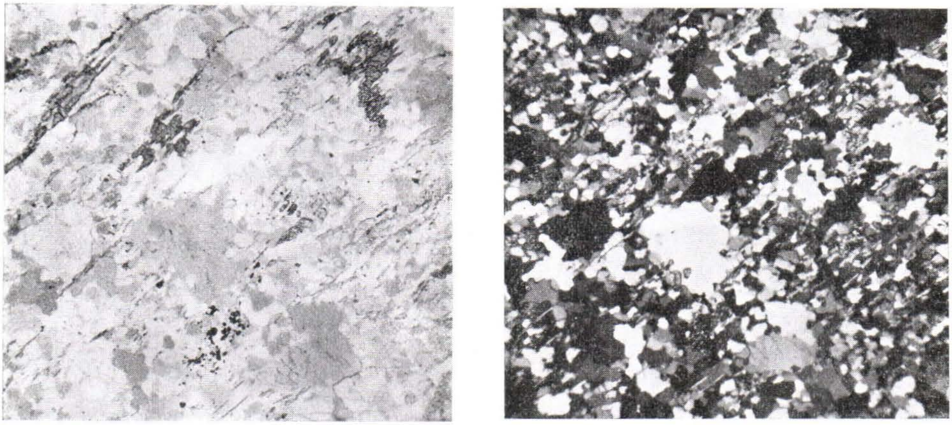


Fig. 27. Kyanite-quartzite of Koli. One Nicol and Nicols crossed. Magn. 18 diam.

The occurrence of kyanite in this place would seem to give support to Harker's (1932) opinion that the kyanite is a stress mineral. Kyanite occurs, however, also as veins filling tension fissures (fig. 28). Unfortunately, I did not see the occurrences in the field, but the investigation of thin sections of the veins and its wall rock shows that these veins were situated perpendicular to 'b' and are thus real tension fissures and that the kyanite also in these veins is orientated

Fig. 28. Kyanite vein in the quartzite of Koli. About $^{2}/_{3}$ nat. size.

parallel to 'b'. The quartz in these veins is coarse-grained, nearly glassy, and it shows a well developed orientation with the vertical axis perpendicular to the walls of the fissures. The long columnar crystals of kyanite have been orientated in the same manner with their longest dimension perpendicular to the walls — as blastetrix — and consequently parallel to 'b' of the tectonite (fig. 29).

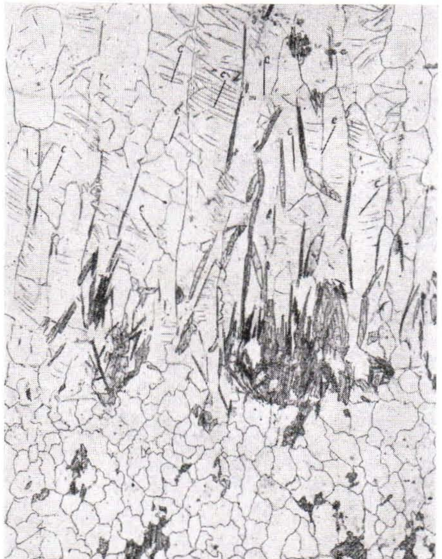


Fig. 29. Kyanite-bearing quartz vein, Koli. Magn. 8 diam.

III. GENERAL OUTLINE OF THE PETROLOGY OF FINNISH QUARTZITES.

A. GRANITIZATION.

In the areas more closely investigated in connection with the present work granitization of quartzites has taken place mainly in some quartzite areas of Ostrobothnia and Western Lapland, while the quartzite areas of South and East Finland have fairly well escaped this process.

As described earlier in connection with the general geological outlines the character of the granites which have penetrated the quartzites is different in various quartzite areas. In the Simsiö area contacts between granite and quartzite are visible only in a few places, as the outcrops on the borders and at the ends of the Simsiö hill are few. The outcrops occur abundantly in that part of the area which Map III comprises. Both ends on Map II are drawn according to the strike of the outcrops of points 17 and 22. The small granite stocks consist of the same biotite-granite as the larger surrounding granite-mass and they have probably the same origin. The small masses are elongated parallel to the schistosity and feldspar grains generally occur in quartzite near to the contact, but not elsewhere. These granite masses have intruded into their present positions without disturbing the strike of the surrounding quartzite.

It is especially this circumstance that suggests the idea that the granites of the small lenses had been brought to their present positions with respect to the quartzite by a process of wholesale replacement of the latter, just as skarn is supposed to have originated from pure limestone. One might suppose that the granite masses of Simsiö as well as the accumulations of the manganese minerals and diopside would be of a similar origin in connection with the metamorphic processes. Their occurrences and shapes, however, are different and, in my opinion, prohibitive of such an assumption. Also the fact that feldspars are not met with in the quartzite far from the contact zones indicates that the sandstone, previous to the metamorphism, has been quartzitic, not arkosic, as it apparently has been in Kälviä and probably also in the quartzite areas of Western Lapland, where feldspar commonly appears as grains among the quartz-grains. In Simsiö the accumulated minerals occur in larger or smaller degree also as dispersed grains.

Other quartzite occurrences in South Ostrobothnia also consist merely of quartz and do not contain feldspar. In contrast to what is the case at Simsiö, these smaller lenses have not been penetrated by granites. As we can see on the maps, these smaller quartzite areas are usually surrounded by amphibolites and in a few cases by migmatites. A primary contact between granites and quartzites is found only in the Simsiö area, and here the granite has penetrated the quartzite as well as the other rocks, viz. amphibolite and migmatite (Map II). In Laihia the amphibolite contains occasionally narrow bands of gray-coloured gneissose biotite-granite, while such bands are not met with in the quartzite. The quartzite occurs here as well as in Orismala completely surrounded by amphibolites. These small lenses have accordingly never been larger than they are now, and no granitization or migmatization has taken place in them. The quartzites of Vittinki, Nurmo, and Lapua join in places with migmatites. In these cases one can suppose that they might have been partly destroyed in the general migmatization. In Lapua this possibility may be true. East of the quartzite areas there occur small rusty lenses among migmatites. The rocks of these consist of coarse-grained quartzite alternating with phyllite. The easternmost of these rocks is found about six kilometers east of Lapua and this quartzite contains ore-minerals and spessartite in the same manner as the Simsiö quartzite. The rock is altered, as it contains mica and feldspar, together with the general minor constituents present in the Simsiö quartzite.

According to the facts mentioned above one cannot speak about a general granitization or migmatization of quartzites in South Ostrobothnia. Rather it seems to me that the quartzite areas in general are well preserved and where they have been destroyed there are generally traces of them left. Granitization has taken place where granites have been intruded into the quartzites, but only in narrow contact-zones and these granites have penetrated the continuous rocks in the same manner. Consequently, granitization here depends upon the local circumstances and not upon the character of the rocks.

In Kälviä the penetrating granite consists of a pegmatitic variety containing muscovite and dark-coloured tourmaline. The same pegmatitic granite has penetrated also the surrounding migmatite, for instance at point 5 in fig. 17, where it is seen in the surface of the migmatite rock as an irregular continuous mass. Its occurrence in the quartzite is more abundant and more discontinuous. It is found here in more or less extensive masses or stocks, in beds and bands, the latter appearing usually in connection with the masses. The granite has evidently met with less resistance in the quartzite than in the migmatite.

The feldspar occurring in the quartzite consists mainly of plagioclase (20—25 % An) but in the granites microcline is the main component, the plagioclase having the same composition as that in the quartzite. At point 3 (fig. 17) the rock consists of plagioclase (30 % An), microcline, quartz, magnetite, sphene, biotite, and muscovite. Thus microcline here occurs together with plagioclase. This rock is gray-coloured and shows a bedding similar to that of the common quartzite. East of this place, at point 4, the rock has the same components and in addition abundant diopside. The plagioclase is richer in anorthite, viz. 60 % An. Both these rocks as well as the quartzite have probably a sedimentary origin, but their composition shows an approximation to gneisses containing abundant microcline and plagioclase. Under the microscope an evidence of the sedimentary origin is seen in the impure cementing matrix around the rounded grains. The feldspar is here the major component, quartz appearing in smaller amounts, and the occurrence of diopside indicates the former presence of calcite in the arkosic sand from which this gneissose rock has probably originated. In this case the sedimentary origin of the gneiss can be established with certainty, but should metamorphism have obliterated all traces of the clastic structure the determination of the origin of the granite derived from it would be more difficult. The pegmatitic granite in Kälviä contains tourmaline, belonging evidently to juvenile granites.

Quirke (1927, 1930) and Collins (1930) have described the migmatization and granitization of the quartzites of the Killarney area in Ontario. The Killarney granite contains quartz grains of original clastic quartzite and they increase in number while the rock gradually passes over into quartzite (the Lorraine quartzite). A gradual passage of this kind from granite into quartzite is common in the pegmatite masses of Kälviä. Here the granular quartz of the contact-zones has been replaced by scattered feldspar grains, sparingly at first and later in increasing amounts. The assimilation of feldspar during magmatic intrusions is clear in both cases. In Killarney this process of metasomatism has been enormous in extent, but in Kälviä as well as in Simsiö it has taken place only in narrow contact-zones.

In Western Lapland we have, however, granites whose origin may be either sedimentary or juvenile. In the explanation of their origin only the occurrence itself can provide some evidence, as there appear no minerals in their composition which could give any hint about their origin. In the quartzite of Kälviä, plagioclase is mainly present in the quartzite, while the feldspar of the granites is mostly microcline. In Western Lapland, on the other hand, microcline occurs in quartzite as well as in granite masses; no minerals containing volatile components are found in granites and no traces of clastic structure appear in that feldspar which occurs in the quartzite. Only the scattered occurrence of feldspar grains may be a reminiscence of sedimentary origin, while the external forms of the granite stocks, masses and bands indicate their closer approximation to the injected granites, being similar to these of the injected granite masses in Kälviä.

The quartzite area in Jyppyrä differs in some respects from the other quartzites in Western Lapland. Together with the pegmatitic variety there occurs another granite which contains abundant mica and forms gneisses with quartzite in the contact zones. This gneissose granite has »injected» the quartzite so perfectly that only a few narrow lenses of pure quartzite are now present. The same variety of quartzitic gneisses which appears upon Jyppyrä is common in extensive areas around it. Feldspar occurs in the gneiss in the same manner as in the quartzite, only being more abundant. The content of An is also the same, viz., from 20 to 25 %. Mica is usually present more abundantly in the gneiss. The plagioclase of the granite masses of Jyppyrä differs from the former in one respect: alteration into sericite has not taken place. Thus these granite masses are probably intrued, being pegmatitic and similar to the corresponding masses in Olostunturi. In contrast to these, the gneisses show closer approximation to the quartzite rich in feldspar, only containing mica and feldspar in greater abundance. They seem to have been formed from arkosic sandstones, the content of feldspar varying from point to point. This variation may be partly due to the original sedimentation — when it occurs on a large scale — and partly to the segregative processes during deformation. The alignment of the feldspar grains in the quartzites is comparable with the formation of the granitic veins in the migmatites by metamorphic differentiation.

Thus the quartzite areas of South Finland and most of those occurring in South Ostrobothnia are generally well preserved against granitization. In those areas where granite masses have intruded, as for instance in the Simsiö area, they have penetrated the quartzites but they have penetrated also the country rocks. The feldspar in the quartzites of Kälviä and Western Lapland is of a sedimentary origin. The original sandstone has been arkosic. Pegmatitic granites have injected these quartzites as well as the country rocks. The quartzite areas of Central Karelia differ in this respect from the first mentioned Karelidic quartzites: penetrating granite veins are here very rare.

B. PETROCHEMISTRY.

In the Pre-Cambrian of Finland there are two genetically different kinds of quartzitic rocks, viz. metasomatic and sedimentogeneous rocks. The former are as a rule connected with sulphidic ores. The most important representatives of this group are the so-called ore-quartzites, occurring in connection with the copper ores of the Orijärvi type (Eskola 1914), and also widely distributed in Central Sweden, e. g. at Falun (Geijer 1916). They are characterized by anthophyllite and cordierite. The other group of metasomatic quartzites includes the sericite quartzites which contain many pyrite-deposits in East Finland, such as those of Otravaara (Saxén-Saksela 1923), Karhunsaari (Saksela 1933 a), and also the famous auriferous sulphide-deposits of the Skellefteå area in Sweden (A. Högbom 1928). These and other metasomatic quartzites are not considered in this memoir, which is concerned only with truly sedimentogeneous quartzites. The petrofabrics of the metasomatic quartzites still remain to be investigated.

Thus all the quartzites now investigated have been formed from sandstones and exhibit the same variations and intermediate gradations in chemical composition as are observed in the sandstones. The metamorphic derivatives of sandstones show a larger complexity in their mineralogical composition, as the same cement of the sandstone may under different conditions of metamorphism form different products. Sandstones have been derived from sands, and their cementing minerals consist of other substances which could be deposited in a relatively insoluble condition, such as silica, hydroxides of iron, manganese and alumina, and carbonates of calcium, magnesium, manganum and iron, and further calcium sulphate, phosphate, etc. Clay and bituminous substances are also common in the cements. At elevated temperatures and under higher pressures the cement recrystallizes, or reactions between the cement and the quartz grains generate another class of mineral species. Some minerals may undergo the normal hydrothermal alteration; feldspar, for instance, often changes into sericite.

According to the chemical composition of the minor constituents the following seven main groups can be distinguished. Most of them are common among the Finnish quartzites.

Quartzites containing:

1. Aluminium silicates.
2. Potassium-aluminium silicates.
3. Calcium-aluminium silicates.
4. Magnesium-iron-calcium silicates or carbonates.
5. Magnesium-iron silicates or carbonates.
6. Calcium silicate or carbonate.
7. Graphite.

1. Among aluminium silicates sillimanite is the most common minor constituent in the quartzitic rocks. The quartzite of Tiirismaa (see p. 68) for instance contains abundant sillimanite and only little of other minor constituents, and consequently it represents a very pure member of the first group. In the Karelidic zone sillimanite quartzites are found e. g. in the hill Rovavaara, in the parish of Salla, described by Hackman and Wilkman (1929). The green-coloured quartzite occurs here as fragments within a rock consisting of a quartzite and of a granite rich in quartz and biotite. Quartz grains in the quartzitic rock are elongated parallel to the schistosity, and fibrous sillimanite is seen arranged in bunches between them.

Together with other minor constituents sillimanite occurs commonly in several quartzites of the Karelidic zone, as for instance in the quartzite of Olostunturi described in this paper. Hackman (1927) has described a crystalloblastic sillimanite-quartzite found as pebbles in a conglomerate from the western slope of the hill Petäjänmaa, Kolari.

Wilkman has described sillimanite-quartzites from the north-eastern slope of the hill Pieni Neulamäki, and on the western slope of the hill Suuri Neulamäki, Kuopio. In the former sillimanite occurs as bunches of long needles usually enclosed in the the quartz grains. In the quartzite of Suuri Neulamäki the sillimanite appears mainly between the granoblastic quartz grains parallel to the schistosity. Muscovite and hematite occur in small amounts. Sillimanite occurs also in the quartzite at Korsunmäki, Kuopio, together with muscovite and a small quantity of ore grains. Feldspar is found as a minor constituent in this rock (Wilkman, 1923).

The quartzite of Koli contains another mineral of the same formula, Al_2SiO_5, viz., kyanite (p. 89).

The third Al_2SiO_5-mineral, andalusite, has only been met with together with other minerals rich in alumina, such as muscovite and biotite. Hackman and Wilkman (1929) described such a quartzitic schist from Kuolajärvi, on the bank of the river Kirintöjoki. Tourmaline, microcline and zircon appear as accessories in this dark-gray rock. The andalusite is seen as light points on the fresh surfaces and as pits on the weathered surfaces.

All three Al_2SiO_5-minerals must have been derived from hydrous silicates of aluminium, such as kaolin, $H_4Al_2Si_2O_9$, etc., which are present in clays. All these silicates break down into mixtures of Al_2SiO_5 and SiO_2 in complete dehydration. Andalusite may also form by a reaction between muscovite and chlorite, as described e. g. by K. Dalmer (1897). A phyllite containing muscovite and chlorite has been transformed by contact metamorphism into a biotite-andalusite schist.

Probably still more important is the possible formation of some of the aluminium silicate minerals from the muscovite (or sericite) which, in turn, may have been formed from potash feldspar by hydrothermal alteration, often in connection with deformation. This is important, as by means of such a process an excess of alumina may originate without weathering differentiation (Arno Schüller 1936). According to Schüller, certain sericite-gneisses in the Fichtelgebirge have been thus formed during »epizonal» metamorphism according to the equation.

$$\underset{\text{Orthoclase}}{3KAlSi_3O_8} + H_2O \rightarrow \underset{\text{Sericite}}{H_2KAl_3Si_3O_{12}} + \underset{\text{Alkali in solution}}{K_2O + 6SiO_2}$$

Later contact metamorphism has changed the sericite into potash feldspar and andalusite or sillimanite:

$$H_2KAl_3Si_3O_{12} + SiO_2 \rightarrow KAlSi_3O_8 + Al_2SiO_5 + H_2O.$$

It is not quite impossible that such a reverted double metamorphism could in part be responsible for the origin of sillimanite in the microcline-rich sillimanite-quartzites of Western Lapland; a definite decision in this question would however require more extensive petrographical studies than could be carried out in this work, besides chemical analyses. As for the sillimanite quartzites of Southwest Finland, such as Tiirismaa, or the kyanite-quartzite of Koli, this explanation seems to be barred, as the quartzites are quite devoid of potash feldspar.

The formation of one or another of the three isomeres is dependent upon the conditions of metamorphism. As all three modifications of Al_2SiO_5 have different specific gravities, viz. andalusite 3.15, sillimanite 3.24, and kyanite 3.61, pressure must exert a considerable influence upon their formation, and also temperature, as kyanite and andalusite are convertible into sillimanite at high temperatures.

2. If potassium has been present in the cement containing hydrous silicates of aluminium, the metamorphic rock is likely to contain mica which, also, may have existed already in the clay. Väyrynen has described sericite quartzites of Kainuu and according to his opinion the sericite here has been derived from kaolin by addition of K_2O from percolating solutions. (Väyrynen 1928 p. 34.) The sericitization of feldspar is a common process in the metamorphism of igneous as well as sedimentary rocks. Accordingly the mica may originate also from feldspar. This must have been the case in several quartzites, for instance in Taalikkala and in Western Lapland. However, feldspar is usually still present, being only partly altered into mica. No traces of feldspar are found in the pure sericite-quartzites of the Kainuu district, a fact supporting the idea that their sericite has been formed from hydrous silicates of aluminium.

The sericite quartzites of Yllästunturi, Muonio, Kallovaara and Pittionvaara, Sodankylä (Hackman 1927 p. 60) contain fuchsite. The quartzite of Yllästunturi has partly a clastic structure and contains tourmaline and zircon as accessories. The occurrence of chromium in these quartzites is difficult to explain. If the forming of sericite has taken place so that the original quartz sand has been argillaceous and potassium has been present in percolating solutions (Clarke 1924 p. 622) the idea that the chromium has been associated with potassium in these solutions is not far out, but it is not easy to see whence the chromium has been derived. In all the localities mentioned this fuchsite-quartzite occurs together with a dark coloured mica-schist and belongs, according to Hackman, to the lower quartzite zone. The muscovite-bearing quartzite of Pieni Kangaslampi, Kuhmoniemi, (Wilkman 1921) contains beds in which fuchsite is met with. The fuchsite here seems rather to be a product of recrystallization of weathered chromium-bearing minerals originally present in quartz sand.

The quartzites of Western Lapland contain mainly feldspar as a minor constituent and this feldspar is microcline. If plagioclase is present it has generally altered into sericite. Consequently these quartzites represent almost pure members of the KAl-silicate quartzites of arkosic origin. The alteration of the plagioclase into sericite is not easy to explain. Clarke (1924 p. 605) assumes that if both albite and orthoclase are present the potassium feldspar first forms sericite according to the following equation:

$$3KAlSi_3O_8 + H_2O \rightarrow KH_2Al_3Si_3O_{12} + K_2SiO_3 + 5SiO_2$$

and the derived potassium silicate thereupon reacts upon the albite, forming potassium mica without paragonite.

This reaction demands a high temperature and pressure. If carbonated water is present the reaction is as follows:

$$3KAlSi_3O_8 + H_2O + CO_2 = KH_2Al_3Si_3O_{12} + K_2CO_3 + 6SiO_2$$

The potassium carbonate forms potassium silicate with one molecule of the liberated silica, and the CO_2 set free can assist in further alteration of feldspar. The occurrence of calcite together with sericite seems to indicate that carbonated solutions have helped the reaction. If only plagioclase is present its alteration is possible in the presence of potassium-bearing solutions, which exchange alkalies with the sodium compounds. In the quartzites of Western Lapland the microcline is not altered at all or only in very small amounts, but plagioclase, as described above, is at the present time almost completely substituted by sericite. In this case the potassium cannot have been derived from microcline; consequently it must have been present in solutions and have caused the change of the plagioclase, the microcline remaining intact. In accordance herewith, we can speak about potassium metasomatism in Western Lapland and also in the Kainuu district. The process could be compared to, though contrasting with, the soda metasomatism in the Stavanger-district described by Goldschmidt (1921). Before metamorphism the sandstones were arkosic in Western Lapland and argillaceous in Kainuu. Potassium-bearing solutions have been present in both districts, transforming albite as well as kaolin into sericite. Where calcite is found together with sericite, as for instance in Selkie, Kontiolahti, the sericite may be derived from feldspar as well as clays. In this district, however, carbonates are common, and occasionally very abundant in quartzites. Hadding (1929, p. 19) has found calcite to be common in the cement of the argillaceous sandstones. In metamorphism such a sandstone should form a quartzite of the Kontiolahti type.

3. When the plagioclase of the arkosic quartzites is richer in anorthite, it may undergo an alteration into epidote, zoisite, or clinozoisite. The transformation is common but not complete. Clarke (1924 p. 606) presents the following reaction:

$$\underset{\text{Albite}}{NaAlSi_3O_8} + \underset{\text{Anorthite}}{4CaAl_2Si_2O_8} + \underset{\text{Water}}{2H_2O} =$$

$$\underset{\text{Zoisite}}{2Ca_2HAl_3Si_3O_{13}} + \underset{\text{Paragonite}}{H_2NaAl_3Si_3O_{12}} + \underset{\text{Quartz}}{2SiO_2}$$

and points out that the variation in the composition of the feldspars and other reacting substances in solutions complicates the reactions. The presence of potassium feldspar causes the forming of muscovite instead of paragonite.

In the Pre-Cambrian of Finland clinozoisite and epidote occur plentifully in two quartzite areas of South-west Finland, viz. the clinozoisite in the quartzite of Kälviä and the epidote in that of Tiirismaa and Taalikkala. In both districts it has probably been produced from feldspar, which is abundantly present and consists mainly of plagioclase. Sericite occurs as another product of the transformation of feldspar and it appears, together with clinozoisite and epidote, also as an aggregate still showing the external shapes of feldspar grains. Clinozoisite and epidote have been recrystallized, appearing as comparatively large grains between the quartz grains. Both these districts have been metamorphosed at a lower temperature, the quartzite of Kälviä showing a granoblastic structure and the rock in Taalikkala being distinctly blastopsammitic.

In the epidote-quartzite of Tiirismaa epidote occurs very abundantly and in the same manner as in the former areas. Muscovite and chlorite are common minor constituents. A few aggregates consisting of finer-grained epidote and muscovite still show the external forms of feldspar grains.

4. The large number of (Mg,Fe)Ca-silicate minerals causes a diversity of types of quartzite in this class. In most cases they have been derived from dolomitic sandstones and the rocks vary according to the degree of their metamorphism and to the character of their other constituents. All degrees of metamorphism can be observed in the Finnish quartzites. Dolomite-bearing quartzites are common in Kainuu, for instance, in Melalahti and Kiehimä (Wilkman 1931). The glassy quartzite of Melalahti contains, besides a dolomite cement, only a few pyrite grains. The quartz shows strain shadows. In the quartzite of Kiehimä mica and zoisite occur together with dolomite. A dolomitic quartzite from Suojärvi shows a clastic structure, the dolomite occurring as cement between rounded quartz grains.

In the Kainuu district the tremolite-quartzite has been met with for instance in Paltamo, Melalahti, in the Kainuu region, where Professor Eskola has found a blastopsammitic variety which contains abundant tremolite as long needles between the quartz grains. Hackman and Wilkman (1929) have described a glassy quartzite near the farm Maaninka, Kuusamo, containing green-coloured aggregates of tremolite. The tremolite has evidently been formed by the reaction of silica upon dolomite, which is common in the quartzites of the neighbouring districts.

Diopside belongs to a higher grade of metamorphism of the same series. Its occurrence as lenses and beds in the quartzite of Simsiö shows the last member of the dolomite-quartzite series which begins with the clastic dolomite-quartzite. These dolomite-quartzites have been derived from sandstones in which the cement consisted of calcium and magnesium carbonates.

The quartzites of the Karelidic zone generally contain dolomite and also the limestones here are dolomitic. In contrast with these components the quartzites of South-west Finland sometimes contain diopside or wollastonite.

The stability relations of carbonates and silicates in limestones and quartzites derived from carbonate-bearing sandstones are apparently as follows. At the lowest temperatures quartz and dolomite are stable together. The following equations show the four known reactions which take place between quartz and dolomite or calcite at successively higher temperatures (Eskola 1919, 1922):

1. $\leftarrow$
2. $\rightarrow$ $8SiO_2+5CaMg(CO_3)_2+H_2O \rightleftarrows H_2Ca_2Mg_5Si_8O_2 +3CaCO_3+8CO_2$
quartz dolomite water tremolite calcite

3. $2SiO_2+CaMg(CO_3)_2 \rightarrow CaMgSi_2O +2CO_2$
quartz dolomite diopside

4. $SiO_2+CaCO_3 \rightarrow CaSiO_3+CO_2$
quartz calcite wollastonite

The first reaction occurs at the lowest temperature and the fourth at the highest one. In South-west Finland some diopside occurs, generally together with wollastonite, for instance in Kuparsaari. According to these four equations there are four kinds of carbonate rocks and quartzites occurring at different temperatures of metamorphism, viz., 1) dolomite-quartzites, 2) tremolite-quartzites, 3) diopside-quartzites, and 4) wollastonite-quartzites. Consequently we have here a geological thermometer whose indications of course also depend upon pressure.

According to Hadding (1929, p. 22) iron carbonate $FeCO_3$ is a common cement mineral in sandstones. The origin of siderite may be analogous with that of calcite, viz. by direct precipitation from the solution of bicarbonate, or it may have been formed through the replacement of limestone by iron (Twenhofel 1926, p. 331). Fossils consisting originally of calcite are frequently now composed of limonite, a decomposition product of the siderite. Siderite is easily oxidized to limonite by solutions of aquatic vegetation, so that the deposit formed is not carbonate, but hydroxide. Ferrous carbonate is consequently more unstable than calcite and magnesite. Between all these carbonates there are many transitional mixtures, and the ankerite $CaFeC_2O_6$, isomorphous with dolomite, occurs usually together with the manganese carbonate, $MnCO_3$, and other carbonates, for instance in the siderite deposits of Penohee district, Michigan (Clarke 1924, p. 583).

In the metamorphism all these carbonates react upon silica, forming different mineral species according to the character of the mixed salts and to the temperature of metamorphism.

Some iron is commonly present in these minerals. If the content of iron is more considerable we have a quartzite containing hornblende. Such quartzites are known from Degerö, Helsinki, and Välivaara, Pallastunturi; in both cases the hornblende has a metasomatic origin. In South Ostrobothnia we have, however, several quartzites which contain minerals rich in iron, together with calcium, magnesium and manganum-bearing minerals, or the rock may contain only one iron mineral, as in Nurmo. In the Simsiö quartzite diopside is most common, but rhodonite and pyroxmangite also occur in abundance. Hornblende and grünerite are found in small amounts, the latter together with the iron-manganese minerals. The common occurrence of diopside indicates that Ca- and Mg-carbonates have deposited with quartz sand, building the dolomitic cement of the sandstone derived from this sand. A part of the iron has probably been deposited as siderite together with the manganese carbonates.

Iron and manganese are dissolved and escape from the rocks by the same reagents at the same time and they are redeposited under similar conditions. A more or less perfect separation of these elements is, however, effected during the early stages of diagenesis, manganese remaining much longer in solution as bicarbonate than iron does. This kind of separation has evidently taken place in the manganese-iron ore deposits of Macskamezö (Kossmat u. C. von John 1919, Quiring 1919) and India (Hezner 1919, Fermor 1919). The manganese is eventually deposited as carbonate in different places than are the iron hydroxides. During the metamorphism manganese and ferrous carbonate have reacted upon silica, building silicates, whereas iron oxides and sulphides have recrystallized uncombined. In the course of deformation the minerals were accumulated in different positions.

In Vittinki these two substances occur well separated in neighbouring portions of the rocks and the separation is seen also in the composition of the minerals. There occur, namely, nearly pure manganese silicates together with iron oxides. To what extent this separated occurrence of iron and manganum in these rocks is a function of an original layered mode of deposition and to what extent it is the result of segregative changes during metamorphism is difficult to state.

In Simsiö iron and manganum occur, however, as components of the same minerals, viz. of pyroxmangites and ferroferous rhodonites, their ratio being variable in different points. One might suppose that the presence of other carbonates had made iron oxide able to react upon silica, but as this reaction has taken place neither in Vittinki nor in other localities which are comparable with it, the assumption that iron-rich manganese minerals are derived from mixtures of siderite, rhodochrosite and some calcium and magnesium carbonates seems more probable.

Accordingly only a part of the iron has been precipitated as hydroxides while together with manganum another part is carried farther in solutions as bicarbonates, and both are then deposited in the same localities as carbonates. The common occurrence of the grünerite in the manganese mineral accumulations affords evidence in favour of the same explanation. But now we must remember that iron-rich silicates, such as iron-hypersthene and grünerite, also occur in Vittinki. If the iron silicates are formed from siderite, this mineral here must have been deposited in different places than has been the case with the manganese carbonate, or the reaction between these two may be possible only when lime is present. As noted in the description, lime is common in the Simsiö, but negligible in the Vittinki quartzite. The reactions between calcite and iron were noted as having taken place so that iron solutions react upon calcite, and in such cases this reaction should have been complete in Vittinki. If so, siderite is formed by this reaction, and we have in any case a mixture of the carbonates before the high temperature metamorphism.

5. Concerning the formation of grünerite the same discussion of the origin of siderite is proper. The most probable assumption no doubt is that the grünerite has been formed from siderite. In the quartzite of Nurmo the grünerite occurs as a cementing mineral between still rounded quartz grains. It has evidently been derived from the cementing material of the original sandstone. In metamorphism this siderite then reacted upon silica, forming grünerite. Iron hydroxides generally do not seem able to react upon silica. Instead they are transformed into oxides. As mentioned above, also siderite may alter into hydroxide in the presence of oxygen, so that the original content of this carbonate may have been larger than indicated by the present amount of grünerite. Magnetite is always a common constituent in the grünerite quartzites and this iron oxide may have originated from siderite by means of oxidation as well as from iron hydroxides.

Fermor and Hezner have given a number of reaction equations which show the equilibrium relations between manganese, silica, carbon dioxide, and manganese silicates at different temperatures. At the lower temperatures the following assemblages are stable:

$$\mathrm{MnSO_3,\ SiO_2,\ MnSiO_3,}$$
$$\mathrm{MnCO_3,\ SiO_2,\ CO_2,}$$

and at higher temperatures

$$\mathrm{MnSiO_3,\ SiO_2,\ CO_2,}$$
$$\mathrm{MnSiO_3,\ MnCO_3,\ CO_2}$$

occur instead of the former. Tephroite is formed at still higher temperatures according to the following equations:

$$\mathrm{MnCO_3 + MnSiO_3 \rightleftarrows MnSiO_4 + CO_2,}$$
$$\mathrm{MnO + MnSiO_3 \rightarrow Mn_2SiO_4,}$$
$$\mathrm{2MnO + SiO_2 \rightarrow Mn_2SiO_4.}$$

The chemical character of iron is in many respects comparable with that of manganum, but the reaction of FeO upon silica generally does not occur. The formation of grünerite may therefore be supposed to take place according to the following equation:

$$\mathrm{7FeCO_3 + 8SiO_2 + H_2O \rightarrow H_2Fe_7Si_8O_{24} + 7CO_2}$$

At the higher temperature the iron-hypersthene would probably be formed according to the following equations:

1. $\mathrm{FeCO_3 + SiO_2 \rightarrow FeSiO_3 + CO_2}$
2. $\mathrm{H_2Fe_7Si_8O_{24} \rightarrow 7FeSiO_3 + SiO_2 + H_2O}$
3. $\mathrm{H_2Fe_7Si_8O_{24} + FeCO_3 \rightarrow 8FeSiO_3 + CO_2 + H_2O}$

Consequently the siderite-quartzite is stable at the lowest temperatures. Grünerite-quartzite is derived from it by one degree higher metamorphism, and quartzites containing iron hypersthene characterize the metamorphism of the highest temperature. In Vittinki iron-hypersthene and tephroite occur together with grünerite and rhodonite, showing that the metamorphism has taken place at fairly high temperatures. According to this the metamorphism of the Simsiö quartzite has been one degree lower, as here neither iron-hypersthene nor tephroite has been found.

Grünerite is common in the quartzite areas of South Ostrobothnia, being most abundant in Nurmo, where calcium and manganum are absent. In the quartzite of Laihia it is also a minor constituent, besides the iron ores. It is rare in Simsiö, occurring, however, sometimes together with the pyroxmangite. In Vittinki it has been found together with the iron-hypersthene.

In the quartzite of Tiirismaa magnetite and hematite are fairly common, and no iron silicate minerals occur. In this case the original sand has apparently contained iron and aluminium hydroxides, the latter having reacted with silica forming sillimanite. In Taalikkala corundum occurs in quartzite. Consequently the aluminium oxide has not here reacted upon silica, a fact which indicates a fairly low grade metamorphism.

When limonite has been present as cement in sandstone, magnetite has been derived from it by dehydration and partial autoreduction. In this case the quartzite contains only magnetite as a minor constituent. In Laihia magnetite occurs as dispersed grains between the quartz grains, and other minor constituents are very few, only a small amount of grünerite being present. Some iron is probably deposited as siderite, but the main part is deposited as hydroxides.

Quartzites containing bands rich in iron ores have been described by Hackman (1925 and 1927) from the Porkonen and Pahtavaara districts in Kittilä-Lapland. These iron ores consist mainly of magnetite and some hematite. Magnetite occurs as very fine-grained aggregates as well as coarse-grained crystals. Apatite and carbonates, probably calcite (dolomite) and siderite, occur as minor constituents in these quartzites. These quartz-banded iron ores and associated »jaspilitic» quartzites belong to a well-known type distributed all over the world. In America they are known under the name of the »iron formations» (W. H. Collins 1928).

Magnetite as placers from original shore-deposits is not rare in the sedimentogeneous rocks of Finland. For instance in Mauri, Suoniemi, magnetite grains are seen in arkosic gneiss (»leptite» of J. J. Sederholm 1897) lying in bands parallel to the schistosity and having evidently been concentrated in these places in the original sand of the shores. The gneiss from Someronvuoret, on which Sander carried out a petrofabric analysis (cf. p. 10), belongs to the same arkosic gneiss.

Iron oxides as well as sulphides are extremely common in quartzites and their deposition has taken place in waters simultaneously with the sand deposition as described earlier.

6. Even though calcite is the most common of all carbonates, it has seldom been found to exist as pure in quartzites. It is usually accompanied by other carbonates or clays, which in subsequent metamorphism have formed other minerals and not wollastonite, which should occur if the lime was pure. In Finland some calcite-bearing quartzites are found in Kainuu, for instance in Korholanmäki, Kajaani (Wilkman 1931). The wollastonite-quartzite of Kuparsaari, Antrea, is an

extreme example of blastopsammitic quartzites of this type. It occurs in the contact zone between limestone and pure quartzite. Calcium carbonate has reacted upon silica, forming wollastonite $CaSiO_3$ (cf. p. 102).

The precipitation of calcite in waters has been well studied, and it is a common cement of sandstones.

7. Graphite in quartzites has been derived from bituminous materials in original sands. The hydrocarbons are formed first, and thence by dehydration coal. Schists containing coal are not rare, and in a high temperature coal is transformed into graphite, which is a common minor constituent in the quartzites of Ostrobothnia. An alternative mode of formation of graphite is by the reduction of CO_2 from the carbonates. Laitakari (1925) has thoroughly discussed the origin of graphite in Finland. From his exposition the most probable assumption concerning the graphite in quartzites would seem to be that it is of organogeneous and bituminous origin.

Thus, with the exception of the peculiar metasomatic quartzites connected with sulphidic ores, all quartzites of the Pre-Cambrian of Finland are of sedimentary origin. In most cases this fact is also seen in the structure of the quartzites. Although the quartzite is wholly recrystallized there are always some portions in the rock masses where traces of clastic structure are visible as impure grain boundaries. In the best instances conglomerates occur in connection with quartzites, giving conclusive evidence of their origin. As nearly all degrees of metamorphism are to be found among the quartzites, we can follow the formation of the accessory minerals and, in accordance therewith, the formation and deformation of the quartzite rocks. The mineral facies of the accessories indicates the conditions during metamorphism. Comparison of the chemical composition of the quartzites with that of the sandstones and finally with that of the sands indicates the geological and other circumstances in which the original quartz sands have been deposited. Our survey of the Finnish quartzites from this point of view leads to a general and unrestricted confirmation of the actualistic principle. The sedimentogeneous quartzites of Finland have primarily originated as sand in the same way in which sand deposits are formed at the present day.

C. PETROFABRICS.

Figure 16 (Pl. VIII) shows schematically 12 types of quartz orientation found in tectonites.

Sahama (1936) and Fairbairn (1937) have represented the known types of quartz orientation in similar ways. They have ten different types, but in the quartzite of Olostunturi there occurs a developed type, which is not one of the known types, viz., No. 4, in fig. 16 (Pl. VIII).

Fig. 17 (Pl. VIII) shows the maxima from 1 to 6 and 8 and 11 in fig. 1. They are numbered I to VII.

I to IV refer to Sander's maxima in D 61 (Sander 1930), V and VI have been rarely found before, but are important in the Finnish quartzites. V is common in the quartzite of Simsiö described in this paper, VI occurs in the quartzites from Olostunturi, (D.M. 20) and VII also in the same quartzite (D.M. 23).

The orientation of all the known quartz maxima with respect to plane 'ab' has been deductively explained by Schmidt, assuming three glide directions in quartz grains. These glide directions are the prismatic axis [0001], the prism-base edges $[2\bar{1}\bar{1}0]$ and the unit rhombohedron edges $[2\bar{1}\bar{1}3]$ according to the directions of closest packing of Si atoms in the quartz lattice.

Type 1 was the first type of quartz orientation (Trener 1906). Since Trener this type has been illustrated by Andreatta in the quartzite from Riva di Tures. (0001) is orientated parallel to 'ab' and $[2\bar{1}\bar{1}0]$ parallel with 'a'. In the quartzites of Simsiö this type prevails in the glassy variety and, as described earlier, gliding along the basal plane has actually taken place.

Type 2 is very common and has been explained by the orientation according to the prism rule, or γ-rule, (Sander 1932, D 24, 26, 27). $(10\bar{1}0)$ is parallel with 'ab' and [0001] parallel with 'a'. This type is frequently associated with a girdle or with other maxima. The single maximum is found less often and is supposed to be caused by the predominance of the glide direction parallel to the c-axis in the quartz lattice. In the diagrams of the quartzites from Junkirova, Rautakero and Jyppyrä one well developed maximum occurs in the 'ab'-zone (D.M. 1 and D.R. 4) or in an asymmetrical position near to 'a' (Jyppyrä). In all these cases ruptural strain shadows and in some cases visible shear surfaces indicate that the prism planes have acted as gliding planes and thus the gliding direction is indicated by the position of the maximum. These diagrams represent Type 2, in which the maximum is caused by a later differential movement. This movement has reorientated the quartz grains, but it has not been able to re-deform the schistosity of the rock.

Type 3 presents maximum II of Sander. It is not common and has been explained in different ways. Sander assumes the predominance of the prism rule and in this case two shear surfaces intersecting in 'b'. Schmidt favours the orientation of various lattice planes and lines into a single shear surface 'ab'. In this type for instance $(\bar{2}1\bar{1}2)$, or $(11\bar{2}2)$, is parallel with 'ab', and $[\bar{2}1\bar{1}3]$ parallel with 'a'. The quartz crystal has one degree of freedom, the c-axis may be situated in one or another maximum which lies symmetrically around 'ab'. The two maxima may be also explained by twinning. If $(\bar{2}1\bar{1}2)$ is a twinning plane, the vertical axes are 84°33′ apart from each other, which is the approximate angle in the diagrams. This type has been described by D. Korn (1932) in an itacolumite from Minas Geraes and by Sander (1930, D 39) in a granulite from Geiersberg in Rosswein, Saxony. In the quartzites of Finland two symmetrical maxima in the 'ac'-zone occur in Simsiö (D.S. 5) the maxima are situated near to 'c' and are probably formed by the dividing of the maximum at 'c' into two separate maxima, and thus the same crystal faces have acted as gliding planes during the orientation process. Only the direction of gliding has oscillated.

Type 4 occurs in the quartzite from Olostunturi (D.M. 23). It has $(10\bar{1}0)$ in 'ab' and $[\bar{2}1\bar{1}3]$ parallel with 'a'. As the quartz grains have one degree of freedom, two directions for 'c' are possible as in case 4 and these two directions cause two maxima, symmetrical about 'ac'. The statistical angle in the diagram is about 106°. Other diagrams from the neighbouring district show an 'ab'-girdle formed from single maxima (D. M. 4, 20). In D. M. 20 the maxima I, VI and VII appear.

Type 5 has been first described by Schmidt (1925 p. 421) in a paragneiss, the Mugl gneiss from the Eastern Alps, and is explained as follows:

Maximum at 'a': $(10\bar{1}0)$ in 'ab', and axis c parallel with 'a'.

Maximum at 'c': basal plane in 'ab', which is the gliding plane.

The girdle is explained by the variation of the gliding direction in the basal plane, or by supposing an internal rotation around 'b'. Philips (1937) has recently described the same type in the Moine schists.

D.S. 40 of quartzite from Jänismäki, Lapua, is an excellent example of this type. Vittinki No. 3 belongs also to this type of orientation.

Type 6 has also been described by Schmidt (1925) in rocks from Greiner Scholle and Val Piora. The maximum in 'b' is caused by $(10\bar{1}0)$ being in 'ab' and $[\bar{2}1\bar{1}0]$ being parallel with 'a'. The maxima in the 'ac'-girdle are explained by planes of prism-basis zone as gliding planes and the edges of these planes with the principal sections as glide-direction. In Olostunturi (D.M. 20) the 'ab'-girdle is connected with maxima VII.

Type 7 is the most common type of quartz orientation and it has been described by many authors, for example by Doris Korn (1928), Lisbeth Korn (1932) and Portman (1928) in crystalline schists from South-west Germany; by Fairbairn (1935 b) in rocks from Oak-Hill and the Sutton formation; by Drescher (1932) in »Dattelquartzite» from Krummendorf, Silesia. Sander, Felkel and Reithofer (1929), Johs (1933) and Maroscheck (1933) have found it in rocks which have recrystallized under stress. This type of orientation has been called B-tectonite by Sander. Axis B is the axis of translation, and Sander supposes it to be a line along which all the shear surfaces intersect.

In Finnish quartzites 'ac'-girdle is common, but it occurs usually in connection with one or several maxima.

Types 8 and 9 are characteristic of granulite areas and have been described by several investigators, type 8 notably by Sander (1930 D 40, 41, 42, 46), Sahama (1936), Closs (1935 b), and Osborne (1936), and type 9 by Rüger (1930), Seng (1931, 1934), Sander (1930 D 43, 45) in granulites from Saxony. Schmidt (1926) has found the two-girdle figure in rocks from the Alps, and Closs (1935 a) in rocks from East Graubünden. The Tiirismaa quartzite belongs to this type.

The maxima in type 8 indicate the orientation of $(10\bar{1}1)$ in 'ab' and of [0001] parallel with 'a'. Two degrees of freedom are possible and two maxima appear symmetrically abount 'ab'. The maximum in 'a' is associated with them and indicates the glide direction parallel to 'a' (Sander 1932, Sahama 1936).

Type 9 is explained by Sander (1934) as girdles of maxima II and III with the corresponding shear surfaces (h 0 l) and (0 k l). I have found this type in a quartzite from Kainuu, (D. Ka. 1.) as described in the present paper (p. 45) and in this case maximum II occurs with maximum III, which is situated near to 'c'. The girdles indicate a rotation axis parallel to 'c'.

In type 10 two girdles have 'b' as rotation axis. The four maxima have been explained by Schmidt, assuming the orientation of $(10\bar{1}1)$ in 'ab' and $[2\bar{1}\bar{1}3]$ in 'a'. Two $[2\bar{1}\bar{1}3]$ directions intersect in $(10\bar{1}1)$ plane and this causes one degree of freedom and maxima symmetrically about 'ac'. Maxima lying symmetrically around 'ab' are caused, as in the cases of 4 and 9. The grains move out of the maxima by means of an intergranular rotation during the deformation, which may bring about a parallel linear arrangement of the grains in the fabric axis 'b'. As a rule, the girdles perpendicular to the tectonic axis 'b' indicate intergranular movement around 'b' and single maxima, as in types from 1 to 5, may appear only in the absence of this movement.

Type 11 has been described by Sander (1930) and Fairbairn (1937 p. 71). In Vittinki D.V. 2 may represent the best developed example of this type among the Finnish quartzites. Type 11 is explained as the »B ⊥ B′ rule» by Sander (1930). The girdle perpendicular to 'a′ requires the same interpretation as has been set up for the 'ac′-girdle, i. e., a rotational strain and intergranular rotation. The strain in this case is called a »crossed» strain. The rotation axis is 'a′. Schmidt has described this type in some rocks from the Pennine Alps (1926).

In type 12 we have three girdles perpendicular to each other and in conformity with the previously mentioned three separate strains, at right angles to one another. This rare type is described by Rüger (1933) in a gneiss from Obermittweida, Saxony.

Among the quartzites of the Pre-Cambrian of Finland well developed examples of two main types of quartz orientation are met with. The plastic deformation occurs in connection with the ruptural one in the quartzites of South Ostrobothnia, being dominant in some cases (Simsiö). Shears have overprinted the orientations and generally rotational strain has also been in action, as is visible in the common occurrence of the girdle figures in the diagrams. The maxima appear mainly in the 'ac′-zone, or in a zone perpendicular to the schistosity. The orientation figures from Western Lapland are contrasted to them in this respect, as here the maxima are generally situated in the 'ab′-zone. Prism planes have acted as gliding surfaces and ruptural grain deformation has been dominant. Only in the quartzite of Olostunturi are Böhm striations visible in some specimens. In the rocks of Western Lapland post-crystallization movements have generally caused intensive shears and re-deformed the quartz grains, so that they have their prism planes parallel to the shear surfaces. Here we have one »Grossgleitfläche» (Rüger 1937, p. 203) and the prism planes have arranged themselves parallel to it, causing one well developed maximum. This is in accord with my observations of the deformation of individual quartz grains. In the beginning the plastic deformation appears as strain shadows, but soon the elasticity of the quartz lattice is exceeded and the crystal begins to yield by gliding. In the case of one shear the prism planes are generally orientated parallel to the gliding direction. But if there are several shears various crystal faces can act as gliding surfaces and all directions of closest packing are used. The gliding along prism faces is most possible, as the elasticity is smallest in this direction (Sonder 1933). Translations parallel to the basal plane and the rhombohedral faces cause visible traces in the quartz lattice as seen from the Böhm striations. This breaking can appear also in directions which oscillate from the basal pinacoid and this is probably due to the screw-like structure of the quartz lattice, as also the mode of breaking.

The petrofabric analyses of the quartzites of Svecofennidic territory show only at few places traces of the vertical movements, which have, however, been common in the Archaean formation of West Finland, with its chiefly vertical standing schistosity. The later movements have probably obliterated them and caused the present orientation, or this kind of movements has not taken place in the quartzite areas. Chiefly, the orientation process seems to be contemporaneous with the folding process. Some diagrams in the Simsiö area (D.S. 40, 46)) may give evidence of vertical movements.

Table XXIII shows the results of the petrofabrics compared to the tectonics in the Finnish quartzites.

Table XXIII.

The relations between the tectonics and the movements according to petrofabrics in Svecofennidic and Karelidic quartzites.

Svecofennidic quartzites.	*Karelidic quartzites.*
	A. Western Lapland.
1) »Schlingen» tectonics prevailing, 'b' mostly vertical, strike E.-W. with deviations.	1) Alpine tectonics, 'b' chiefly horizontal, strike mainly N.-S.
2) Dominant orientation: contemporaneous with the folding, differential movements horizontal, with many deviations.	2) Dominant orientation: »Overprinting». One strong horizontal penetrative movement.
(Exception: Tiirismaa, »Overprinting» dominant, but original orientation also preserved. Movements mainly horizontal).	(Exception: Olostunturi. Orientation contemporaneous with folding. Movement: the direction of 'a', the dip of which 20°—30°. Overprinting sometimes visible.)
	B. Kainuu and Karelia.
	1) Alpine tectonics, 'b' chiefly horizontal. Strike mainly N.-S. Dominant orientation: contemporaneous with folding: 'ac'-girdle. Traces of a girdle in the horizontal plane.

When the present work was commenced, the petrofabrics of the Karedilic zone were expected to be different from those of the Svecofennidic territory. This assumption has been partly fulfilled. but at the same time great local variations have been discovered. Thus the investigation of the petrofabrics must first apply to every special case and after that the general tectonical conclusions can give certain elucidation of the geological circumstances unde which the tectonites have been formed.

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N:o 1.	Ramsay, Wilhelm und Nyholm, E. T. Cancrinitsyenit und einige verwandte Gesteine aus Kuolajärvi. S. 1—12. 4 Fig. 1895	15: —
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: —
N:o 5.	Berghell, Hugo. Bidrag till kännedomen om Södra Finlands kvartära nivåförändringar. S. 1—64. 16 fig. 1 plansch. 1 karta. Deutsches Referat: Beiträge zur Kenntniss der quartären Niweauschwankungen Süd-Finlands. 1896	30: —
*N:o 6.	Sederholm, J. J. Über eine archäische Sedimentformation im südwestlichen Finland und ihre Bedeutung für die Erklärung der Entstehungsweise des Grundgebirges. S. 1—254. 97 Fig. 5 Taf. 2 Karten. 1897	75: —
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: —
*N:o 11.	Hackman, Victor. Neue Mitteilungen über das Ijolithmassiv in Kuusamo. S. 1—45. 12 Fig. 1 Taf. 2 Karten. 1899	25: —
*N:o 12.	Ramsay, Wilhelm und Borgström, L. H. Der Meteorit von Bjurböle bei Borgå. S. 1—28. 20 Fig. 1902	20: —
*N:o 13.	Frosterus, Benj. Bergbyggnaden i sydöstra Finland. S. 1—168. 18 fig. 8 tafl. 1 karta. Deutsches Referat: Der Gesteinsaufbau des südöstlichen Finland. 1902	70: —
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: —
*N:o 17.	Fircks, Curt. On the Occurrence of Gold in Finnish Lapland. P. 1—35. 15 fig. 1 map. Frontispiece. 1906	20: —
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: —
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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: —
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N:o 38.	Tanner, V. Studier öfver kvartärsystemet i Fennoskandias nordliga delar. III. Om landisens rörelser och afsmältning i finska Lappland och angränsande trakter. S. 1—815. 139 fig. 16 tafl. Résumé en français: Études sur le système quaternaire dans les parties septentrionales de la Fennoscandia. III. Sur la progression et le cours de la récession du glacier continental dans la Laponie finlandaise et les régions environnantes. 1915	150: —

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* Epuisée.
Out of print.

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:—
N:o 68.	Tanner, V. Jordskredet i Jaarila. S. 1—18. 2 fig. 10 bild. Résumé en français. 1924	15:—
N:o 69.	Auer, Väinö. Die postglaziale Geschichte des Vanajavesisees. S. 1—132. 10 Fig. 10 Taf. 11 Beil. 1924	50:—
N:o 70.	Sederholm, J. J. The Average Composition of the Earth's Crust in Finland. P. 1—20. 1925	20:—
N:o 71.	Wilkman, W. W. Om diabasgångar i mellersta Finland. S. 1—35. 8 fig. 1 karta. Deutsches Referat. 1924	20:—
N:o 72.	Hackman, Victor. Das Gebiet der Alkaligesteine von Kuolajärvi in Nordfinnland. S. 1—62. 6 Fig. 1 Taf. 1925	30:—
N:o 73.	Laitakari, Aarne. Über das jotnische Gebiet von Satakunta. S. 1—43. 14 Abbild. 1 Karte. 1925	30:—
N:o 74.	Metzger, Adolf A. Th. Die Kalksteinlagerstätten von Ruskeala in Ostfinnland. S. 1—24. 9 Abbild. 2 Karten. 1925	20:—
N:o 75.	Frosterus, Benj. Ueber die kambrischen Sedimente der karelischen Landenge. S. 1—52. 1 Fig. 1925	30:—
N:o 76.	Hausen, H. Über die präquartäre Geologie des Petsamo-Gebietes am Eismeere. S. 1—100. 1 Übersichtskarte. 13 Fig. 2 Taf. 1926	30:—
N:o 77.	Sederholm, J. J. On Migmatites and Associated Pre-Cambrian Rocks of Southwestern Finland. Part II. The Region around the Barösundsfjärd W. of Helsingfors and Neighbouring Areas. P. 1—143. 57 fig. in the text and 44 fig. on 9 plates. 1 map. 1926	60:—
N:o 78.	Väyrynen, Heikki. Geologische und petrographische Untersuchungen im Kainuugebiete. S. 1—127. 37 Fig. 2 Taf. 2 Karten. 1928	40:—
N:o 79.	Hackman, Victor. Studien über den Gesteinsaufbau der Kittilä-Lappmark. S. 1—105. 23 Fig. 2 Taf. 2 Karten. 1927	40:—
N:o 80.	Sauramo, Matti. Über die spätglazialen Niveauverschiebungen in Nordkarelien, Finnland. S. 1—41. 8 Fig. im Text. 11 Fig., 1 Profildiagramm und 1 Karte auf 7 Taf. 1928	15:—
N:o 81.	Sauramo, Matti and Auer, Väinö. On the Development of Lake Höytiäinen in Carelia and its Ancient Flora. P. 1—42. 20 fig. 4 plates. 1928	15:—
N:o 82.	Lokka, Lauri. Über Wiikit. S. 1—68. 12 Abbild. 1928	30:—
N:o 83.	Sederholm, J. J. On Orbicular Granites, Spotted and Nodular Granites etc. and on the Rapakivi Texture. P. 1—105. 19 fig. in the text and 50 fig. on 16 plates. 1928	50:—
N:o 84.	Sauramo, Matti. Über das Verhältnis der Ose zum höchsten Strand. S. 1—16. 1928	10:—
N:o 85.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, 1. 1 stéréogramme. P. 1—88. 1929	40:—

N:o 86.	Sauramo, Matti. The Quaternary Geology of Finland. P. 1—110. 39 fig. in the text and 42 fig. on 25 plates. 1 map. 1929	60: —
N:o 87.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, 2. P. 1—175. 48 fig. 8 planches. 1929	70: —
N:o 88.	Tanner, V. Studier över kvartärsystemet i Fennoskandias nordliga delar. IV. Om nivåförändringarna och grunddragen av den geografiska utvecklingen efter istiden i Ishavsfinland samt om homotaxin av Fennoskandias kvartära marina avlagringar. S. 1—593. 84 fig. 4 tavl. 1 karta. Résumé en français: Études sur le système quaternaire dans les parties septentrionales de la Fennoscandie. IV. Sur les changements de niveau et les traits fondamentaux du développement géographique de la Finlande aux confins de l'océan Arctique après l'époque glaciaire et sur l'homotaxie du quaternaire marin en Fennoscandie. 1930	150: —
N:o 89.	Wegmann, C. E. und Kranck, E. H. Beiträge zur Kenntnis der Svecofenniden in Finnland. I. Übersicht über die Geologie des Felsgrundes im Küstengebiete zwischen Helsingfors und Onas. II. Petrologische Übersicht des Küstengebietes E von Helsingfors. S. 1—107. 4 Fig. 16 Taf. mit 32 Fig. 1 Übersichtskarte. 1931	40: —
N:o 90.	Hausen, H. Geologie des Soanlahtigebietes im südlichen Karelien. Ein Beitrag zur Kenntnis der Stratigraphie und tektonischen Verhältnisse der Jatulformation. S. 1—105. 23 Fig. im Text und 12 Fig. auf 4 Taf. 1 Übersichtskarte. 1930	50: —
N:o 91.	Sederholm, J. J. Pre-Quaternary rocks of Finland. Explanatory notes to accompany a general geological map of Finland. P. 1—47. 40 fig. 1 map. 1930	30: —
N:o 92.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, 3. P. 1—140. 29 fig. 3 planches. 1930	50: —
N:o 93.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, 4. P. 1—68. 12 fig. 6 planches. 1931	40: —
N:o 94.	Brenner, Thord. Mineraljordarternas fysikaliska egenskaper. S. 1—159. 22 fig. Deutsches Referat. 1931	70: —
N:o 95.	Sederholm, J. J. On the Sub-Bothnian Unconformity and on Archæan Rocks formed by Secular Weathering. P. 1—81. 62 fig. 1 map. 1931	50: —
N:o 96.	Mikkola, Erkki. On the Physiography and Late-Glacial Deposits in Northern Lapland. P. 1—88. 25 fig. 5 plates. 1932	50: —
N:o 97.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, 5. P. 1—77. 15 fig. 1932	40: —
N:o 98.	Sederholm, J. J. On the Geology of Fennoscandia. P. 1—30. 1 map. 1 table. 1932	30: —
N:o 99.	Tanner, V. The Problems of the Eskers. The Esker-like Gravel Ridge of Čahpatoaiv, Lapland. P. 1—13. 2 plates. 1 map. 1932	15: —
N:o 100.	Sederholm, J. J. Über die Bodenkonfiguration des Päijänne-Sees. S. 1—23. 3 Fig. 1 Karte. 1932	50: —
N:o 101.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, 6. P. 1—118. 17 fig. 5 planches. 1933	50: —
N:o 102.	Wegmann, C. E., Kranck, E. H. et Sederholm, J. J. Compte rendu de la Réunion internationale pour l'étude du Précambrien et des vieilles chaînes de montagnes. P. 1—46. 1933	30: —

N:o 103.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, 7. P. 1—48. 2 fig. 1933	25: —
N:o 104.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, 8. P. 1—156. 33 fig. 7 planches. 1934	55: —
N:o 105.	Lokka, Lauri. Neuere chemische Analysen von finnischen Gesteinen. S. 1—64. 1934	30: —
N:o 106.	Hackman, Victor. Das Rapakiwirandgebiet der Gegend von Lappeenranta (Willmanstrand). S. 1—82. 15 Fig. 2 Taf. 1 Analysentabelle. 1 Karte. 1934	35: —
N:o 107.	Sederholm, J. J. On Migmatites and Associated Pre-Cambrian Rocks of Southwestern Finland. Part III. The Åland Islands. P. 1—68. 43 fig. 2 maps. 1934	40: —
N:o 108.	Laitakari, Aarne. Geologische Bibliographie Finnlands 1555—1933. S. 1—224. 1934	50: —
N:o 109.	Väyrynen, Heikki. Über die Mineralparagenesis der Kieserze in den Gebieten von Outokumpu und Polvijärvi. S. 1—24. 7 Fig. 1 Karte. 1935	20: —
N:o 110.	Saksela, Martti. Über den geologischen Bau Süd-Ostbothniens. S. 1—35. 11 Fig. 1 Titelbild. 1 Taf. 1 Karte. 1935	25: —
N:o 111.	Lokka, Lauri. Über den Chemismus der Minerale (Orthit, Biotit u. a.) eines Feldspatbruches in Kangasala, SW-Finnland. S. 1—39. 2 Abbild. 1 Taf. 1935	25: —
N:o 112.	Hackman, Victor. J. J. Sederholm. Biographic Notes and Bibliography. P. 1—34. With a vignette. 1935	20: —
N:o 113.	Sahama (Sahlstein), Th. G. Die Regelung von Quarz und Glimmer in den Gesteinen der finnisch-lappländischen Granulitformation. S. 1—119. 5 Fig. 80 Diagramme. 3 Taf. 1936	40: —
N:o 114.	Haapala, Paavo. On Serpentine Rocks in Northern Karelia. P. 1—88. 21 fig. 2 maps. 1936	30: —
N:o 115.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, 9. P. 1—505. 83 fig. 20 planches. 1936	100: —
N:o 116.	Paraîtra prochainement.	
N:o 117.	Kilpi, Sampo. Das Sotkamo-Gebiet in spätglazialer Zeit. S. 1—118. 36 Abbild. im Text. 3 Beil. 1937	50: —
N:o 118.	Brander, Gunnar. Ein Interglazialfund bei Rouhiala in Südostfinnland. S. 1—76. 7 Fig. im Texte u. 7 Fig. auf 2 Taf. 1937	40: —
N:o 119.	Paraîtra prochainement	

ADDENDA AND CORRIGENDA.

To Bibliography:

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FORD, W. E., and BRADLEY, W. M., Pyroxmangite, a New Member of the Pyroxene Group, and its Alteration Product: Skemmatite. Amer. Journ. Sci., No. 36, 1913.

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To Plates VIII—X:

All the petrofabric diagrams are drawn as seen from above.

The mineral composition of the quartzite of Taalikkala and Antamoinen (p. 73, and 106) was given according to Hackman (1934), and that of Kirintöjoki (p. 98) according to Hackman and Wilkman (1929), as also the other statements concerning the mineral compositions in the chapter „Petrochemistry'' were quoted from earlier investigations. Dr. E. Mikkola has stated, according to his communication, in the thin sections of Prof. Hackman, that there is no corundum in the quartzite of Antamoinen and no andalusite, but instead scapolite, in the quartzitic schist of Kirintöjoki.

Summation of Table IV for 100.12 read 99.62; omit 99.62 under Mol.
„ „ „ VI „ 100.22 „ 100.38
„ „ „ VII add — 0.01; Tables XIII, XVI, and XIX add + 0.01

Mode of Table XIX, Water	for	0.6	read	0.7
Title-page	„	8 Plates	„	10 Plates
Page 20 line 14 from top	„	Saksela (1933)	„	Saksela (1933 b)
„ 51 „ 7 „ „	„	fig. 26	„	fig. 13
„ 56 „ 4 „ „	„	D. L. 30	„	D. S. 30
„ 62 „ 19 „ bottom	„	D. L. 1	„	D. L. 2
„ 89 Table XXIII	„	Koli, Juuka	„	Koli, Pielisjärvi
„ 105 line 5 from top	„	$MnSO_3$	„	$MnCO_3$
„ 108 lines 5, 6 „ „	„	maxima from 1 to 6 and 8 and 11 in fig. 1	„	maxima of types 1—6, 8, 10 in fig. 16
„ „ line 18 „ bottom	„	Sander (1932)	„	Sander (1930)
„ 110 „ 7 „ top	„	Johs (1933)	„	Johs (1932)
„ 115 „ 9 „ „	„	Gloss and transfer to page 114.	„	Closs
Plate VIII Fig. 17 Maximum in b	for	IV	read	VI
„ „ D. S. 30	„	$\xrightarrow[\text{N90°E}]{}$	„	$\xrightarrow[\text{N75°E}]{90°}$
„ IX	„	D. Ti. 20	„	D. Ti. 27

PLATE I.

Fig. 1. Contact between granite and diopside-bearing quartzite west of Simsiö. 1. Quartzite. 2. Diopside. 3. Granite. Scale 1 : 7.

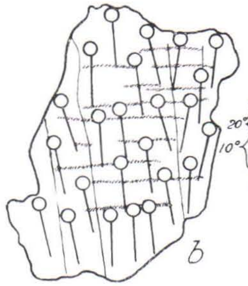


Fig. 2. Map of the c-axis in a quartz grain in quartzite from Petäjänvaara, Rovaniemi.

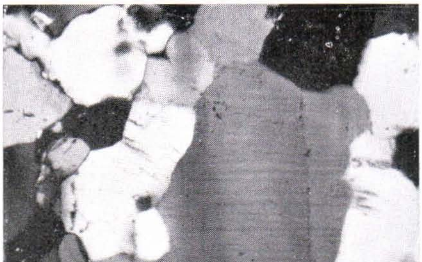


Fig. 3. The same quartz grain as in fig. 2. Magn. 25 diam.

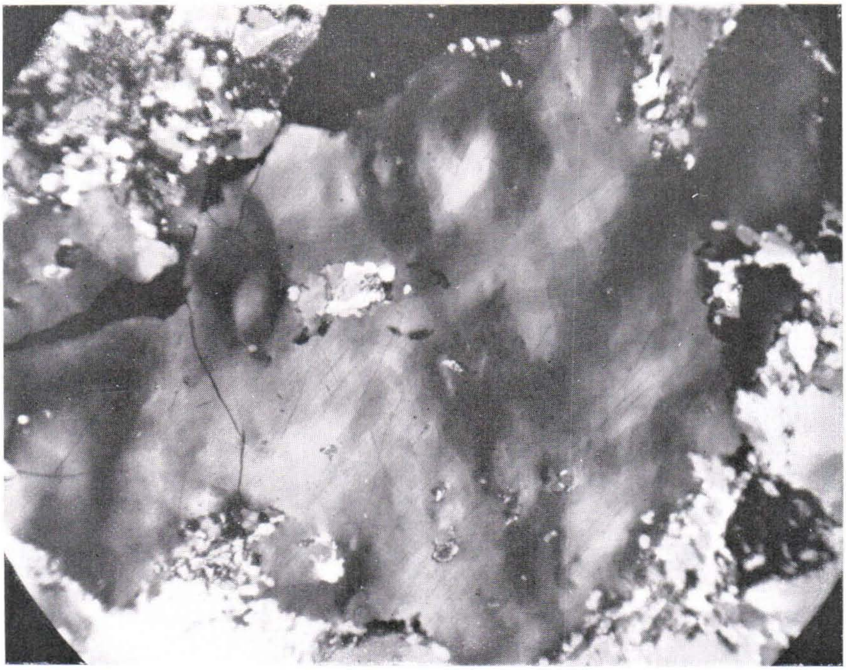


Fig. 4. Strained quartz perpendicular to the c-axis, Simsiö 27. Magn. 30 diam.

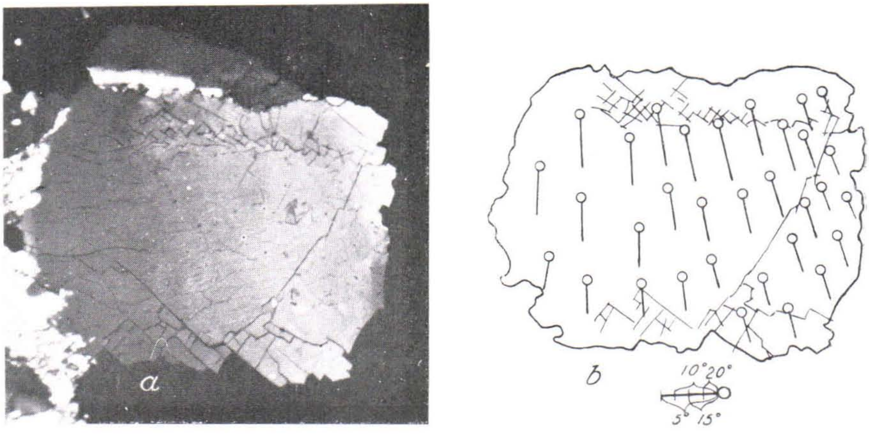


Fig. 5. Photo and axial map of a quartz grain. Maaselkä, Aunus. Magn. 20 diam.

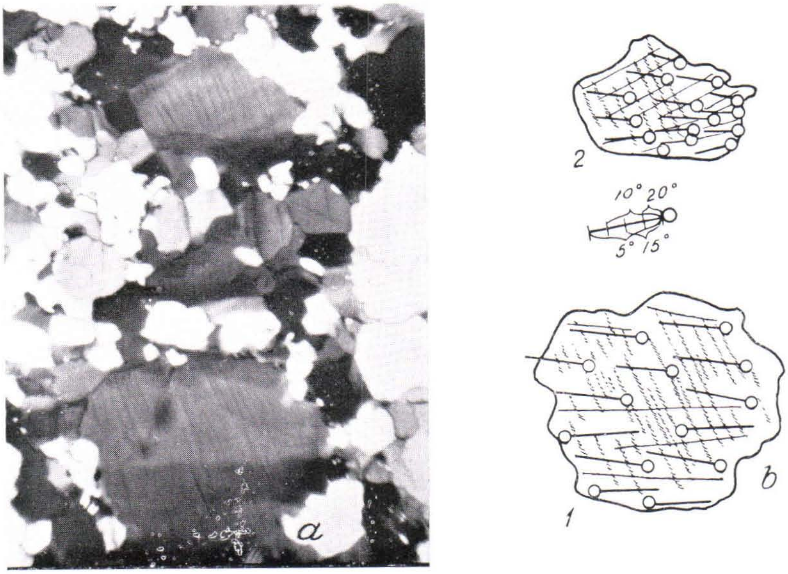


Fig. 6. Quartz grain with two visible deformations, Petäjävaara, Rovaniemi. The angles are multiplied by three. Magn. 25 diam.

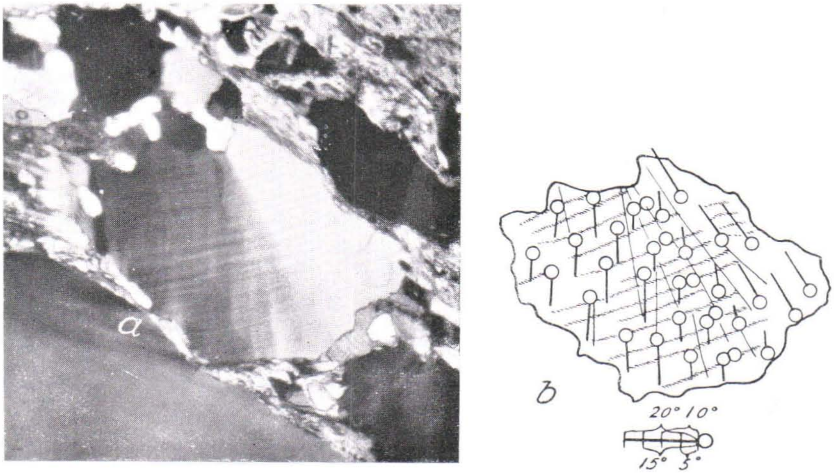


Fig. 7. Böhm striations and ruptural strain shadows. The other series of Böhm striations on the right hand side is situated in a plane which makes an angle with the plane of the figure. Quartzite from Selkie, Kontiolahti. Magn. 25 diam.

PLATE IV.

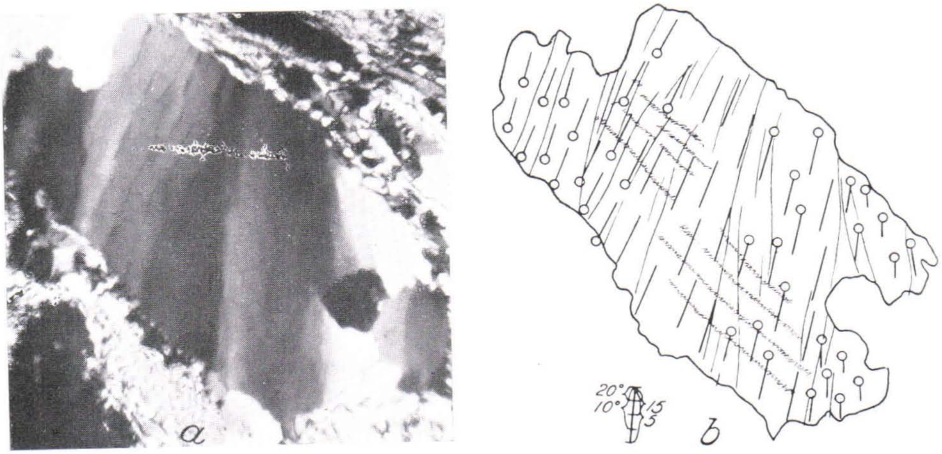


Fig. 8. Relict Böhm striations and ruptural strain shadows. Quartzite from Vaaksaus, Suojärvi. Magn. 20 diam.

Fig. 9. Quartz grains with Böhm striations from the quartzite of Vittinki. Magn. 25 diam.

Fig. 10. Böhm striations in the quartzite of Simsiö 4 a. Magn. 30 diam.

Fig. 11. Böhm striations in the quartzite of Simsiö 1. Magn. 30 diam.

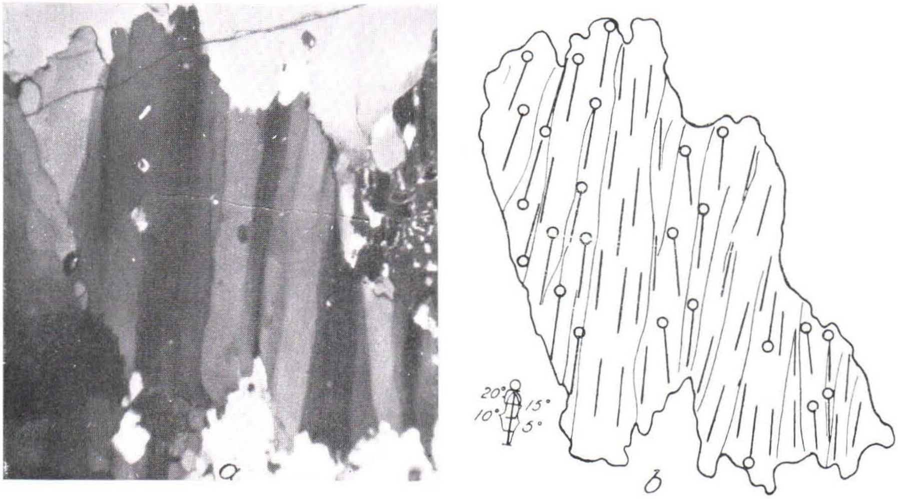


Fig. 12. Quartz grain, Simsiö 17. Magn. 20 diam.

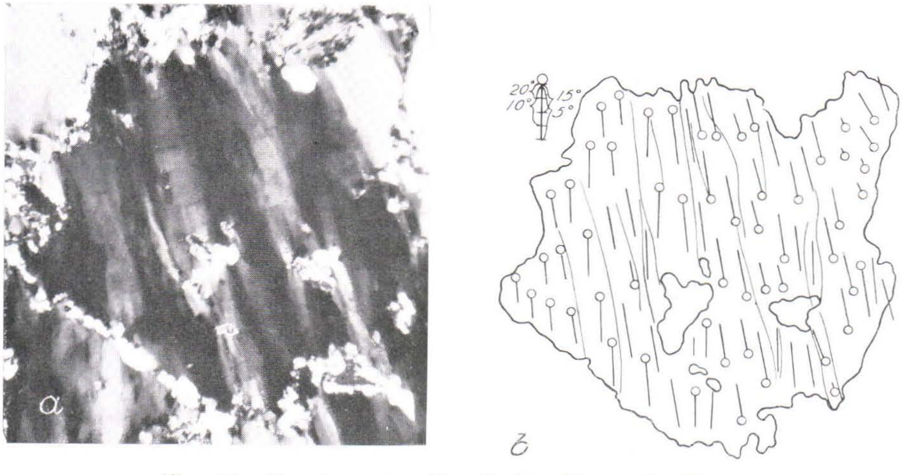


Fig. 13. Quartz grain, Simsiö 27. Magn. 20 diam.

PLATE VII.

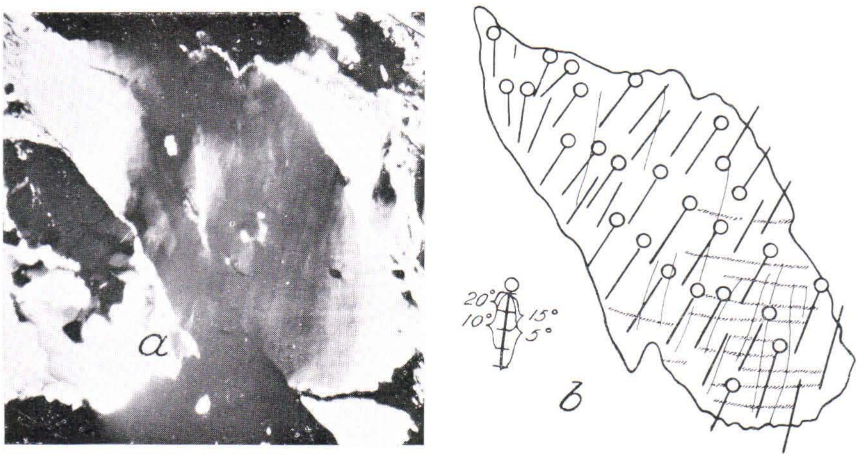


Fig. 14. Böhm striations in the quartz grain in the quartzite of Olostunturi. Magn. 25 diam.

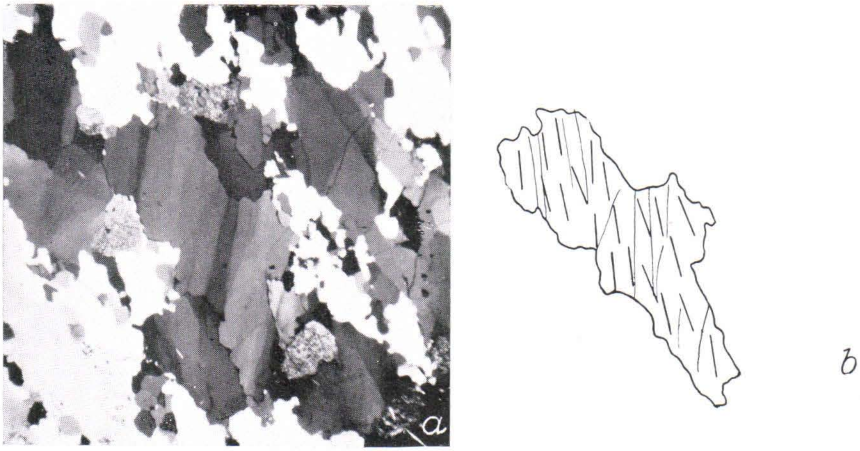
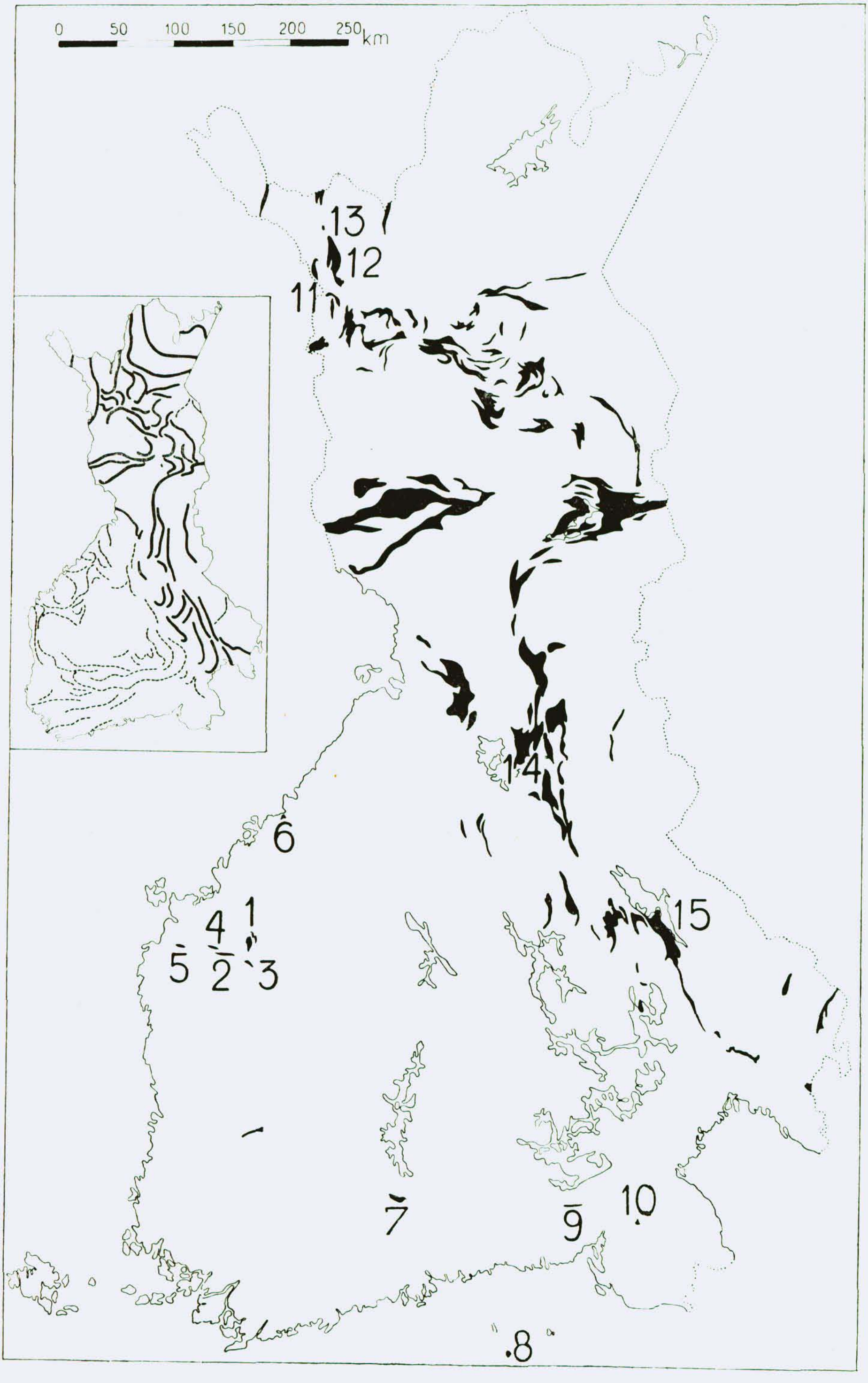


Fig. 15. Ruptural strain shadows in the quartzite of Olostunturi. Magn. 20 diam.

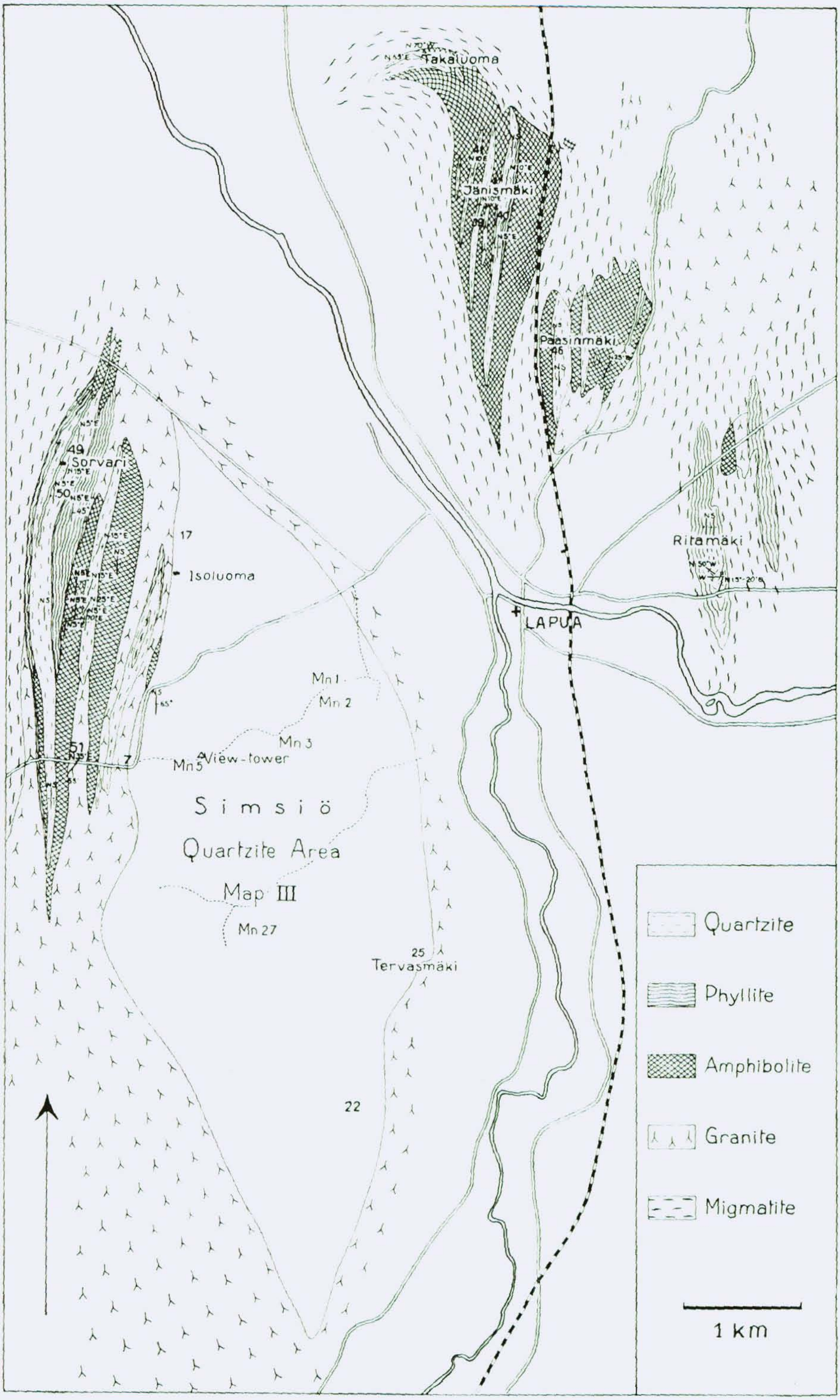
THE QUARTZITE AREAS OF FINLAND

BY ERKKI MIKKOLA



MAP II.

THE QUARTZITE AREAS OF LAPUA



MAP III.

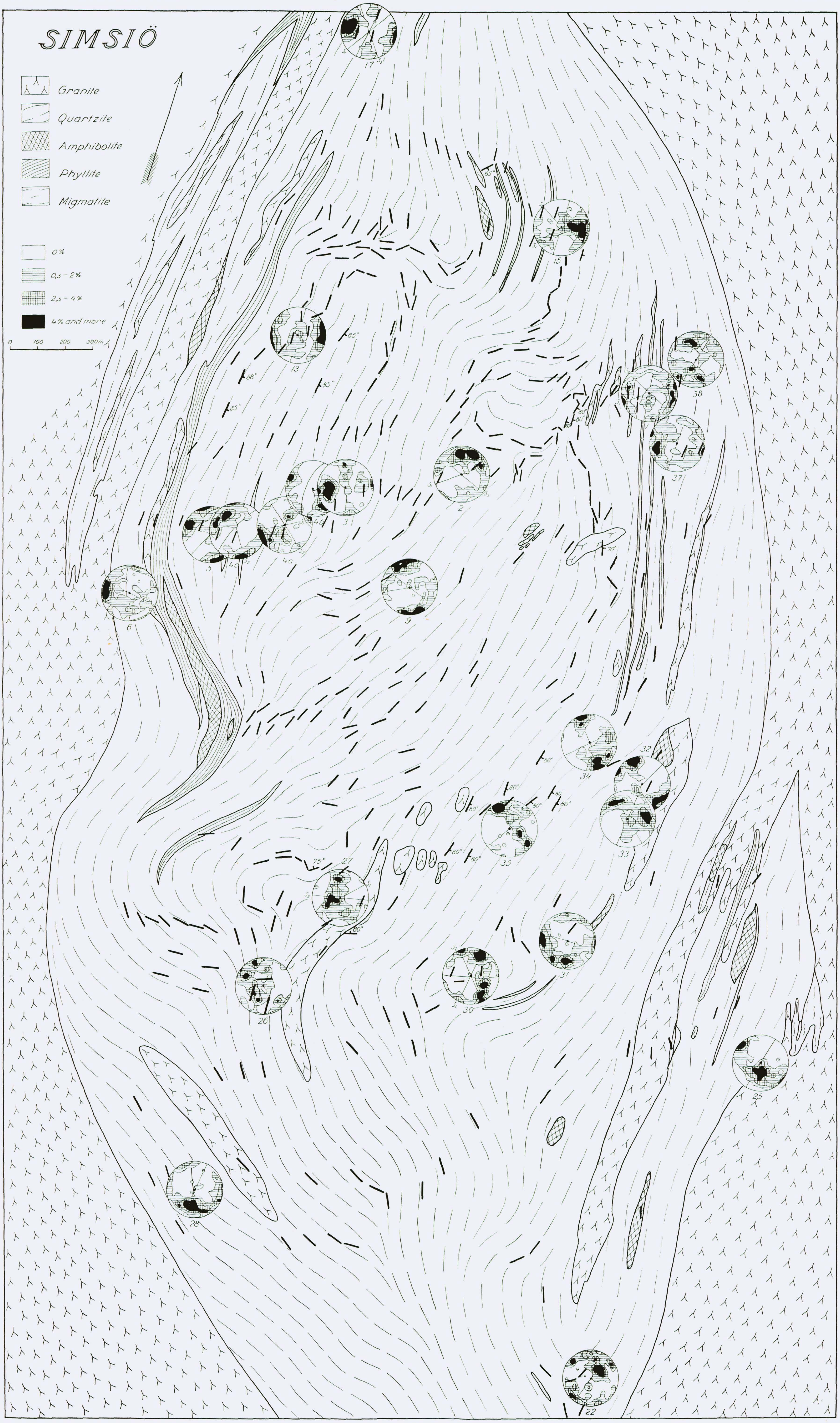
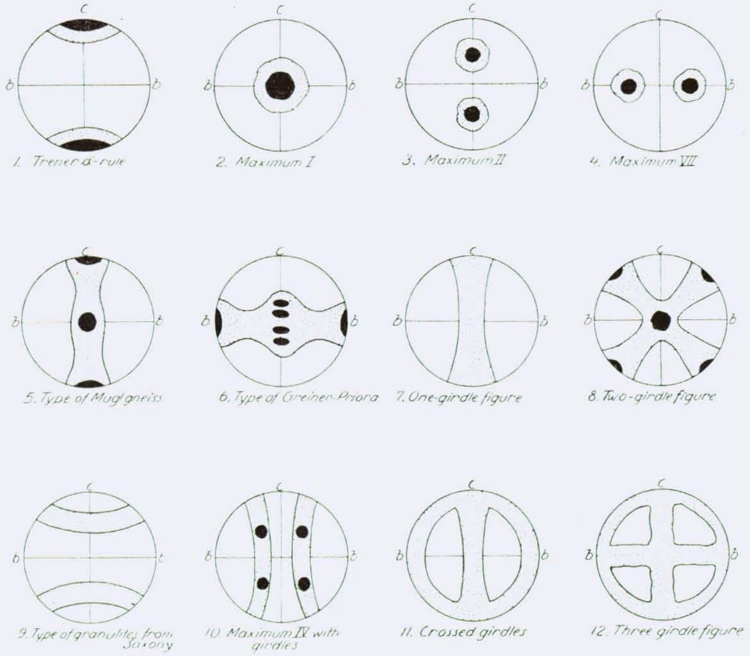

SIMSIÖ
Granite
Quartzite
Amphibolite
Phyllite
Migmatite
0%
0,5 - 2%
2,5 - 4%
4% and more
0
100
200
300m
17
15
13
38
37
2
3
4a
4a
5
40
6
9
70°
34
32
33
35
27
75°
80°
85°
88°
65°
31
30
26
25
28
22

PLATE VIII.


1. Trener a-rule

2. Maximum I

3. Maximum II

4. Maximum VII

5. Type of Mugl gneiss

6. Type of Greiner-Priora

7. One-girdle figure

8. Two-girdle figure

9. Type of granulites from Saxony

10. Maximum IV with girdles

11. Crossed girdles

12. Three girdle figure

Fig. 16. Types of quartz orientation

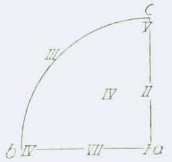
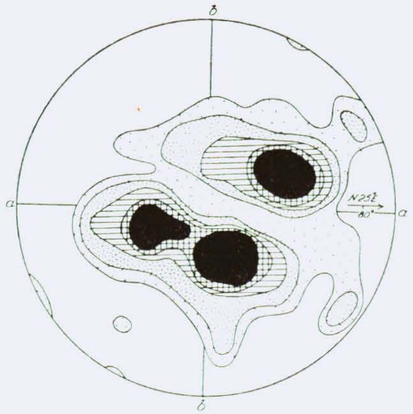
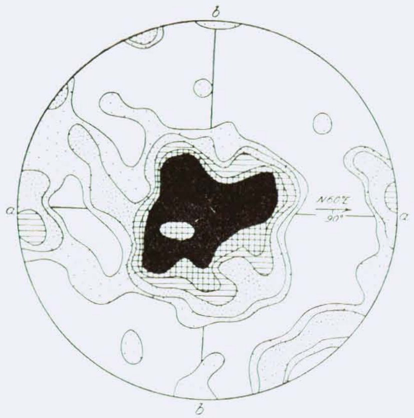
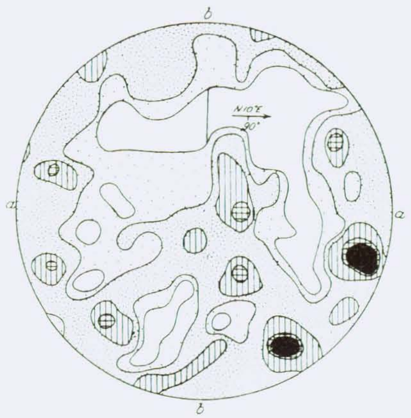


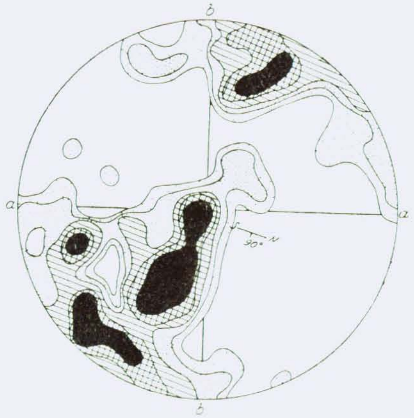
Fig. 17. General maxima of quartz orientation

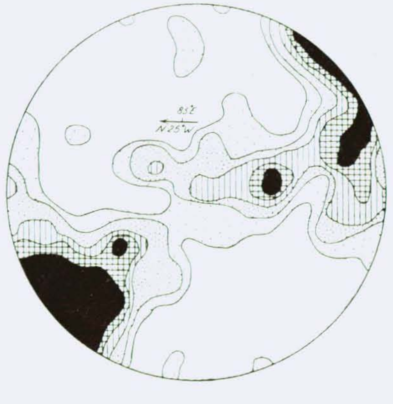
Fig. 18. Contouring of the diagrams

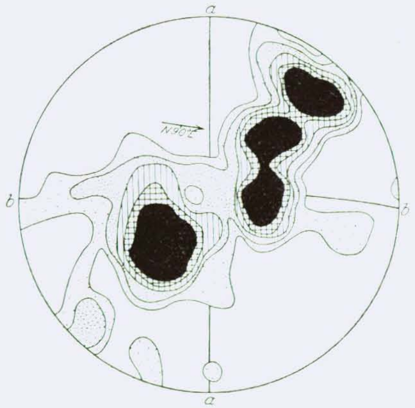

D.S. 4c. Simsiö, Lapua. 200 Quartz (4–11/2)

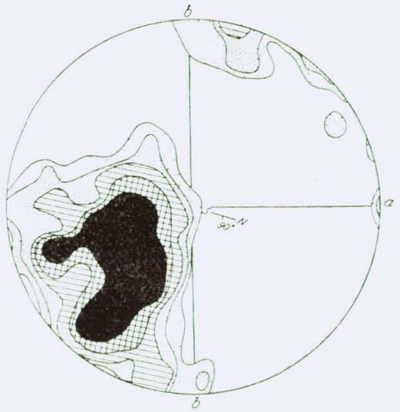

D.S. 9. Simsiö, Lapua. 205 Quartz (4–9)

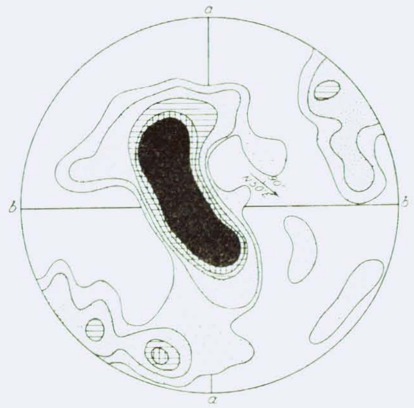

D.S. 41. Jänismäki, Lapua. 200 Quartz (4–12)

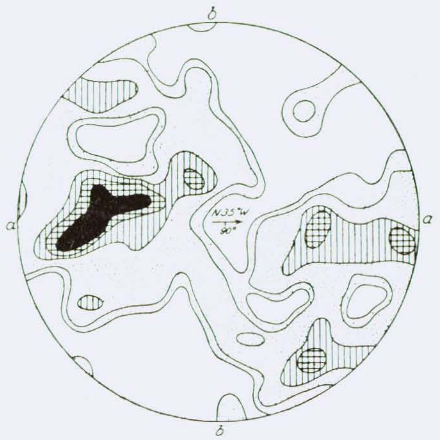

D.S. 46a. Paasinmäki, Lapua. 200 Quartz (4–10)

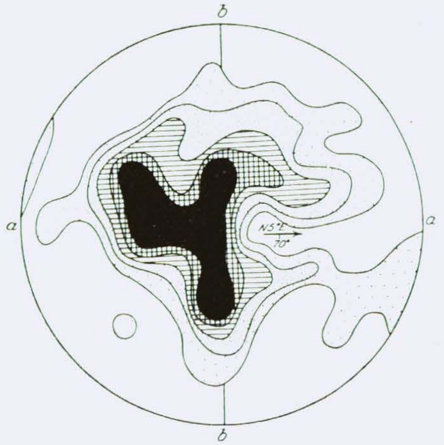

D.S. 28. Simsiö, Lapua. 200 Quartz (4–13)

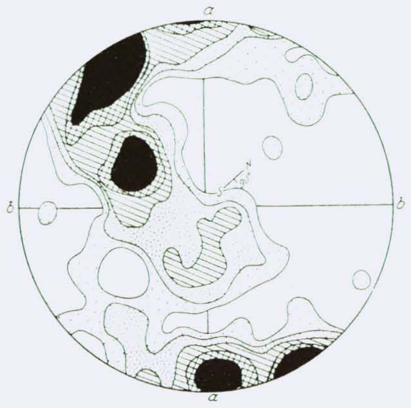

D.S. 30. Simsiö, Lapua. 200 Quartz (4–13)

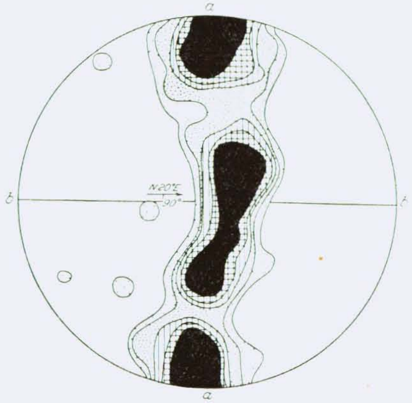

D.S. 46b. Paasinmäki, Lapua. 160 Quartz (4–14)

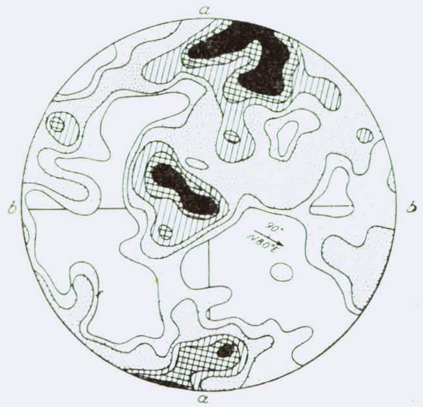

D.S. 49. Sorvari, Lapua. 200 Quartz (4–11/2)


D.S. 1a. Simsiö, Lapua. 200 Quartz. (4–5)


D.S. 4b. Simsiö, Lapua. 202 Quartz (4–7)


D.S. 39. Jänismäki, Lapua. 207 Quartz. (4–10)


D.S. 40. Jänismäki, Lapua. 202 Quartz


D.S. 50. Sorvari, Lapua. 200 Quartz. (4–6)

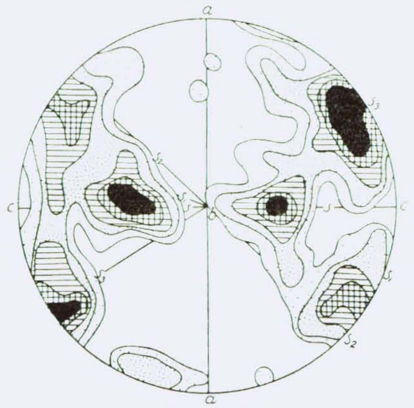
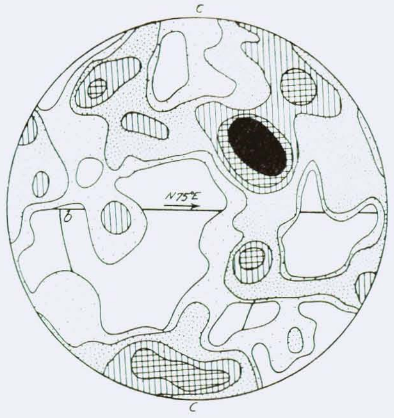
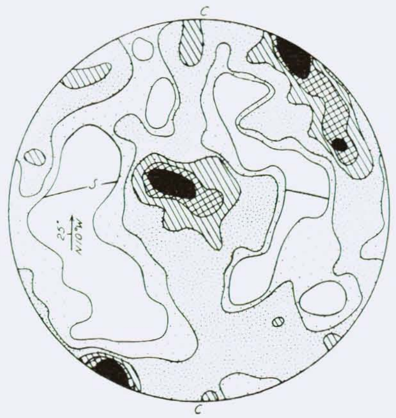

D. Ka 1. Kurikkavaara, Kainuu. 200 Quartz (4–7 1/2)

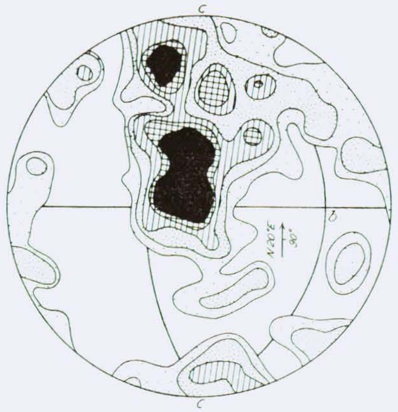
PLATE IX.



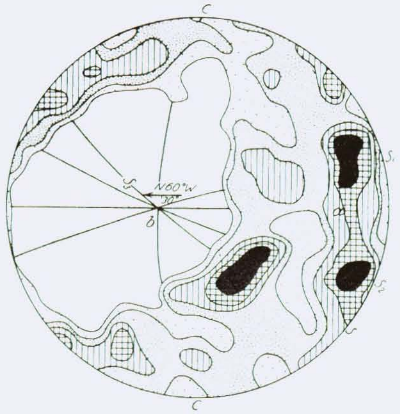
D. V. 1. Vittinki. 200 Quartz. (4–6)



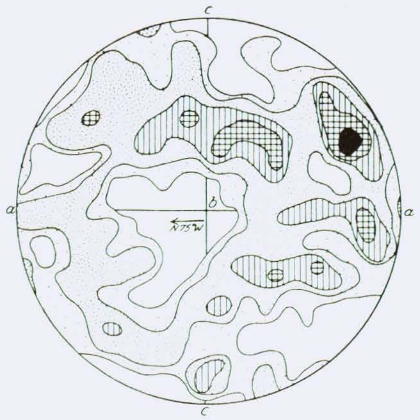
D. V. 2. Vittinki. 200 Quartz. (4–6)



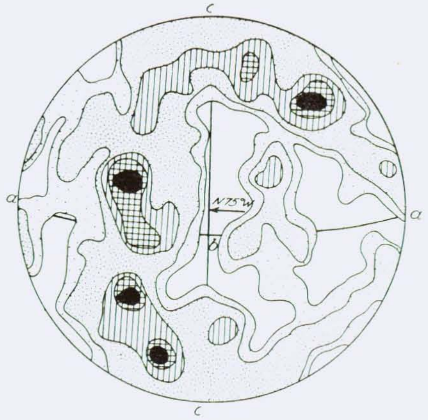
D. O. 1 Orismala 200 Quartz. (4–13)



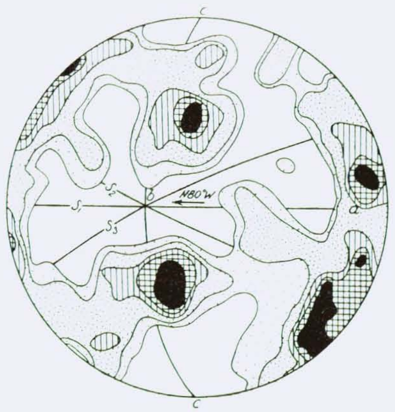
D. L. 2 Lahia. 200 Quartz (4–7½)



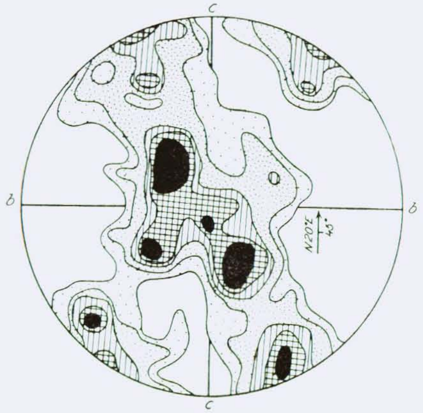
D. Ti. 9. Tyhnynmäki, Hollola. 200 Quartz (4–5)



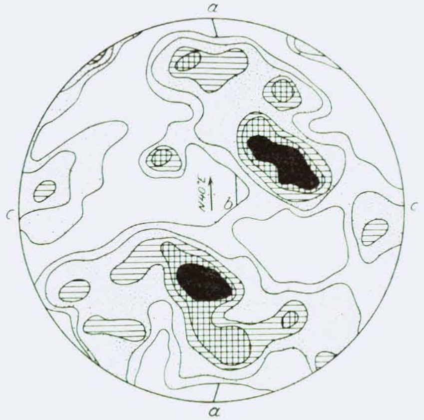
D. Ti. 10. Tyhnynmäki, Hollola. 200 Quartz (4–5)



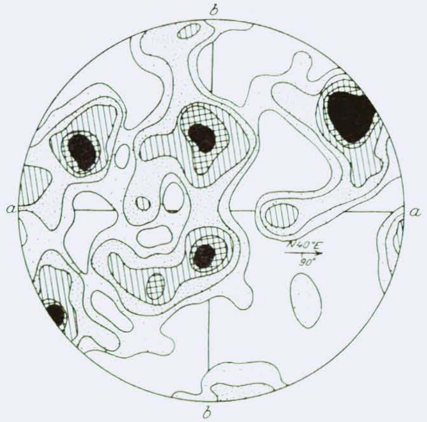
D. V. 3 Vittinki. 201 Quartz. (4–5)



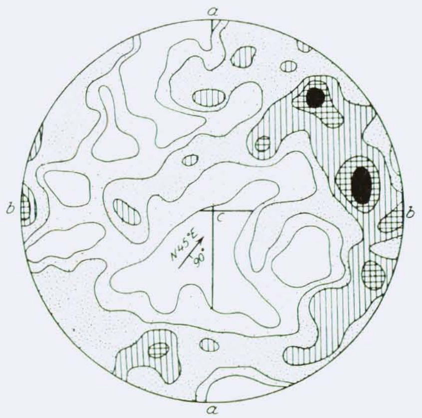
D. V. 4. Vittinki. 200 Quartz. (4–6)



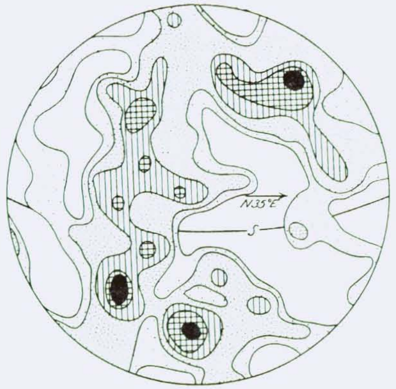
D. Ti. 1. Pirunpesä, Tiirismaa 200 Quartz (4–7½)



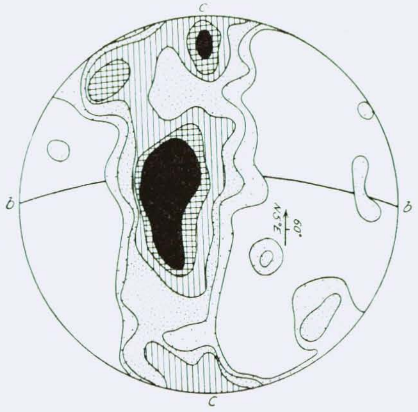
D. Ti. 4 Pirunpesa, Tiirismaa 200 Quartz. (4–6)



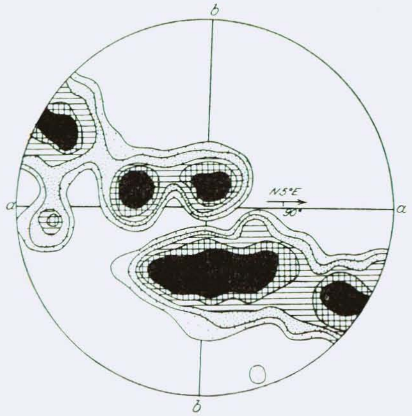
D. Ti. 13 Rautakankara, Lahti. 200 Quartz (4–4½)



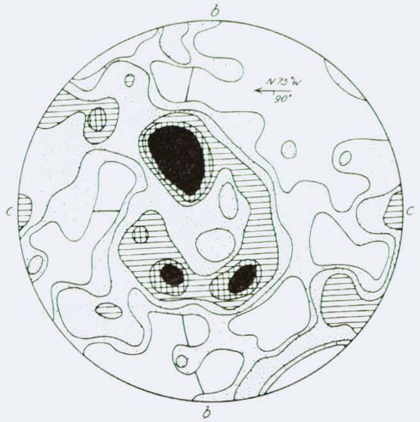
D. Ti. 17 Rautakankara, Lahti. 200 Quartz (4–4½)



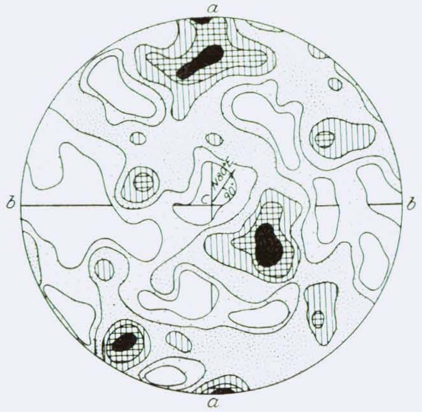
D. V. 5. Vittinki. 200 Quartz. (4–12)



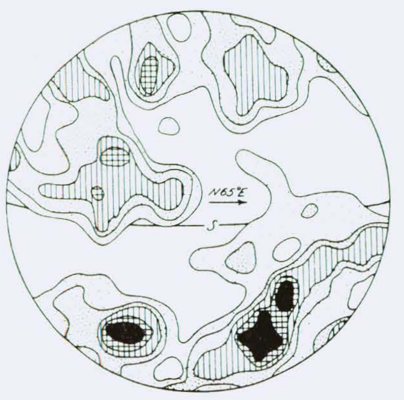
D. N. 3. Nurmo. 201 Quartz (4–8)



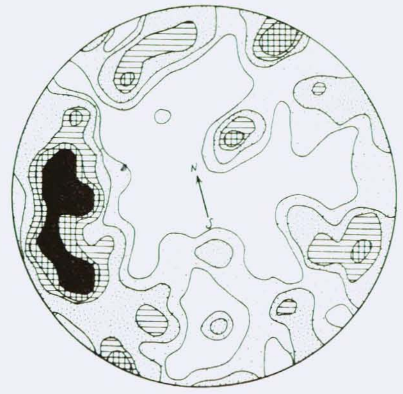
D. Ti 23 Pirunpesä, Tiirismaa. 200 Quartz (4–7½)



D. Ti 29 Tiirismaa. 200 Quartz (4–5½)

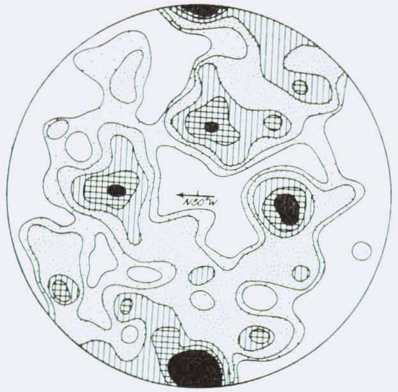


D. Ti. 20 Rautakankara, Lahti. 200 Quartz (4–5½)

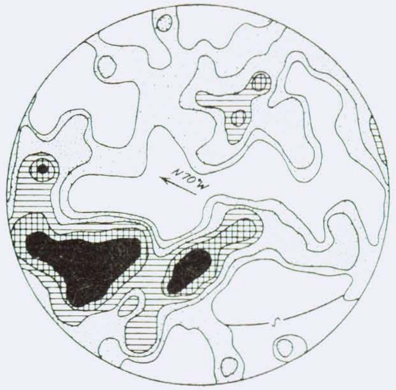


D. T. 4 Tytarsaari 200 Quartz. (4–7)

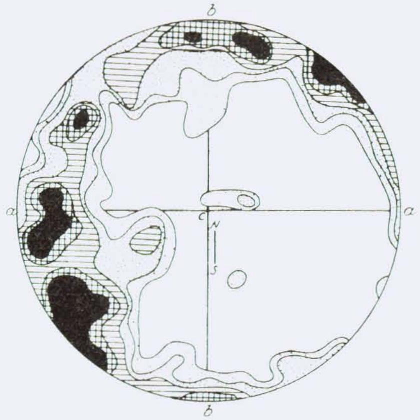
PLATE X.



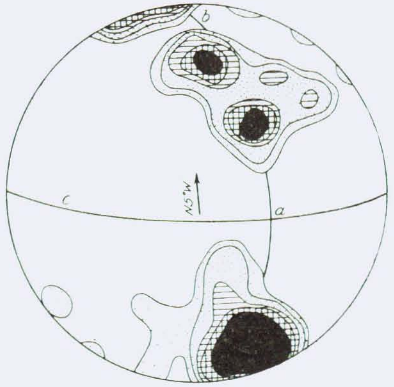
D. T. 6. Tytarsaari 200 Quartz (4–8)



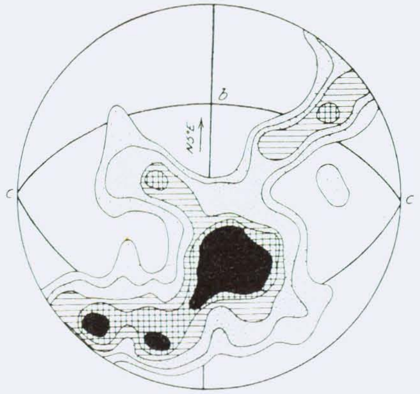
D. T. 15. Tytarsaari. 200 Quartz (4–9)



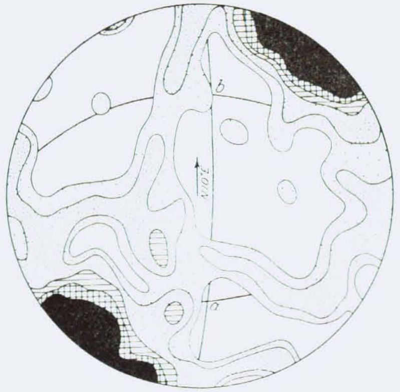
D. M. 20. Olostunturi, Muonio. 200 Quartz (4–9)



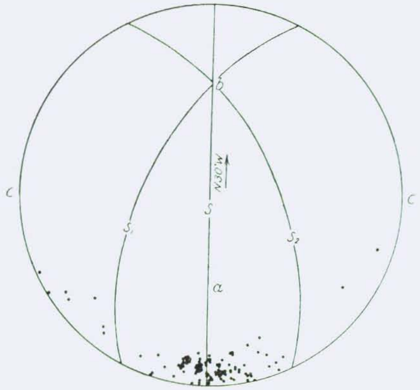
D. M. 23. Olostunturi, Muonio 200 Quartz (4–32)



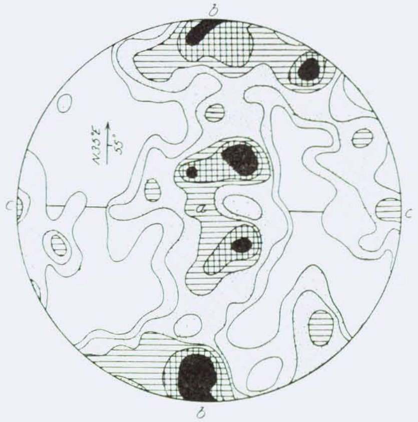
D. J. 6. Jyppyra, Hetta 200 Quartz (4–18–2)



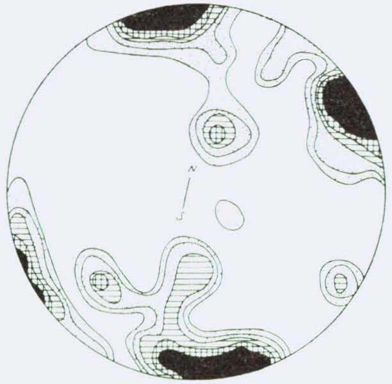
D. J. 7. Jyppyra, Hetta 200 Quartz (4–12)



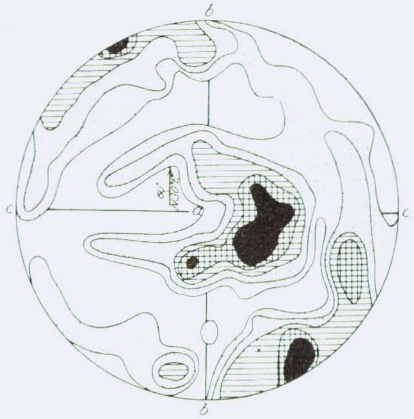
D. M. 1. Junkirova, Muonio



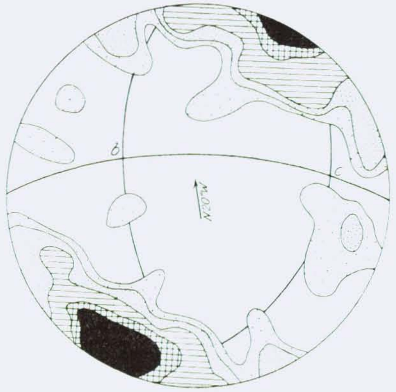
D. M. 4. Olostunturi, Muonio. 200 Quartz (4–6½)



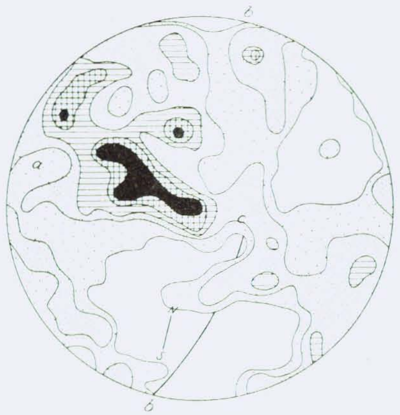
D. M. 25. Olostunturi, Muonio 150 Quartz (4–12)



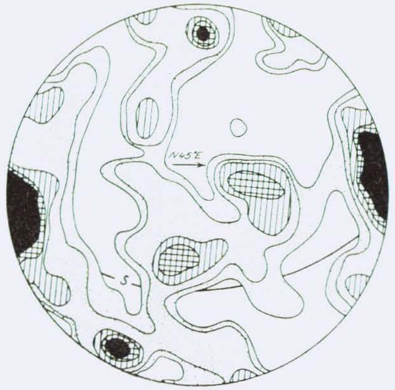
D. M. 28. Olostunturi, Muonio 207 Quartz (4–8)



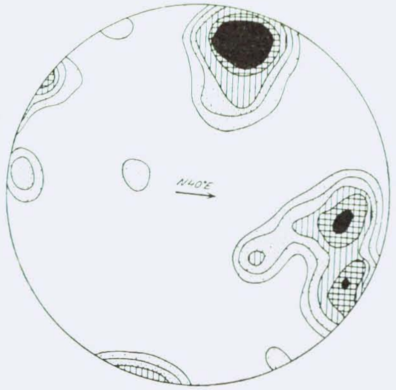
D. J. 8. Jyppyra, Hetta 200 Quartz (4–15)



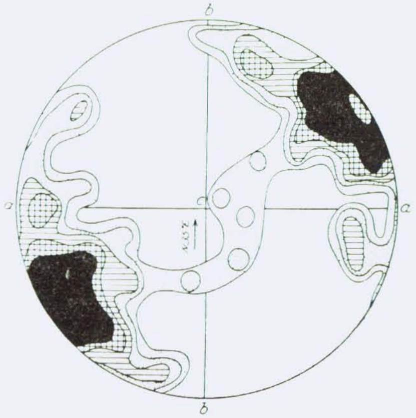
D. P. L. 1. Pieni Leppimaki, Kiehima 200 Quartz (4–6½)



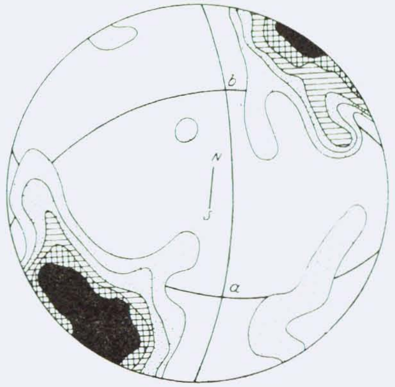
D. M. 8. Olostunturi, Muonio 200 Quartz (4–9)



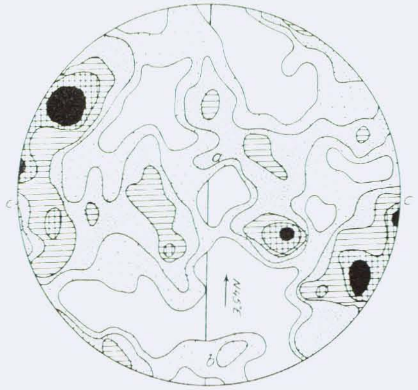
D. M. 10. Olostunturi, Muonio. 150 Quartz. (4–33)



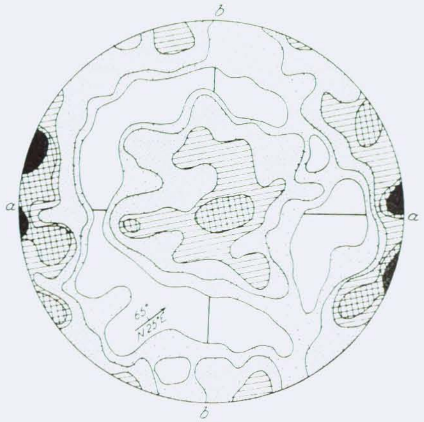
D. R. 1. Rautakero, Ounastunturi 104 Quartz (4–5)



D. J. 5. Jyppyra, Hetta 200 Quartz (4–13)



D. Mi. 1. Nieslahti, Kiehima 200 Quartz (4–5)



D. Ko. 2. Koli, Juuka 200 Quartz (4–5)