SVERIGES GEOLOGISKA UNDERSÖKNING

SER. C. Avhandlingar och uppsatser. N:o 416.

ÅRSBOK 32 (1938) N:o 6.

THE INJECTION METAMORPHISM OF THE MURUHATTEN REGION

AND PROBLEMS SUGGESTED THEREBY

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TORSTEN DU RIETZ

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STOCKHOLM 1938
KUNGL. BOKTRYCKERIET. P. A. NORSTEDT & SÖNER
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TABLE OF CONTENTS.

I. Introduction.

In an earlier paper by the author, viz. Peridotites, Serpentines, and Soapstones of Northern Sweden etc., the injection gneisses of the Muruhatten region were shortly described in connection with the metamorphism of the peridotites of that region. As this problem could not be fully dealt with in that paper, it has been taken up for a further study, the results of which will be put forward in this paper.

Some complementary investigations were made in the field in 1935, and the main part of the description was written in the early part of 1937, but it was thought convenient that it be complemented by a comparison with the progressive metamorphism of a region of analogous position in Southern Lappland, viz. the neighbourhood of Lake Borka which had been investigated by the author at an earlier visit. Two sections were surveyed here in 1937, and the relationship of this region will be described in a special chapter.

As the author had gathered a rich material of green hornblendes from the Muruhatten region these amphiboles have been studied in some detail, especially as to the alumina content and the axial angles of the minerals.

A short review of the part of the earlier paper dealing with the Muruhatten region will be given: In the Frostviken parish of Northern Jämtland within the crystalline schists, a region south of Kvarnbergsvattnet is composed of mica-schists, gneisses, amphibolites, and peridotites. The gneissic rocks preponderate around Muruhatten and Lillfjället. In the central part injection gneisses prevail. The mica-schists are strongly injected with pegmatitic and granitic material and the original mica-schist is hard to discern. In the external parts the injections are mostly recognized as distinct lenses and veins in the schists. Alternating portions of injected gneisses and simple mica-schists commonly appear. Thin-banded, veined gneisses may appear which are not always possible to distinguish from the gneisses of wholly sedimentary origin. The coarse, distorted gneisses or »augen»-gneisses of the central parts are generally more easily recognized as injection gneisses.

In the peripheral parts the granite or aplite injections are generally of trondhjemitic- (albite-oligoclase to oligoclase) to adamellitic composition while those of the central parts are of potassic or alkali-intermediate composition; here granitic or pegmatitic material may appear as large separate bodies.

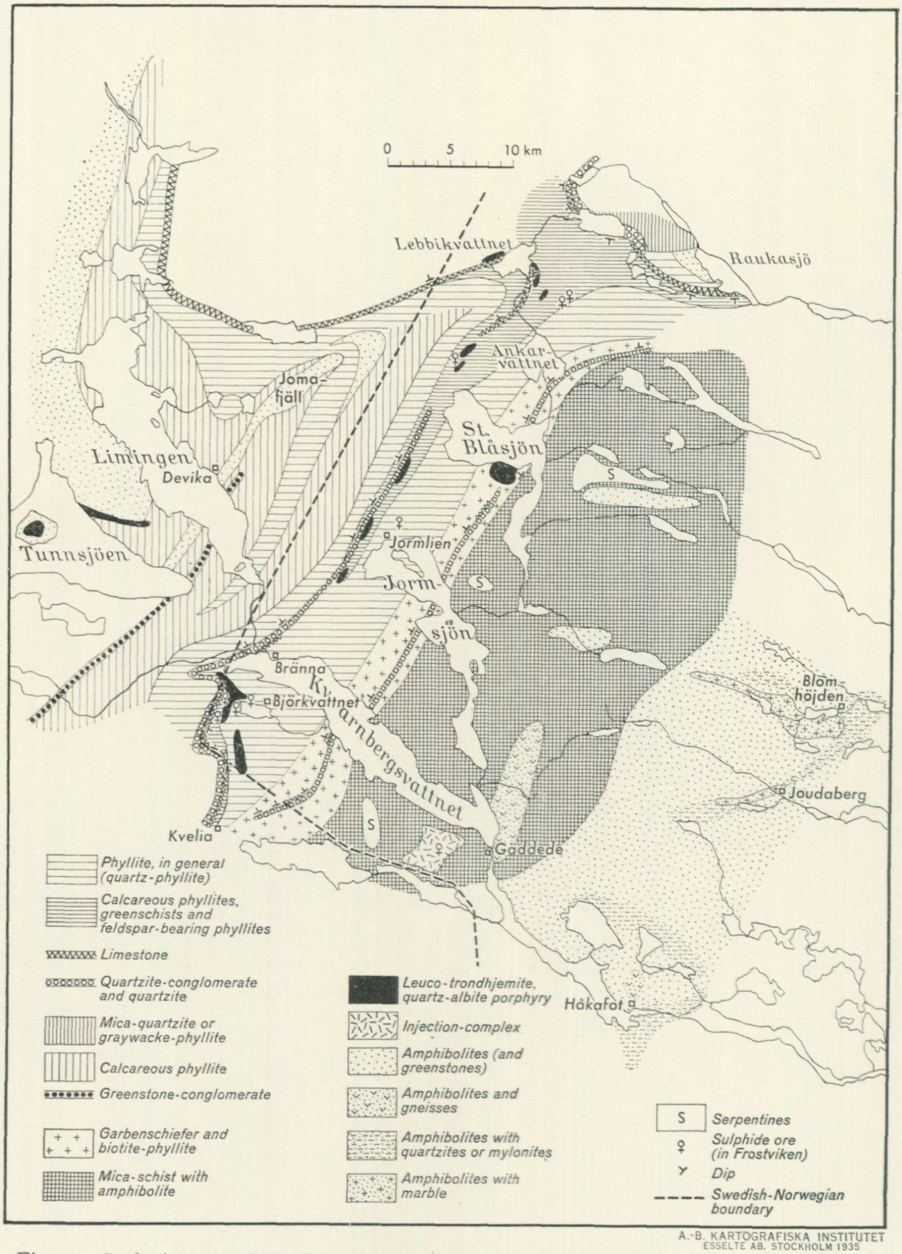


Fig. 1. Geologic map of W. Frostviken (and neighbouring parts of Norway), N. upwards.

Mineralogically, the granitic intrusions are of rather pegmatitic composition. They are generally not so coarse-grained as regular pegmatites and may often be classified as aplites. Rather differentiated fractions, with feldspar or quartz dominant, occur. The alkalies are often differentiated, as the pegmatites may have either prevailing acid plagioclase or potash feldspar. The larger granitic bodies are principally predominatingly potassic, while in the smaller lenses sodic plagioclase prevails. The former are generally coarse-grained, the latter rather fine-grained.

The simple mica-schists are generally thin-banded, often with separate layers of mica, and quartz with feldspar. They are rich in quartz, and may partly be designated as mica-quartzites and quartz-mica-schists or gneisses, as a pronounced feldspar content, of acid plagioclase, is mostly present.

The injection of granitic material is much more common in the mica-schists than in the amphibolites. These are generally not injected with pegmatitic or aplitic material. When this has happened, it has mostly produced a formation of biotite in the amphibolites, or also a hydrothermal alteration of the rocks. Sometimes migmatitic rocks have been developed between the amphibolites and the granitic injections. The pegmatites may also have caused a recrystallization of the amphibolites. The granitic rocks are often tourmaline-bearing close to the basic or ultra-basic rocks and show every transition from granite aplites over tourmaline pegmatites to hydrothermally altered rocks. Many profiles and detailed descriptions were given concerning the metamorphism of the ultrabasics, but that problem is not the main subject of this paper.

A geologic map of the Muruhatten area in the scale of 1 : 20,000 was printed in the paper mentioned (G. F. F. Vol. 57, 1935), p. 160. This map will be referred to for the use of this treatise too. For a general geologic map of the Frostviken region reference is made to the maps published in G. F. F., 1935, p. 677 (7) and 1936, p. 432 (8). The first one is reprinted here with English text (Fig. 1).

As a rather similar injection metamorphism (but of another character) is fully described from the Norwegian Caledonides in the Stavanger region by V. M. Goldschmidt (13) a short summary of this paper will be given.

The chief intrusions of trondhjemites or granites have taken place at the boundary between the early cambro-silurian phyllite-formation and the superimposed greenschist-formation. The regional rock of the district is a phyllitic quartz-muscovite-chlorite schist. When approaching a Caledonian granite small porphyroblasts of spessartinite-almandite garnet appear in the phyllite. Closer to the intrusives chlorite and some muscovite is substituted by biotite, and the garnet becomes less manganiferous. The grain size becomes larger and a typical garnet-micaschist appears. The order between biotite and garnet is thus contrary to the general order. Pneumatolytic processes are often revealed by the presence of tourmaline. At the innermost contact (mica-schist, feldspar-bearing mica-schist and injection-gneiss) orthite is rather common.

At the transition from phyllite to garnet-phyllite and garnet-micaschist an enrichment in albite or plagioclase occurs in the matrix. Approaching the intrusives the albite content increases and may be megascopically visible. Rocks with albite porphyroblasts are typical of the injection contacts. Besides garnet a greenish gray amphibole and some clinozoisite appear. In the next stage also potassic feldspar occurs. This is a gneiss or injected mica-schist. It is at first a metasomatic process with but little addition of material. The metamorphic rocks are generally veined by granitic bodies. A higher stage of metamorphism is represented by mechanically intruded material in the mica-schist.

The injections in the green-schists are recognized by the formation of much amphibole which, together with clinozoisite, plagioclase, garnet and some biotite, is the chief mineral.

The quartz-muscovite-chlorite phyllite has quartz, muscovite, and chlorite as dominating minerals. Albite is decidedly less than quartz. Carbon and some carbonate are usually present. Accessory minerals may be apatite, greenish brown tourmaline, magnetite, titanite, rutile, and zircon.

The quartz-muscovite-chlorite-garnet phyllite has somewhat larger grain-size, and small knots of garnet. An average mineral composition of the rock may be: quartz, muscovite, chlorite, albite, magnetite, garnet, rutile, carbon, apatite, pyrite about in this order of abundance.

The quartz-muscovite-biotite-garnet phyllite has biotite instead of chlorite and some muscovite. The minerals are generally quite visible and the texture is often hornfelslike. The biotites and garnets are usually porphyroblastic, and clinozoisite, amphibole and tourmaline are often present. Calcareous sediments have much calcite which with increasing metamorphism is transferred into epidote or amphibole and also into titanite.

Albite-porphyroblastic schist appears with increasing supply of soda, and locally porphyroblasts of both sodic and potassic feldspar may occur as transition to »augen»-gneiss.

When mechanically intruded material increases, injection gneisses are formed. Common are bedded gneisses where the intruded material is interbedded with schists. Veined gneisses are usually seen. Augen-gneisses have besides quartz, plagioclase, and mica also large »augen» of potassic feldspar, generally micro-perthite or microcline, and they may be injected schists or protoclastic, injected, igneous rocks.

The SiO_2 content as well as the Na_2O increases successively with the metamorphism while Al_2O_3 decreases. The Na_2O supply cannot have been introduced in the form of albite, because the Al_2O_3 content of the rock formed is too low for that. The introduction must thus have taken place in the form of Na-silicate. The same thing is applicable to the lime. The phyllites have consequently been supplied with the oxides SiO_2, Na_2O, CaO, while water has been removed. In the augen-gneisses, however, feldspar has been mechanically introduced. Minerals with excess of Al_2O_3 over alkalies and lime decrease and minerals with saturated alumina increase. Myrmekite and chessboard-albite point to albitization of potassic feldspar. The alkali-silicates might have been liberated from the granite by hydrolysis of potassic feldspar with formation of muscovite. It is thus by muscovite-bearing rocks as e. g. the trondhjemites, that the Na_2O has been liberated, while the K_2O has been fixed in muscovite.

II. The mica-schists (older, sedimentary rocks)

In the exterior parts of the Muruhatten region and within certain parts of the central area where the influence of the injected granitic rocks is slight, the character of the mica-schists can be studied. They are thin bedded, grayish schists, rich in quartz, and are generally cataclastic re-crystallized rocks without any traces of the primary clastic texture, though some large rounded grains of quartz or plagioclase may be seen, and in that case usually with an uneven rim of secondary growth. The chief minerals of the rocks are quartz, micas and acid plagioclase, generally with some garnet, epidote, ore minerals, and chlorite secondary to biotite. Rutile or titanite, orthite, apatite, carbon, tourmaline, and zircon are often seen. The average proportion of the minerals is about: quartz $>$ plagioclase $=$ biotite $\geqq$ muscovite $>>$ epidote $=$ ore minerals $>$ titanite (or rutile) $>$ garnet $>$ apatite.

Table 1. Quartz-mica-schist from Muruhatten.

Analyst N. Sahlbom.

	Weight %	Mol. prop.	Mineral composition according to the analysis [1] Weight %		Niggli values
SiO_2	69.29	11,491	Quartz	43.5	si 335
TiO_2	0.61	76	Oligoclase (An_{21}[2])	9.4	ti 2.2
Al_2O_3	15.01	1,469	Muscovite	30.1	al 43
Fe_2O_3	2.29	143	Sericite (secondary)	0.1	fm 29
FeO	2.22	309	Biotite	13.5	c 7
MnO	0.09	13	Chlorite	0.1	alk 21
MgO	1.62	402	Garnet (almandite)	0.2	k 0.69
CaO	1.32	235	Epidote (with orthite)	2.0	mg 0.40
Na_2O	1.42	229	Titanite	0.5	c/fm 0.23
K_2O	4.72	501	Apatite	0.3	
P_2O_5	0.15	11	Magnetite		
S	0.02	6	(titanomagnetite)	0.2	
H_2O^+	1.48	821	Pyrite	0.1	
	100.24			100.0	

The plagioclase of the rocks is an oligoclase and it is often a prominent mineral averaging about 15 weight % of the mineral composition with a variation from 0—30 %. Some rock types could thus petrographically be described as gneisses, though the general appearance of the rocks is that of the mica-

[1] Volumetric measurement shows following percentage (weight %): Quartz 46.5, plag. 7, muscovite 28, biotite 15, chlorite 0.1, garnet 0.3, epidote-orthite 2.2, titanite 0.2, apatite 0.4, ore minerals 0.2 %.

[2] The composition of the plagioclases is generally determined on the universal stage: $\perp$PM, $\perp\gamma$, $\perp\alpha$, and albite twins. For control purposes refraction indices are often determined.

schists. In some types (the quartzitic) muscovite is the predominating mica, with up to 30 % of the rock, but generally the biotite predominates. The biotites are brownish to olive-brown (generally γ reddish brown and α pale yellowish green) of ordinary grain-size. The garnets are very small and scanty in the mica-schists in contrast to the injected schist where they often are abundant and very much larger.

A typical quartz-mica-schist has been taken for analysis, Table 1, p. 9.

The plagioclase is an oligoclase with a composition An_{20-21} both according to the analysis and the optic properties. It is slightly sericitized in the central parts. The biotite is strongly pleochroitic, γ dark olive-brownish green $\geq \beta$ olivebrown $> \alpha$ greenish yellow. It is smaller in size than the muscovite which is about as large as the garnet. The epidote is a pistazite with a core of orthite.

The analysed rock type is richer in muscovite and poorer in plagioclase than the average type. For comparison Rosiwal measurements are made of some other rock types (weight %):

Table 2—5.

	2	3	4	5
Quartz	47.5	31.9	48.6	37.7
plagioclase	19.5	11.8	16.5	25.2
muscovite	13.1	26.1	20.1	—
biotite	18.8	25.1	13.5	16.8
chlorite	0.3	—	—	18.3
epidote (or epidote-orthite)	0.3	2.0	1.2	—
apatite	0.1	—	} 0.1	0.4
ore minerals	0.3	2.6	}	1.2
garnet	—	0.5	—	—
titanite	0.1	—	—	0.1
rutile	—	—	—	0.3

These are all typical, sedimentary mica-schists with similar minerals as the analysed rock. They are fine-grained, laminated rocks with the micas as the largest minerals. The last one is somewhat hydrothermally altered.

Some types are slightly metamorphosed by the pegmatitic-hydrothermal solutions and are partly re-crystallized with some porphyroblastic minerals. Three rock types are calculated by the Rosiwal method[1] (weight %):

Table 6—8.

	6	7	8
Quartz	53.7	50.6	33.9
oligoclase	22.3	15.8	17.2
muscovite	1.2	13.7	2.9
biotite	19.3	9.1	22.4
chlorite	0.1	6.7	5.0
garnet	—	1.7	9.7
epidote	3.0	0.1	0.1
apatite	0.1	—	0.1
tourmaline	—	} 0.1	0.1
rutile	—	}	0.1
carbonaceous material	—	—	7.2
magnetite	} 0.3	—	} 1.3
iron sulphides	}	0.5	}
chalcopyrite	—	1.7	—
zircon	tr.	tr.	—

[1] In general an average of two rock slides.

The plagioclase is poikiloblastic with a composition averaging An_{20}. The biotite is slightly paler than in other rocks described before, and it is rather much chloritized (penninite-chlinochlorite). The biotite is often interlaminated with muscovite which is phengitic in one of the rocks. The reddish garnet is poikiloblastic (with quartz grains) and somewhat chloritized. Tourmaline and rutile occur as in the pneumatolytic-hydrothermally crystallized rocks, though they are of smaller size. The colour of the tourmaline is about the same as in the pegmatites.

The last rock type represents a primary black shale and it is a rather unusual rock type in this district, the general type being originally arenaceous sediments and feldspar-bearing sandstones, relatively poor in alumina and lime. These sediments are thus exceptionally rich in soda, probably because of weathering of plagioclase-rich rocks such as plagioclase granites etc. The younger cambro-silurian sediments to the west of this region are often rich in acid plagioclase which is rather characteristic for this part of the Caledonian range, just as a great part of the igneous rocks is of trondhjemitic character (of different epochs of the Caledonian). In a neighbouring area, north of Kvarnbergsvattnet, in the same tectonic (stratigraphic) position where the injection metamorphism is slight, the author has also studied the mica-schists. The rock varieties are there almost exactly the same as in the Muruhatten region, though the quartz-mica-schists are more common, and the rocks are generally a little more chloritized.

Törnebohm (22) who had mapped an extensive part of the central Scandinavian Caledonian, classified the crystalline schists (or seve-schists) together with the sparagmites (to a great part feldspar-bearing sandstones), and he assumed that the seve-schists partly were metamorphosed sparagmites. — It is even now difficult to ascertain if the rocks described above belong to the lower part of the Cambro-Silurian or to the Sparagmite formation (Eocambrian).

The unusually Na-rich composition of the Swedish caledonian schists and slates has been indicated by many geologists as e. g. by Quensel (18) who has emphasized their high Na-content as well as low Al-percentage and high Mg. This is typical for both the köli-rocks (less metamorphosed sediments) and the seve-rocks of Southern Lappland and was exemplified by Q. with several new analyses.

III. Injection-gneisses.

Lenticular bodies of granitic intrusions are often seen in the schists of this region. They have often a pegmatitic- or aplitic texture and generally correspond to a pegmatitic phase of granitic composition, with a dominating content of feldspar, much quartz and subordinately micas, mostly muscovite. The mica is sometimes almost lacking.

These lenticular intrusive bodies vary very much in size from thin veins to a width of at least 50 meters. Typical lit-par-lit injections are not common. They are mostly diffuse and uneven. Within the most injected parts such diffuse lit-par-lit injections are more frequent. As there is little difference in appearance between the non-injected mica-schists and the injected material, it is clear that the transitions may be indistinct. It is generally neither a crystallizing nor a crystallized rock that is injected but rather a solution which has reacted with the environment and thus obscured the contacts. Within the central parts of the region it seems as if the original rocks have been quite permeated and made plastic, and they cannot be recognized.

The injected material can be rather massive especially in the potassium-dominant bodies, but it is often quite schistose with grain-size varying from

Fig. 2. Lenticular intrusions of feldspar-rich pegmatite in mica-schist, with diffuse streaks in the mica-schist around.

pegmatitic to aplitic. Particularly the sodium-rich injection-granites are rather schistose. Coarse-grained veins of potassic pegmatites were observed traversing earlier schistose injection-granites, of intermediate character, or richer in sodium.

These schistose, small-grained, injected granites may be distinguished from the gneissic mica-schists by a somewhat larger grain-size, lighter colour on account of few dark minerals, and by the great percentage of feldspar which exceeds the quartz.

The injected material often occurs as veins in the mica-schists often very uneven and with transitions into lumps and streaks. Within some parts the injected rocks show large »augen» of feldspar (prevailingly potassium feldspar), but otherwise an enrichment of quartz and muscovite corresponding to the pneumatolytic-hydrothermal stage of the potassic-pegmatite intrusions. This phase with strong enrichment in muscovite and quartz may be quite preponderant around larger bodies of potassic dominant pegmatites.

Large porphyritic microclines are common in the injected schists, often as isolated »augen», or together with a diffuse injecting. Clusters of such »augen» are often congregated, sometimes as an extension of a lenticular intrusion, showing the permeation of the magmatic solutions with crystallization in massive bodies, clusters of crystals and as isolated porphyritic feldspars.

Fig. 3. Segregations of feldspar-augen in diffuse streaks in the mica-schist. About 1/2 nat. size.

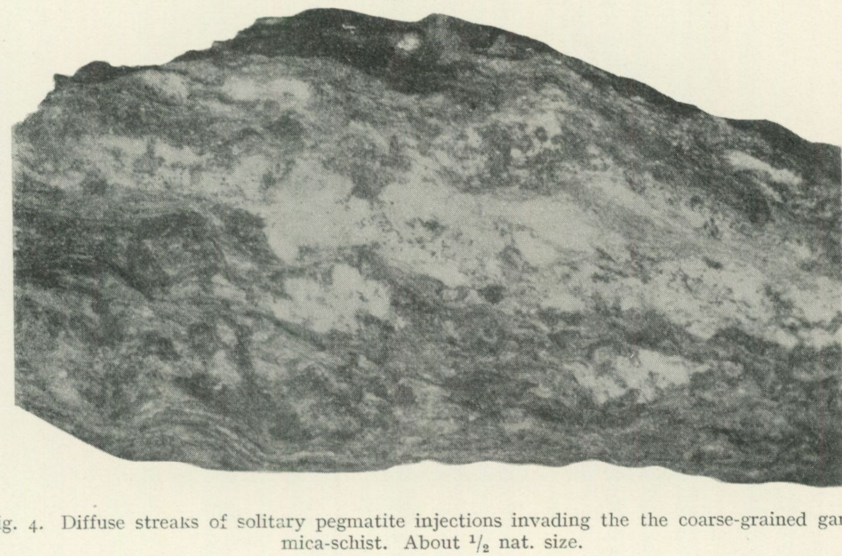


Fig. 4. Diffuse streaks of solitary pegmatite injections invading the the coarse-grained garnet-mica-schist. About 1/2 nat. size.

Fig. 5, shows a plastic, re-crystallized, injected schist with schlieren of micaceous material from the primary mica-schist. This type is enriched in muscovite and quartz and has augen of potassic feldspar. $^1/_2$ natural size.

Fig. 6. Quartzitic mica-schist with diffuse veins of aplitic material in the lower part, and a pegmatite dissecting the schist in the upper part of the photo. $^1/_{10}$ nat. size.

Sometimes the injections are differentiated in separate streaks of feldspar, and separate ones of quartz.

The pure granitic and pegmatitic intrusive bodies show that there is not only a slight addition of material with re-crystallization of the schists to intrusive-like bodies. The composition of the schists is not an extreme argillaceous sediment with a great excess of Al, but an almost saturated rock, characterized by a high Na_2O and SiO_2 content as compared with ordinary mica-schists, and a high MgO content as compared with the magmatic granites. The injected schists have about the same excess of Al_2O_3 as the non-injected rocks, but more feldspar, especially potassium feldspar. The injected rocks have an intermediate composition between the injected granites and the primary mica-schists. The

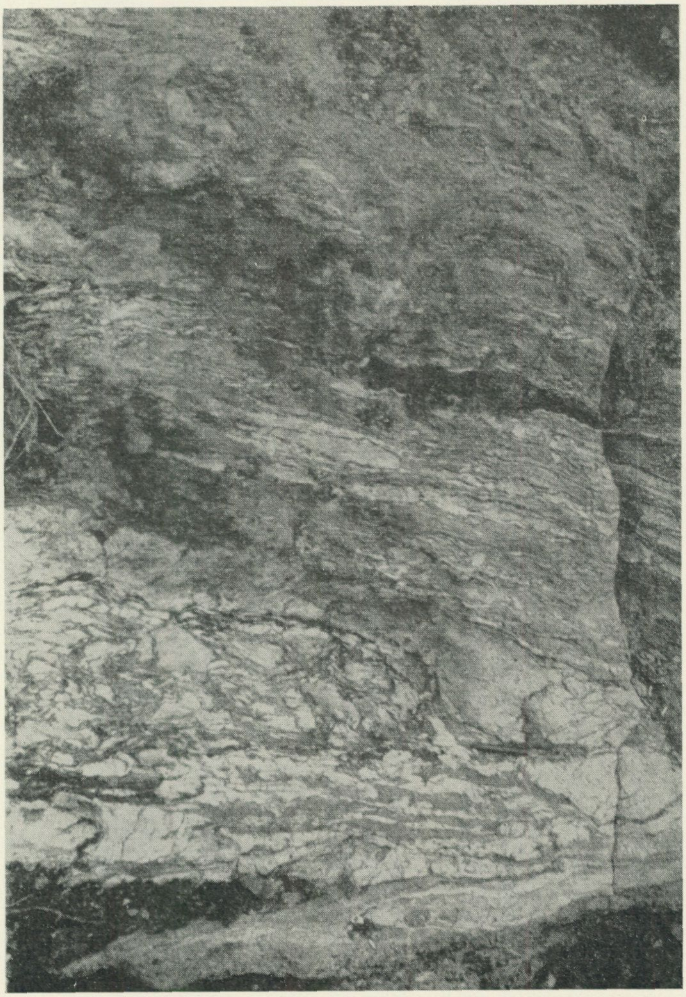


Fig. 7, shows injections close to amphibolite in the neighbourhood of a big peridotite body with a strong enrichment of biotite (and tourmaline) against the basic rocks (upper part of the fig.).

analyses and the mineral composition show that the injected, gneiss-like rocks have a small excess of alumina, but the pneumatolytic-hydrothermally injected rocks have an excess of Al_2O_3 which is greater than in the original mica-schists.

When the injections in the schists are in contact with basic igneous rocks, especially with the peridotites, an aureol of a strong biotite formation is seen which sometimes has a width of one or a few m, but sometimes it is quite visible for 30 or 40 m from the ultra-basic, as e. g. Säterberget—Lillfjället. The pegmatites then generally form streaks of albite or albite-oligoclase surrounded

Fig. 8, shows a pegmatite intrusion close to a peridotite with much formation of biotite, muscovite, and tourmaline around the masses of plagioclase. About natural size.

by masses of biotite and muscovite. By reaction with the Mg-extreme neighbouring rocks evidently all potassium feldspar has been converted into biotite and some muscovite has also been formed, while the pegmatites have been desilificated (and also somewhat decalcified). Sodium has remained on account of which these pegmatites often are extreme plagioclase-pegmatites, generally together with some mica and tourmaline. Aplites and pegmatites close to basic rocks are thus usually enriched in biotite, and they are poor in potassium feldspar, and have a schistose appearance. They are consequently difficult to distinguish from the gneiss-like mica-schists when no transition zones occur. Small injections will be so diffuse that they are not recognized.

The injected rocks in general have a much increased grain-size. Particularly noticeable is the enlarged size of the garnet which also has increased in quantity, though it is especially numerous close to the basic rocks, favoured by the excess of basic oxides just as the tourmaline is.

a. Intrusive igneous rocks.

1. Trondhjemitic granites.

A sample of a large lenticular granite intrusion from Smalsundsberget has been analysed. It is a white, granular rock, rather aplitic in texture with some slightly porphyritic grains of plagioclase and muscovite.

The plagioclase is an oligoclase, $Ab_{82}An_{18}$ ($\gamma = 1.546$, $\alpha = 1.538$, $\perp$ PM 3°, max. symetr. ext. angle $3^1/_2$°) which agrees with the analysis. Some small myrmekitic plagioclases in the groundmass point to an earlier content of potassic feldspar, probably albitized by the formation of muscovite. The biotite has an intermediate pleochroism with: γ brownish, $\geq \beta$ olive-brown, $> \alpha$ pale greenish yellow.

This granite corresponds well with Goldschmidt's trondhjemites of the types with low An-content (12).

Table 9. Trondhjemite from Smalsundsberget, Muruhatten region.

Analyst N. Sahlbom (partly by R. Blix).

	Weight	Mol.prop.	Mineral composition[1]		Niggli values	
SiO_2	75.85	12,579	Quartz	39.2 (by weight)	si	450
TiO_2	0.00		oligoclase	52.5	al	49.5
Al_2O_3	14.21	1,390	muscovite	7.4	fm	3.5
Fe_2O_3	0.28	17	biotite	0.6	c	14
FeO	0.20	28	epidote	0.1	alk	33
MnO	n. d.		apatite	0.2	k	0.15
MgO	0.18[2]	45		100.0	mg	0.42
CaO	2.20	392			c/fm	3.7
Na_2O	4.86	784	Norm			
K_2O	1.31	139	Q	37.5		
P_2O_5	0.10[2]	7	Or	7.7		
H_2O^+	0.40	222	Ab	41.1		
BaO	0.00		An	10.3		
	99.59		C	1.0		
			Σ Sal	97.6 %		
Sp. gr.	2.67		Hy	0.6		
			Mt	0.4		
			Ap	0.2		
			Σ Fem	1.2 %		
			Alsbachose			

This rock is an extreme type of the region, as other examined rock specimens are richer in potassium than this one. A similar rock type is the »injection-gneiss» of Muruhatten described in the earlier paper (6), the analysis of which will be recapitulated here.

[1] The calculated composition agrees with the volumetric analysis except for plagioclase and muscovite which were $48^1/_2$ and 10 % according to measurement.

[2] Estimated.

Table 10. Injected trondhjemite, Muruhatten.

Analyst I. Sucksdorff.

SiO_2	59.23	9,823
TiO_2	n. d.	
Al_2O_3	20.50	2,006
Fe_2O_3	1.87	115
FeO	4.64	646
MgO	2.58	640
CaO	1.79	319
Na_2O	6.73	1,085
K_2O	2.52	267
H_2O	0.52	289
MnO	tr.	
	100.38	

Sp. gr. = 2.78.

Norm			
Or		15.0	
Ab		57.1	
An		8.9	
C		3.4	
Σ Sal		84.4	
Hy	$MgSiO_3$	5.4	11.1
	$FeSiO_3$	5.7	
Ol	Mg_2SiO_4	0.8	1.7
	Fe_2SiO_4	0.9	
Mt		2.8	
Σ Fem		15.6	Akerose

Actual composition	
Plagioclase (An 11.5)	65.0 %
Quartz	6.0
Biotite	22.0
Garnet	5.0
Zoisite	0.2
Magnetite	1.7
Apatite	0.1 %
	100.0

Niggli values	
si	189
al	39
fm	29
c	6
alk	26
k	0.20
mg	0.42
C/fm	0.21

This rock type has been slightly contaminated by reaction with basic rocks, especially with peridotite. This has resulted in a loss of SiO_2, CaO and probably also a little K_2O and an addition of chiefly MgO and some iron. This reaction has produced the crystallization of biotite and garnet at the expense of quartz and some muscovite. The plagioclase is poor in anorthite, decidedly richer in albite than the rocks otherwise are. The loss of CaO has evidently gone to formation of tremolite-actinolite at the peridotite border. The outer parts of the injected rock are much more altered and are surrounded by an aureole rich in biotite (much chloritized) and tourmaline. — In other parts of the same rock-mass where the reaction is less prominent the rock is richer in quartz and has muscovite, but very little garnet and biotite.

Transitionary rock types towards the more common intermediate granites also occur. They are generally small-grained, with granitic texture or somewhat cataclastic. The composition of one type is about: plagioclase $>$ quartz $\geq$ microcline $>$ muscovite $>>$ garnet.

Another, a little richer in microcline has been calculated by the Rosiwal method:

Table 11.

Quartz	22.2 % (by weight)
oligoclase (An_{17})	38.2
myrmekite	1.3
microcline	11.2
muscovite	17.7
muscovite-symplectite (muscovite + quartz)	4.7
biotite	4,7 %

This rock is somewhat gneissoid and uneven in composition. The microcline is often porphyritic and some porphyritic grains of plagioclase also occur. Much smaller grains of both plagioclase and microcline are seen. The muscovite occurs as large blades, though also as smaller flakes, and often as an intergrowth of muscovite and quartz secondary to both potassic feldspar and plagioclase (symplectite). Some myrmekitization of microcline occurs, often associated with muscovite-symplectite after microcline. The microcline is a little perthitic and has a high index of refraction pointing to a microcline richer in sodic feldspar than is usual. The biotite has a strong pleochroism: γ greenish olive $\geqq \beta$ brownish-olive $>> \alpha$ greenish yellow.

The rock is a lenticular body in a feldspar-rich mica-schist, and it is probably contaminated by material from the schists. The percentage of micas is quite as high as that of the mica-schist, but with muscovite preponderant. The magmatic solutions have evidently had an excess of Al_2O_3, and probably more K_2O than shown by the rock analysis. At the late (hydrothermal) stage of the crystallization muscovite has been formed partly by reaction with the earlier crystallized feldspars. The myrmekitic albite-oligoclase was probably formed at the same time.

2. *Aplites.*

Several of the granitic rocks are very fine-grained and have been classified as aplites. They are petrographically generally of the same type as the rocks described in the preceding division. As most of the rocks have been observed close to amphibolites or peridotites they are more or less contaminated, and often surrounded by tourmaline-rich aureoles. The compositions of these aplites are consequently similar to the injected trondhjemite from Muruhatten described above.

An average type of aplite has been calculated by Rosiwal measurements and recalculated to a rock analysis by mineral compositions ascertained from other analyses:

Table 12. Trondhjemitic aplite, calculated. Muruhatten.

			Mineral composition		Niggli values	
SiO_2	67.47	11,189	Quartz	24.0 %	si	280
TiO_2	0.45	56	oligoclase An_{17}	57.0	ti	1.4
Al_2O_3	16.61	1,625	potassic feldspar	0.2	al	41
Fe_2O_3	0.50	31	muscovite	0.5	fm	23
FeO(MnO)	2.57	358	biotite	16.0	c	10
MgO	2.09	518	garnet	1.0	alk	26
CaO	2.33	415	tourmaline	0.5	k	0.23
Na_2O	4.97	802	rutile	0.2	mg	0.55
K_2O	2.20	233	sulphides	0.2	c/fm	0.42
P_2O_5	0.16	11	apatite (+zircon)	0.4		
S	0.08	25		100.0		
B_2O_3	0.05	7				
H_2O^+	0.52	289				
	100.00					

The aplites often show transitions from types with purely magmatic to others with much hydrothermal minerals, and they are by contamination richer in reactionary minerals than the granitic rocks. To the reactionary minerals may be reckoned: biotite, garnet, tourmaline, rutile, iron sulphides, and partly zoisite (epidote).

3. *Intermediate granites.*

Most of the intrusive granites are of an intermediate composition. They are generally granitoid with porphyroblastic feldspars and granular matrix, though they are less granulated than the more trondhjemitic varieties and are thus a little more coarse-grained. Two similar rock types are analysed:

Table 13. Muscovite-granite, W. of Muruhatten.

Analyst N. Sahlbom.

			Mineral composition[1]		Norm		Niggli values	
SiO_2	74.65	12 380	Quartz	37.0 %	Q	35.5	si	442
TiO_2	0.07	9	plagioclase An_{14}—		Or	26.4	ti	0.3
Al_2O_3	14.30	1 399	An_{15}	24.4	Ab	28.3	al	50
Fe_2O_3	0.56	35	microcline	19.7	An	4.1	fm	7.4
FeO	0.52	72	myrmekite (plag.		C	2.4	c	6.6
MnO	0.10	14	+ quartz)	2.5	Σ Sal	96.7	alk	36
MgO	0.19	47	muscovite	14.5			k	0.47
CaO	1.04	185	biotite	1.0	Hy	1.1	mg	0.24
Na_2O	3.35	540	garnet	0.4	Il	0.1	c/fm	0.9
K_2O	4.46	473	apatite	0.3	Mt	0.8		
P_2O_5	0.15	11	iron sulphides		Ap	0.4		
BaO	tr.		(+ iron oxides)	0.2	Σ Fem	2.4		
H_2O^-	0.62	344		100.0 %	Alaskose			
	100.01							
H_2O^+	0.10							
Sp. gr.	2.68							

This granite is of an adamellitic type, or aplite-granitic to engadinic according to Niggli. Both plagioclase and microcline occur as porphyritic grains, though the microcline often appears as matrix to the plagioclase. The larger plagioclases have a composition about An_{15}—An_{16} while the smaller ones are richer in albite, and the myrmekite plagioclase is about An_{11}. The microcline is generally without its typical twinning. Its refraction indices are about $\gamma = 1.5275$, $\alpha = 1.520$, and the axial angle $2V_\alpha = 84 \pm 3°$. It is slightly richer in sodic feldspar than the microcline calculated out of the pegmatite on p. 23.

The structure of the rock is protoclastic and slightly cataclastic.

Table 14. Adamellitic granite, W. of Muruhatten.

Analyst N. Sahlbom.

			Mineral composition		Norm		Niggli values	
SiO_2	75.89	12 585						
TiO_2	0.00		Quartz	38.6 %	Q	39.0	si	490
Al_2O_3	13.82	1 352	plagioclase (An_{17}—		Or	21.4	al	53
Fe_2O_3	0.50	31	An_{18})	29.2	Ab	29.1	fm	6
FeO	0.40	56	microcline	18.9	An	5.5	c	8.5
MgO	0.15[2]	37	myrmekite (plag. +		C	2.2	alk	32.5
CaO	1.20	214	quartz)	2.0	Σ Sal	97.2	k	0.46
Na_2O	3.45	556	muscovite	10.1			mg	0.24
K_2O	3.61	383	biotite	1.0	Hy	0.7	c/fm	1.4
P_2O_5	0.07[2]	5	apatite	0.1	Ap	0.2		
H_2O^+	0.80	444	magnetite	0.1	Mt	0.7		
BaO	0.00			100.0 %	Σ Fem	1.6		
	99.89				Tehamose			

[1] Vol. measurement showed slightly less of Q and plag. and somewhat more of muscovite.

[2] Estimated.

It is an adamellitic muscovite-granite of aplite-granitic to yosemitic magma-type according to Niggli (though high content of si and al). This rock is more gneissic than the one described above and it is partly similar to an »augen»-gneiss on account of stronger granulation. The microcline mostly occurs as porphyroblastic grains often bent and with uneven perthitic intergrowth due to stress (Fig. 9). Crushed grains also occur in the lepidoblastic matrix. Some

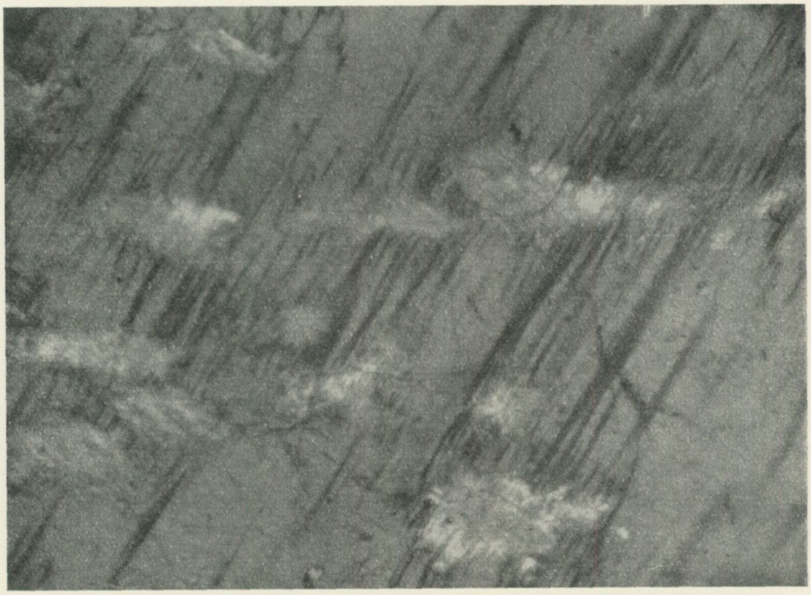


Fig. 9. Uneven perthitic intergrowth in microcline produced by stress.

parts of the rock sections show strong crushing where a re-crystallization of muscovite has occurred among the small grains of quartz and feldspar. Porphyritic crystals of plagioclase are also undulous, often bent and with crushed margins. They are sometimes penetrated by muscovite blades (as well as the microcline). The microcline often envelopes the plagioclase grains, though small grains of microcline are also seen in the porphyritic plagioclases. The rock conveys the impression that an enrichment in potassium has occurred after the main part of the plagioclases have crystallized, and still later is the crystallization of the muscovite. This is a familiar feature from the rocks of this region pointing to a continuous crystallization beginning with a formation of chiefly plagioclase, then a crystallization of chiefly potassic feldspar when a rock richer in plagioclase has already crystallized, and finally a strong formation of muscovite which reacts with the earlier formed minerals. A little sodium is hereby liberated producing the myrmekitization of some porphyritic microclines.

The mineral composition of two more potassic rock types are calculated volumetrically (weight %):

	15.	16.
Quartz	27.3	27.2
plagicolase	28.1	10.4
microcline	27.2	51.4
myrmekite (plag. + quartz)	1.8	
muscovite	11.0	9.8
biotite	4.5	
allanite	0.1	
apatite		0.1
garnet		1.1
	100.0 %	100.0 %

Both rocks are gneissoid, the first one small-grained and the other more coarse-grained, rather pegmatite-like, also seen by the composition approaching that of the pegmatites described below. The microcline is porphyroblastic and poikilitic, at least at the margins. The plagioclase forms smaller grains. It is about An_{16} in the first rock and more sodic in the second.

The microcline in two rock sections had fine interpositions probably of sillimanite, but it is generally not sericitized.

4. *Potassic, graphic granites or pegmatites.*

Large pegmatitic bodies have been observed in several places. One was almost 100 m long and about 50 m wide. These pegmatites have generally a graphic texture and they are not gneissic. They consist predominantly of microcline.

Table 17. Potassic pegmatite, Lillfjället.

Analyst N. Sahlbom.

			Mineral composition		Norm		Niggli values	
SiO_2	72.46	12,017						
TiO_2	0.09	11	Quartz	24.0 %	Q	23.4	si	425
Al_2O_3	14.46	1,415	plagioclase	3.0	Or	53.9	ti	0.4
Fe_2O_3	0.08	5	microcline	64.4	Ab	19.2	al	49
FeO	0.37	51	myrmekite (plag.+		An	0.6	fm	3
MnO	0.01	1	quartz)	0.5	C	0.6	c	2.4
MgO	0.11	27	muscovite	5.4	Σ Sal	97.7	alk	46
CaO	0.36	64	muscovite-symplec-				k	0.73
BaO	0.09	6	tite (muscovite+		Hy	0.8	mg	0.3
Na_2O	2.27	366	quartz)	1.2	Il	0.2	c/fm	0.78
K_2O	9.13	969	biotite	0.9	Mt	0.1		
P_2O_5	0.20	14	apatite	0.5	Ap	0.5		
H_2O^+	0.28	155	ilmenite	0.1	Σ Fem	1.6		
	99.91		epidote	tr.	Omeose			
Sp. gr.	2.62			100.0 %				

The composition of this rock is similar to many graphic granites in Washington's Analyses of igneous rocks.

The biotite of the rock is much altered to chlorite, and a little prehnite is perceived. The intermediate composition of the plagioclase is about An_{10}, but larger grains seem to be An_{13} (albite twins max. ext. 8°, ext. $\perp a = 8°$). It occurs as small grains between the large microcline grains and it is also seen within the microcline. The large microclines have intergrowth of quartz grains with equal extinction positions. The photo, fig. 10, shows this texture and also some inplication texture between muscovite and quartz at the borders of muscovite grains at contacts with microcline (Fig. 11). The microcline has about the

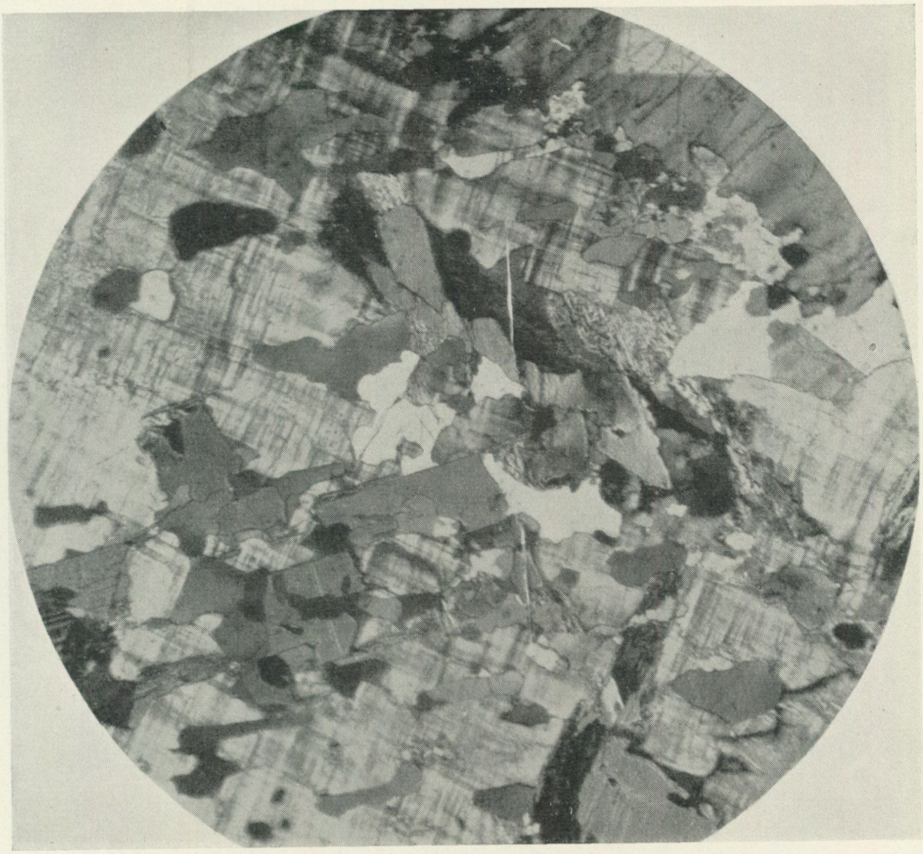


Fig. 10. Microcline with granophyric intergrowth of quartz, and muscovite dissecting the feldspar.

following refraction indices: $\gamma = 1.527$, $\alpha = 1.5195$. A calculation of the composition of the mineral according to the rock analysis which agrees well with the Rosiwal measurements gives the following result:

SiO_2	65.7 %
Al_2O_3	18.3
CaO	0.1
BaO	0.1
Na_2O	2.8
K_2O	13.0
	100.0 %

This gives a small excess of alkalies, and deficiency of Al_2O_3 ($^1/_3$ %).

Two other pegmatites show the following mineral composition:

	18	19
Quartz	23.6	11.8
albite	8.3	1.8
myrmekite	—	1.2
microcline	67.9	81.9
muscovite	0.2	3.3
	100.0	100.0 %

Both rocks have also some symplectite intergrowth of muscovite and quartz. The large microclines are somewhat perthitic and also poikilitic. The plagioclase of the first rock type is almost pure albite.

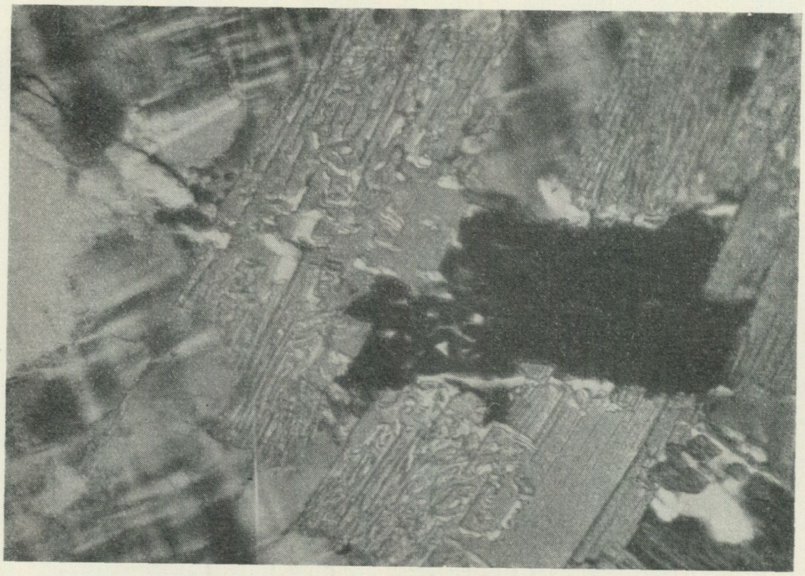


Fig. 11. Symplectitic intergrowth of quartz and muscovite replacing microcline.

b. Injected mica-schists.

In the injected areas banded gneisses often occur, where veins of feldspathic material can be discerned in the bedded mica-schist. These veins are generally a trifle reddish due to their content of potassic feldspar. They may have every dimension from thin veins up to lenticular pegmatoid bodies. Thin veins of granitic or pegmatitic material are thus common in the environment of the larger intrusions. Sometimes there are more lumps and »augen» of feldspathic material instead. In the exterior parts of the region this permeating of the mica-schist is less noticeable, but in the central parts the soaking of the rocks may be so complete that they look like regular ortho-gneisses.

A typical, veined mica-schist has been analysed:

Table 20. Injected mica-schist, W. of Muruhatten.

Analyst N. Sahlbom.

			Mineral composition[1]		Norm		Niggli values	
SiO_2	63.08	10,461	Quartz	29.6 %	Q	26.3	si	249
TiO_2	0.84	105	Oligoclase (An_{22})	19.0	Or	26.1	al	42
Al_2O_3	18.01	1,762	Potassic feldspar	8.8	Ab	15.8	fm	33
Fe_2O_3	1.54	96	Muscovite	10.4	An	6.3	c	6.5
FeO	4.81	669	Biotite	24.0	C	7.8	alk	18.5
MnO	0.11	15						
MgO	2.05	508	Chlorite	0.1	Σ Sal	82.3	k	0.6
CaO	1.56	278	Sillimanite	2.5			mg	0.37
Na_2O	1.87	302	Cyanite	3.7	Hy	11.5	c/fm	0.2
K_2O	4.43	470	Apatite	0.5	Il	1.6	ti	2.5
P_2O_5	0.23	16	Iron sulphides	0.1	Mt	2.2		
H_2O^+	1.32	733	Titano-magnetite	0.5	Ap	0.5		
	99.85		Secondary sericite	0.8	Σ Fem	15.8		
H_2O^-	0.18		Weight %	100.0	Adamellose			
Sp. gr.	2.80							

Compared with igneous rocks the composition shows too high value of Al_2O_3 and also of MgO. The P_2O_5 content seems rather high for a mica-schist.

The rock represents a plagioclase-rich mica-schist, about of the same type as the mica-schists Nos. 2 and 6 on page 10, injected with adamellitic to potassium-granitic material (chiefly feldspar). An enrichment in potassic feldspar and possibly some plagioclase and micas has occurred as compared with the original schist. The content of Al-silicates is remarkable as these minerals have not been observed in the non-injected mica-schists. The cyanite was probably formed during the combined action of the magmatic intrusion and stress at an early epoch. As is seen by the rock slices it was not stable and has been partly converted into sillimanite which in its turn has a beginning replacement by mica. With the referred composition of the rock the Al-silicates are not stable as they should react with potassic feldspar and form mica. They have evidently been formed as an early metamorphism product, but are vanishing by the continued action (viz. injection) of the magmatic materials.

Another similar, streaky mica-schist in the neighbourhood which was a little less injected has about the following mineral composition:

	21
Quartz	45.9 weight %
oligoclase	25.2
sericitized plagioclase	2.4
potassic feldspar	6.0
myrmekite (plag. + quartz)	0.2
muscovite	3.6
biotite	13.9
chlorite	0.1
garnet	0.2
apatite	0.3
sillimanite	1.4
cyanite	0.4
zircon	0.1
ore grains	0.2
cordierite, rutile	0.1
	100.0

[1] Volumetric measurement gave the following composition in weight %: Quartz 31, plag. 20, potassic feldspar 8 1/2, muscovite 8, biotite 27, chlorite 0.1, sillimanite 2, cyanite 3, apatite 0.4, ore minerals 0.3 %.

The mixed origin, and the unsaturated composition of the rock, is displayed by the great number of minerals. The rock had fewer veins of injection than the one described before, and this is also shown by the decrease in potassic feldspar and muscovite.

A typical injected gneiss from the central part of the region has also been analysed. It is a contorted, mica-rich rock of the same type as that in fig. 5, close to a large pegmatite body:

Table 22. Injected mica-schist, W. N. W. of Murutorpet.

Analyst N. Sahlbom.

SiO_2	71.34	11,831
TiO_2	0.53	66
Al_2O_3	14.32	1,401
Fe_2O_3	1.39	87
FeO	3.04	423
MnO	0.10	14
MgO	1.46	362
CaO	1.30	232
Na_2O	1.81	292
K_2O	3.91	415
P_2O_5	0.05	3
H_2O	0.92	511
	100.17	
S	0.00	
H_2O^-	0.15	
Sp. gr.	2.77	

Mineral composition	
Quartz	43.0 %
plagioclase An_{26}—An_{27}	17.2
potassic feldspar	4.9
muscovite	16.7
biotite	15.0
allanite	0.05
sillimanite (+cyanite)	2.7
apatite	0.1
rutile	0.05
sulphides	0.05
magnetite	0.2
zircon	0.05
	100.0 weight %

Norm	
Q	39.0
Or	23.1
Ab	15.3
An	6.2
C	4.8
Σ Sal	88.4
Hy	7.4
Il	1.0
Mt	2.0
Ap	0.1
Σ Fem	10.5
Tehamose	

Niggli values	
si	301
al	42.3
fm	29.4
c	7
alk	21.3
k	0.59
mg	0.37
c/fm	0.24
ti	2.0

A sedimentary origin of this acid rock is indicated by the high values of MgO, iron and TiO_2 (chiefly contained in the micas). The content of potassic feldspar and muscovite points to the magmatic influence (perhaps also the zircon and sulphides). Some biotite and muscovite are congregated, and they are often larger than the other minerals. The feldspars partly form large poikiloblastic grains and partly smaller ones of the magnitude of the quartz grains. The sillimanite (and a small percentage of cyanite) forms thin needles penetrating the plagioclase, but they are generally enveloped in the micas.

The mica-schists of these injected rocks have primarily been quartzitic mica-schists. The biotite of the schists have generally a rather strong pleochroism in olive-brownish colour.

c. Injected gneisses.

Some parts of the injected schists are quite gneissoid rocks and »augen»-gneisses. They are very feldspar-rich mica-schists (para-gneisses) which have been much injected and metamorphosed. There has partly been an addition of granitic material, but partly, and mainly, an enrichment in potassic feldspar. Large, porphyritic microclines are formed up to 4 cm in length. The microcline is generally without its typical twinning, and it is sometimes perthitic. The distribution of the porphyroblasts is very uneven, sometimes many together but often only solitary ones, indicating an uneven enrichment in potassium. The microclines are poikilitic, partly as a matrix enveloping the other minerals, but also as independent crystals, rather rectangular in form though sometimes granulated. Resorbed grains of quartz and plagioclase are often found within the microcline crystals.

The plagioclase may also be porphyritic, up to $^1/_2$ cm in size, though usually not. It varies in composition about An_{21}—An_{27}, averaging An_{24}.

An average of three rock samples gives the following composition:

Table 23. Injection-gneiss, E of Muruhatten, calculated.

			Mineral composition		Niggli values	
SiO_2	75.79	12,602	Quartz	46.6 %	si	439
TiO_2	0.32	40	oligoclase (An_{24})	29.6	ti	1.4
Al_2O_3	12.34	1,207	potassic feldspar	5.0	al	42
Fe_2O_3	0.80	50	myrmekite (plag.+quartz)	0.3	fm	23
FeO	1.91	266	muscovite	6.1	c	10
MgO	1.24	307	biotite	11.9	alk	25
CaO	1.63	291	chlorite	0.1	k	0.37
Na_2O	2.83	456	epidote	0.1	mg	0.46
K_2O	2.52	267	apatite (+ rutile)	0.1	c/fm	0.43
H_2O^+	0.62	344	zircon	0.1		
	100.00		ore minerals	0.1		
				100.0 %		

The composition of this rock is thus rather similar to a trondhjemitic granit, though the content of MgO and TiO_2 is high and the alkali percentage is low.

The less injected rocks of this area have about the same content of plagioclase but decreasing potassic feldspar which is the main material added by the injection.

d. Muscovitization.

Most of the injected schists and injection-gneisses show some muscovitization of the feldspars, especially of the microclines. It is blades of muscovite penetrating the feldspars in several directions, pointing to hydrothermal alterations of the rocks in the latest stages of the injection metamorphism, often accompanied by formation of tourmaline, garnet and precipitation of sulphides, and sometimes followed by chloritization of the biotite. The injected granites and pegmatites often show alteration of potassic feldspar to muscovite also. Some parts of the central area of injection-gneisses show rocks enriched in muscovite, or in muscovite and quartz with solitary »augen» of potassic feldspar. This generally occurs as an outer aureole around microcline-pegmatites. One rock of this type has been calculated volumetrically:

Table 24. Injected mica-schist, Lillfjället.

Quartz	47.4	% (by weight)
plagioclase	18.4	
potassic feldspar	1.5	
muscovite	29.0	
biotite	2.5	
garnet	0.4	
tourmaline	0.4	
apatite	0.2	
sulphides	0.2	
zircon	tr.	
	100.0	%

The rock is rather coarse-grained with large muscovites and porphyritic grains of plagioclase, up to $^1/_2$ cm in size. Only solitary larger potassic feldspars occur as »augen» one or two cm in length.

The plagioclases are sericitized which shows itself to be intimately associated with the crystallization of the muscovites. The tourmalines are larger than in the schists, about of the same magnitude as in the pegmatites, with pleochroism from dark bluish green to pale yellowish green. The biotite has the usual colour of that of the injected schists, viz. dark brown-olive to pale greenish yellow. It has often been altered to a greenish penninite.

Associated with muscovitization is a formation of biotite close to basic igneous rocks. Next to the peridotite or amphibolite the biotite dominates over the muscovite, but departing from the contact the muscovite increases. An enrichment in tourmaline occurs near the basic rocks, generally accompanied by a chloritization of the biotite. The feldspar is here always a plagioclase as the potassic feldspar is transformed into biotite by reaction with the Mg-rich rocks.

A good section through the injected and muscovitized schist with increasing reaction when approaching a big peridotite is to be seen at Säterberget. Three samples taken in successive order from Lillfjället towards Säterberget show the following mineral development:

1) Quartz $>$ plagioclase $>$ biotite $\geq$ muscovite $>$ potassic feldspar $>$ epidote $\geq$ apatite. Some of the potassic feldspars are porphyritic, otherwise they form a matrix around the plagioclases.

2) Plagioclase + quartz = muscovite $>$ biotite $>>$ sulphides $>$ rutile $\geq$ zoisite (or clinozoisite) $>$ tourmaline (feldspar $>$ quartz). The sulphides consist of pyrrhotite and some pyrite, often with pyrite as a core inside the pyrrhotite. The muscovite has grown through the plagioclases in every direction, with very different sizes of the blades. The potassic feldspar has successively disappeared.

3) Biotite $\geq$ muscovite $\geq$ plagioclase $>$ sulphides (generally pyrrhotite) $>$ zoisite (+ orthite) $>$ rutile = tourmaline. Towards the peridotite contact the biotite and tourmaline increases and the muscovite vanishes, though the biotite is generally chloritized.

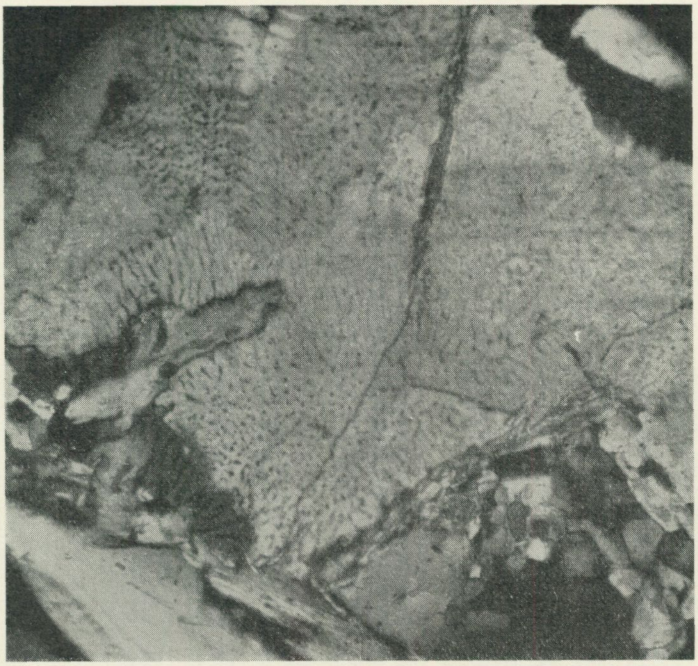


Fig. 12, shows muscovite intrusion in microcline with conversion of the microcline into myrmekite. The vermicular quartz is often oriented to the muscovite.

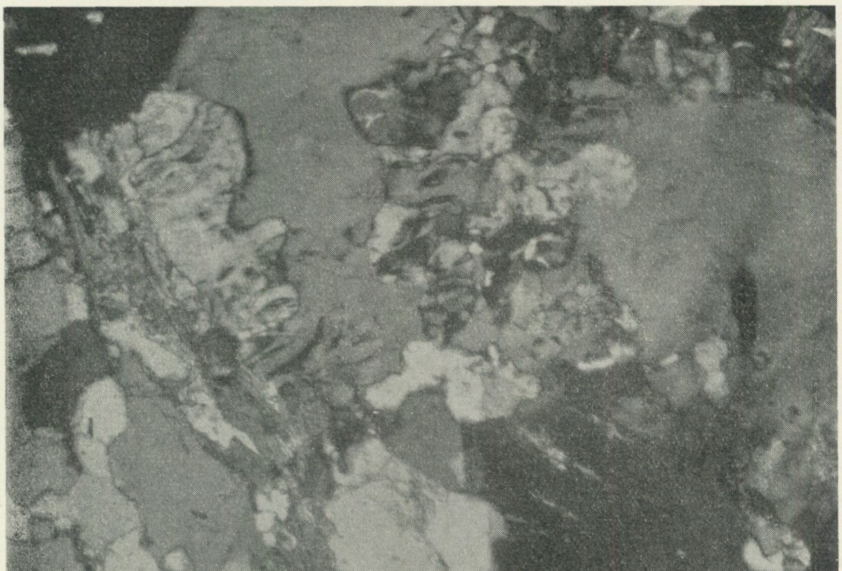


Fig. 13. Sponge-like myrmekite-plagioclase attacking the microcline, generally in the neighbourhood of muscovites.

The muscovitized, pegmatite-injected rocks are very much like greissen, and the origins of these rocks are also similar, both being pneumatolytic-hyrothermal alterations following pegmatite injections.

In thin sections the intrusion of muscovite into microcline is generally associated with two typical micro-textures viz. muscovite-quartz-symplektite and myrmekite. The muscovite-symplektite develops when the muscovite blades enter the microclines. Quartz is evidently set free by the conver-

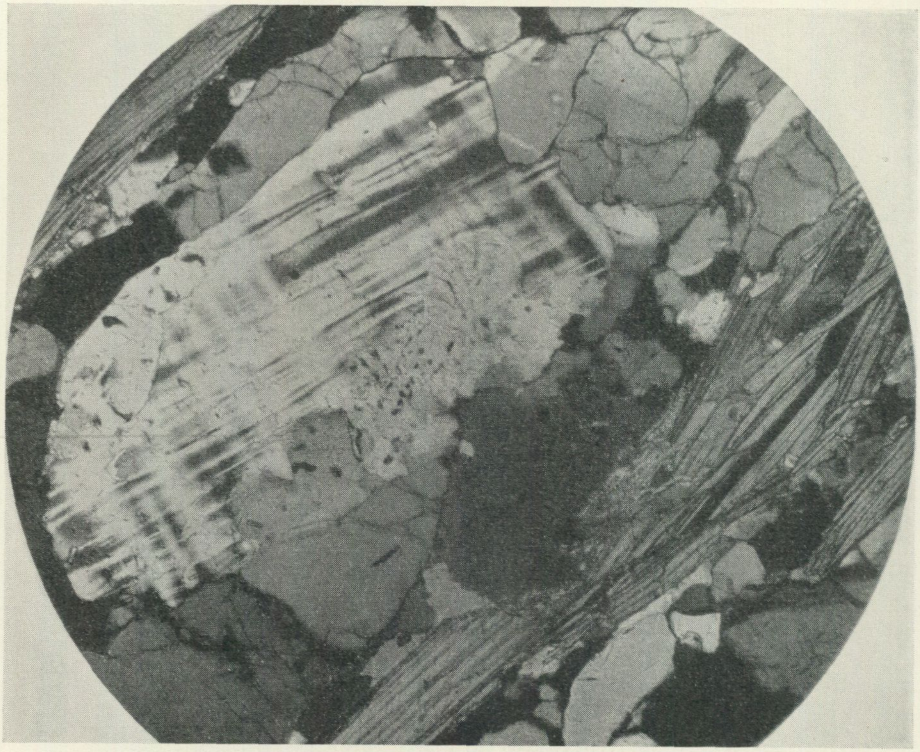


Fig. 14, shows sponge-like myrmekiteplagioclase attacking the microcline (with radiating vermicular quartz in the myrmekite).

sion of microcline into muscovite and an intergrowth of quartz and muscovite is formed. The photo, fig. 10, shows such an intergrowth. The intrusion of muscovite into microcline or close to it, is mostly followed by a conversion of microcline into myrmekite, beginning at the margins. A typical view of this is pictured in fig. 12, showing the rods of vermicular quartz going out from the muscovites intruding the microcline or bordering it. Figs. 13 and 14 show sponges of myrmekite-plagioclase transforming the microcline, generally starting in the neighbourhood of the muscovites. The rest solutions have evidently been rich in alumina as well as potassium and have reacted with the earlier formed feldspar under development of

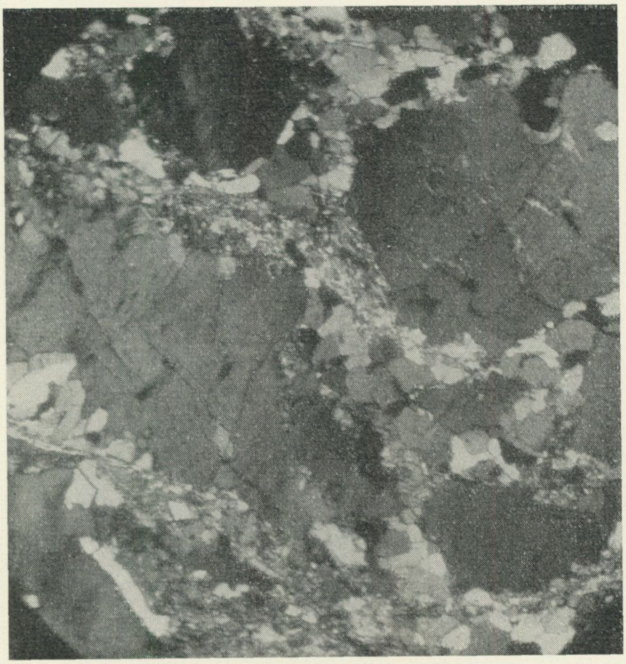


Fig. 15. Injection-granite showing partial crushing of the grains (at the rims of the large grains).

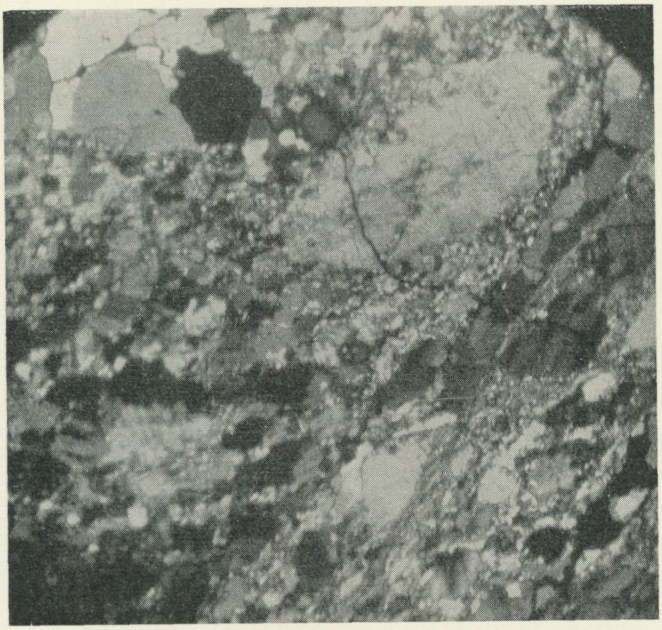


Fig. 16. Injection-granite showing strong crushing of the grains.

muscovite. At the same time Na_2O has been set free and attacked the microcline and partly converted it to plagioclase with the excess of silica precipitated *in situ*. Part of these quartz vermicules might have been generated by the excess of silica formed at the conversion of potassium feldspar to mica.

e. Discussion.

Referring to a facies classification, the rocks of the Muruhatten region generally show transitionary stages between different facies on account of the great variation of the material, the incomplete reaction between the different types, and the continuous change of the injection metamorphism from almost magmatic to hydrothermal stages. The incomplete saturation is often shown by the great number of minerals in some rocks which should not occur in a stable facies. Before the introduction of the granite-pegmatite intrusions the region was composed of sedimentary rocks varying between argillaceous rocks and more or less feldspar-bearing sandstones. Calcareous rocks seem to be quite wanting. Basic igneous rocks, now in the amphibolite facies, are very common in this area. Some of them have been intrusive rocks, while others may have been extrusive. They have evidently been strongly metamorphosed before the main intrusions of the salic rocks. The region is also rich in ultrabasic rocks which better resisted the metamorphism before the granitic injections.

The great variety of the rocks and the variation of the salic intrusions, starting with plagioclase-rich rocks and passing over to potassic dominant types has produced rather complex rock masses.

A general table (cf. pp. 34—35) of the chief rock types of the injections, injected schists, and mica-schists, based on volumetric analyses will give a condensed review of the preceding descriptions (the metamorphism of the basic rocks will be discussed in a later chapter).

The lenticular pegmatitic-granitic bodies correspond to the pure concentrations of almost entirely introduced material crystallized along the planes of schistosity of the schists. Sometimes a large complex of the schists has been thoroughly permeated by the introduced solutions, and the original material of the schists may be discerned as streaks or micaceous stripes in a gneiss-granitic matrix (compare the photo, fig. 5). In the larger lenticular bodies one often sees a pure pegmatitic rock in the center and a mica-bearing rock against the borders with a diffuse transition to a mica-schist which generally has veins, lenses, or »augen» of feldspar-rich material in the neighbourhood (cf. photos, figs. 2, 3, and 4), and clusters or »augen» of feldspar in the continuation of the larger body. There is thus no difference in the added material, but only a difference of the degree of concentration. In the central areas one often sees larger pegmatite bodies, and the size of the feldspar crystals are naturally also bigger than in the small bodies.

A comparison with Goldschmidt's description of the injection metamorphism of the central zones of the Stavanger region shows great similarities, though the main part of the injected material in the Stavanger area is composed of trondhjemites, and in the Muruhatten region it is composed of intermediate to potassic granites. Both kinds of injections are thus found in these regions though in a reverse order. The country rocks of the Stavanger region should primarily have been potassium-dominant rocks, and the added material was predominantly sodic; in the Muruhatten region the conditions were the reverse. As in many other instances the metamorphism has aimed at a chemical equalization in both examples.

In Frostviken many Na-dominant acid igneous rocks are met with in the westerly (and less metamorphic) parts of the region. One may thus easily conceive that they are a farther away transported phase of the central zone, viz. the Muruhatten region. This region corresponds to the migmatite-front of the transition zone (Übergangszone) at the border of the »Oberbau» according to Wegmann (23). The Stavanger region corresponds to a higher level of the migmatite-front in the »Oberbau», partly also correlative with some migmatites of W. Västerbotten (cf. A. Högbom, 14, p. 34), though that level may be still higher, corresponding to the intrusions of the westerly part of the Frostviken district (though these rocks are less active).

Goldschmidt counts with an originally homogenous material with a great excess of Al_2O_3 in argillaceous rocks, and points to an increasing Na percentage toward the trondhjemites. In the Muruhatten region much of the originally sedimentary rocks must have been arenaceous and feldspar-bearing, and have not had any marked excess of Al. The injected rocks show about the same rate of Al as the mica-schists. The added material has about the character of intermediate or potassic granites in the form of alkali-aluminium-silicate, partly probably in the form of aluminate. In the late pegmatitic to hydrothermal stage Al has been introduced in excess, transforming some of the feldspars to micas. This might partly be accounted for by removal of alkali, as the feldspars are less stable at this late stage. The micas have been formed principally at the expense of potassic feldspar, and at the same time a little sodium has been freed and produced a slight myrmekitization of the potassium feldspars (cf. photos, figs. 13 and 14).

The extreme Na-dominant intrusions are generally met with in the neighbourhood of basic or ultra-basic rocks. A migration of potassium has occurred from the injections to these rocks for the formation of biotite at the borders. These granites or aplites are thus biotite-bearing and somewhat desilificated. The injections have originally not been so Na-extreme in these cases. But several isolated plagioclase-rich intrusions in the mica-schists show that we still have had series of intrusions, starting with Na-dominant rocks (more granulated and recrystallized), with transitions to pure potassic pegmatites (which are but little cataclastic).

In the case of the pegmatite intrusions in the mica-schists they are not so easily perceived, as the equilibrium of the mineralfacies of the rocks is scarcely

Rock types of the Muruhatten injection complex tabulated

Rock No.	19	17	18	16	15	13	14	11	9	12	10 a	10
	Injected (igneous) rocks											
	Pegmatites			Granites						Contaminated aplitic rocks		
Quartz	11.8	24.0	23.6	27.2	27.3	37.0	38.6	22.2	39.2	24.0	4.3	6.0
Potassic feldspar	81.9	64.4	67.9	51.4	27.2	19.7	18.9	11.2	—	0.2	—	—
Myrmekite (plag. + quartz)	1.2	0.5	—	—	1.8	2.5	2.0	1.3	—	—	—	—
Plagioclase	1.8	3.0	8.3	10.4	28.1	24.4	29.2	38.2	52.5	57.0	51.0	65.0
Muscovite	3.3	5.4	0.2	9.8	11.0	14.5	10.1	17.7	7.4	0.6	3.7	—
Muscovite-quartz-symplectite	—	1.2	—	—	—	—	—	4.8	—	—	—	—
Biotite	—	0.9	—	—	4.5	1.0	1.0	4.7	0.6	16.0	2.6	22.0
Chlorite	—	—	—	—	—	—	—	—	—	—	17.7	—
Garnet	—	—	—	1.1	—	0.4	—	—	—	1.0	2.1	5.0
Sillimanite	—	—	—	—	—	—	—	—	—	—	—	—
Cyanite (disthen)	—	—	—	—	—	—	—	—	—	—	—	—
Epidote (orthite)	—	tr.	—	—	0.1	—	—	—	—	—	0.2	—
Zoisite	—	—	—	—	—	—	—	—	0.1	—	—	0.2
Tourmaline	—	—	—	—	—	—	—	—	—	0.5	16.5	—
Apatite	—	0.5	tr.	0.1	tr.	0.3	0.1	—	0.2	0.4	0.2	0.1
Zircon	—	—	—	—	—	—	—	—	—	tr.	—	tr.
Rutile	—	—	—	—	—	—	—	—	—	0.2	0.3	—
Titanite	—	—	—	—	—	—	—	—	—	—	—	—
Sulphides	—	—	—	—	—	0.2	—	—	—	0.2	tr.	—
Magnetite	—	—	—	—	—	—	0.1	—	—	—	—	1.7
Ilmenite	—	0.1	—	—	—	—	—	—	—	—	—	—
Carbon	—	—	—	—	—	—	—	—	—	—	—	—
Cordierite	—	—	—	—	—	—	—	—	—	—	—	—
Calcite	—	—	—	—	—	—	—	—	—	—	1.5	—
Remarks	Perthitic microcline											
	Graphic texture (But slightly metamorphosed rocks)			Pegmatitic granite	Adamellitic granite			Oligoclase granite (tonalite)	Trondhjemitic, aplitic granite	Rocks contaminated by reaction with amphibolite and peridotite		
				(Protoclastic or cataclastic rocks)					(Cataclastic rocks)			

according to volumetric analyses. (Weight %.)

23 a	23 b	23 c	20	21	22	24	7	8	5	3+4	6	2	1
Rocks of mixed origin							Chiefly sedimentary origin						
Injection-gneiss, augen gneiss			Injected schists				Metasomatically modified mica-schists		Mica-schists				
44.7	48.9	45.4	29.6	45.9	43.0	47.4	50.6	33.9	37.7	42.3	53.7	47.5	43.5
9.2	5.6	1.3	8.8	6.0	4.9	1.5	—	—	—	—	—	—	—
0.3	0.5	0.1	tr.	0.2	—	—	—	—	—	—	—	—	—
30.4	26.8	31.5	19.0	25.2	17.2	18.4	15.8	17.2	25.2	14.4	22.3	19.5	9.4
4.6	7.5	6.1	11.2	6.0	16.7	29.0	13.7	2.9	—	22.6	1.2	13.1	30.2
—	—	—	—	—	—	—	—	—	—	—	—	—	—
10.2	10.4	15.1	24.0	13.9	15.0	2.5	9.1	22.4	16.8	18.7	19.3	18.8	13.5
0.2	—	—	0.1	0.1	—	—	6.7	5.0	18.3	—	0.1	0.3	0.1
—	—	—	—	0.2	—	0.4	1.7	9.7	—	0.2	—	—	0.2
—	—	—	2.5	1.4	} 2.7	—	—	—	—	—	—	—	—
—	—	—	3.7	0.4	}	—	—	—	—	tr.	—	—	—
--	0.1	0.2	—	tr.	0.05	—	0.1	0.1	—	1.6	3.0	0.3	2.0
—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	0.4	0.05	0.1	—	—	—	—	—
0.1	tr.	0.1	0.5	0.3	0.1	0.2	tr.	0.1	0.4	0.1	0.1	0.1	0.3
tr.	0.1	0.1	—	0.1	0.05	tr.	tr.	—	—	tr.	tr.	—	—
—	—	0.1	—	0.05	0.05	—	0.05	0.1	0.3	—	—	—	—
—	—	—	—	—	—	--	—	—	0.1	—	—	0.1	0.5
} —	0.1	—	0.1	}	0.05	0.2	2.2	}	}	—	—	}	0.1
} 0.3	—	—	} 0.5	} 0.2	0.2	—	—	} 1.3	} 1.2	1.1	0.3	} 0.3	} 0.2
} —	—	—	}	}	—	—	—	}	}	—	—	}	}
—	—	—	—	—	—	—	—	7.2	—	—	—	—	—
—	—	—	—	0.05	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—
Large microcline augen (poikiloblastic and often perthitic)													
Augen-gneiss formed by addition of potassic material to plagioclase-rich mica-schists			Introduction of potassic or adamellitic material to semipelitic sediment			Enrichment in quartz and muscovite	Quartz-rich mica-schist.	Garnet-bearing phyllitic mica-schist.	Mica-schist rich in oligoclase	Quartz-rich (sericitic) mica-schist.	Mica-schist rich in quartz and oligoclase	Mica-schist rich in quartz and oligoclase	Quartz-rich (sericitic) mica-schist

disturbed by the intrusions, the materials being rather similar. In pegmatite intrusions in amphibolites and peridotites the different materials in contact with each other are heterogeneous, and reactions will occur between the two phases, effecting that equilibrium is reached in neighbouring parts with transitions to both sides. The formation of tourmaline is favoured by the presence of basic oxides in excess, and therefore much tourmaline has often crystallized at the contacts of the pegmatitic intrusions and the basic rocks.

Goldschmidt considers that close to a granite purely magmatic or crystallizing granitic addition has occurred, but at a distance the pegmatitic phase passes over into a purely metasomatic. G. considers it to be granitic action all the time, though he distinguishes between infusing of crystals from a granite (trondhjemite), and granitic solutions which cannot carry any Al_2O_3. In this region all observations point to an addition of solutions with alkali-aluminium-silicates in excess, with different concentrations of material. In the outer zones it would be conceivable to suspect a diffuse addition of Na-silicate, producing plagioclase, but observations point to originally clastic, feldspar-rich rocks which furthermore are common also among the less metamorphic schists to the west. It is difficult to distinguish between magmatic crystallizing injections and solutions. It is rather the same kind of solutions which have permeated the rocks more or less, and in different concentrations. The mica-schists were very rich in quartz, and as the injected rocks have not been further enriched in quartz, it is possible that silica (and also some potassium) has migrated further away and is responsible for the common quartz-banding of some schists and slates to the west of this region.

Some injected schists have a small percentage of cyanite and sillimanite which should not be stable in these rocks. The cyanite might be a regional-metamorphic product that becomes unstable at the further injection metamorphism and is converted into sillimanite which later is transformed into micas. Knowing the enrichment in Al_2O_3 that often occurs together with the injection-metamorphism, as e. g. increased formation of micas, tourmaline, garnet etc., it is conceivable to suspect an addition of Al in this case too (or a removal of alkalies producing an excess of Al_2O_3).

Sederholm's description of the migmatitization of older rocks by the Hangö-granite in Finland shows many similarities and offers comparison with the Muruhatten region. The Hangö-granite is often intruded as lit-par-lit injections, as intrusive breccias, and as pegmatitic or aplitic veins and dykes. The earlier rocks of the region were mostly leptites (here generally greyish, bedded, feldspar-rich rocks) which have been mixed up with material from the granite that in large quantities »permeated the schists so as to form a composite rock. But also those portions which are now so rich in feldspar that the composition is nearly that of a granite, still retain a schistose texture. The darker parts of the leptite sometimes form fragments surrounded by more granitic portions, and their forms, sometimes showing ragged outlines, give the impression that the schistose rocks have been torn in pieces. At other places a better preserved schist and a granite alternate lit-par-lit. These intimately connected migmatitic masses have later been penetrated by better separated veins of red aplite and pegmatite, belonging to the same granite, which have afterwards been folded, often in the extremest degree.»[1] The folding has evidently occurred before the final consolidation of the granitic magma, as earlier folded veins are intersected by quite straight ones. Migmatites composed of leptitic rocks mixed up with veins of Hangö-granite are here also rich in almandite garnet which Sederholm considers to be formed by autometamorphic changes due to the influence of mineralizers emanated from the magma.

The intrusion of the Hangö-granites and the migmatization of that region evidently corresponds to a deeper cut of that area as compared with Muruhatten. The stress is far less in the Finnish area and the intrusions are more magmatic with almost »stoping» character, and with brecciations by the potassic granite; but transitions to metasomatic changes occur, and some of Sederholm's nebulitic remains are partly assimilated (and reacted) eruptive breccias, some are metasomatic alterations. The intrusions are partly syn-tectonic and partly late- to almost post-tectonic in both areas. Sederholm's ptygmatic folding with later intersecting veins corresponds to the crumpling of the injected mica-schists with later cutting, pegmatitic veins of the Muruhatten region.

N. H. Magnusson (17) who has recently described the pegmatitization of the Kantorp district, shows, with several rock analyses, that the pegmatitization has been accompanied by an excess of Al_2O_3. Typical Al minerals as cordierite, andalusite, sillimanite, have been formed besides garnet and micas. Magnusson considers that the excess of Al has been formed by removal of lime and probably silica and alkalies. He partly regards Al as supplied in excess together with iron, magnesium, and water, by the solutions. The Kantorp region now represents a precipitation-front of aluminium, iron, and magnesium-rich material, while probably silica, alkalies, and lime, have been removed to other areas. He thinks that the pegmatitization to a large scale is a sweating out of the earlier leptitic and granitic rocks during the metamorphism, almost *in situ*.

On account of many new descriptions of granites and gneisses as granitized or »activated» sediments with addition by diffusion or injection more or less *in situ* (e. g. by G. H. Anderson, Ebert, Quirke and Collins) that question will be briefly discussed for this region. To explain the intermediate granites and potassic pegmatites as activated mica-schists this requires an addition of almost exclusively K_2O and some Al_2O_3, but scarcely any SiO_2 or Na_2O. This might possibly explain the alkali-intermediate granites, but not the sodic dominant types. The potassium extreme pegmatites could hardly be considered as originated out of the plagioclase-rich mica-schists of this region, but must be supplied from outside sources. To explain the trondhjemite granites these should be regenerated out of the plagioclase-rich mica-schists if not differentiated out of the potassic granites. If they were fused or sweated out of the mica-

[1] Cited after SEDERHOLM (20).

schist it would be difficult to explain their appearance as distinct bodies and their abundance of plagioclase as compared with the quartz content, as there do not seem to be any quartz-rich bodies formed at the same time. If the trondhjemites were formed out of the potassic granites through reaction, they should naturally not be earlier formed which they evidently are. The alkali-intermediate rocks might be conceived as originated out of the plagioclase-rich mica-schist by addition of potassic material or out of the potassic granites by reaction with basic rocks; but their intimate connection with more sodic and more potassic rocks clearly favours an intrusion of a differentiated suite, which is also shown by the degree of metamorphism, starting with sodium dominant types and terminating with potassium extreme pegmatites (which sometimes also dissect the other types).

As to the origin of the magmatic solutions or »ichor» producing the injection metamorphism and granitic rocks of this part of the Caledonian range reference is made to the excellent discussions of Eskola (10), on the origin of granitic magmas.

A Niggli-variation diagram of the analysed rocks gives very uneven curves thus further illustrating the heterogenous origin of the rocks.

IV. Comparison with the Borka region of Southern Lappland.

In a district more than 100 km NNE of the Muruhatten region in about the same tectonic position, at the village and the lake of Borka in Southern Lappland, N of the Marsfjäll mountains, the author has made a survey of the rocks and the increasing metamorphism from the phyllites W of Borka to the injection-gneisses at the middle part of Lake Borka. In an earlier geologic survey of this region the present writer had recognized that it was here possible to get a profile all through pelitic sediments which for a comparable study of the metamorphism and the successive alteration towards the east should be very favourable. Two detail sections have thus been surveyed from the village of Borka toward the east, one on the northern side of the lake, the other on the southern, to the eastern part of the lake.

On the western side of the village of Borka there are phyllites and quartz-phyllites with some porphyroblasts of biotite (a formation of biotite porphyroblasts is still visible about 5 km to the west of Borka), which at Borka are changed into biotite-phyllites with consecutive transition into mica-schists. 500 m to the east of Borka these pass over into garnet-micaschists with a prominent development of garnet. Subsequently veins and lenses of feldspar material appear, at first more diffuse and solitary veins, but already $1^1/_2$ km east or southeast of Borka quite visible. Toward the east injected veins increase in number and size. At the middle part of the Borka lake there are gneissic injection rocks with successively more homogeneous appearance, but still to a great part of sedimentary origin. Purely igneous gneisses are thus not met with here, though the added material can dominate. Toward the east amphibolitic rocks preponderate and seem to limit the injected zone eastwards. In this innermost, eastern part of the injection-gneisses even the amphibolites have been noticeably affected by the injection processes, while several layers of amphibolite at the northwestern part of Lake Borka are not perceivably changed.

The transition from phyllite in the west, to biotite-phyllites, mica-schists, injected schists, injection-gneisses, and homogeneous gneiss-like rocks in the east, is quite continuous even with a consecutive growth in the size of the minerals. The dip and strike of the rocks are rather constant, generally with a N.N.E. strike and a medium dip toward the W. N. W. No marked overthrusts or greater displacements have been observed, but the whole complex shows differential movements (shown by the development of the micas, the banding and parallell orientation of the minerals etc.), increasing toward the east with the appearance of strongly banded gneisses and partly crushing of the rocks. The strong and oriented tectonic movements of this region are conspicuously noticeable on comparing the Borka gneisses with the corresponding rocks of the Muruhatten region which are far less tectonized.

The first appearance of the injections in the mica-schists is indistinct, as faint, diffuse veins. They will then become quite distinct, though more general is the appearance of »augen» of a reddish potassic feldspar (microcline or microcline perthite), similar to those seen in the photos, figs. 17 and 18. These »augen» may be distinguished from the smaller, whiter and evenly distributed primary »augen» of plagioclase of the mica-schists. There are generally solitary »augen» or swarms of »augen» of microcline, and also single veins of chiefly feldspar. Toward the central parts of the injection zone streaks and stretched »augen» of chiefly feldspar material increase in number, cf. photos, figs. 19—23. The difference between the chiefly sedimentary and chiefly intrusive origin of the bands is still visible, though there are also more homogenous types than those photographed.

A series of rock types calculated by volumetric analyses has been put together in a table (pp. 42 and 43), starting with the rocks from the western parts followed by consecutively more easterly rocks. The homogenous, fine-grained rocks are generally represented by one slide, the coarse-grained, inhomogenous rocks by two or three.

The phyllitic rocks of Borka, and N. W. of it, are curly, finely folded, very fine-grained slates, chiefly of a quartz-phyllitic to phyllitic character with quite subordinate layers of dark, graphite-bearing phyllites. They are sometimes differentiated into partly chlorite-rich layers, and partly sericite- and quartz-rich layers. A certain banding is often perceived in the thin sections developed by different grain size of the quartz stripes. The biotites are generally somewhat porphyritic, of a larger grain size than the chlorites. Contrary to what is the case in Muruhatten region there is hardly any retrograde metamorphism, because of which the increasing percentage of biotite toward

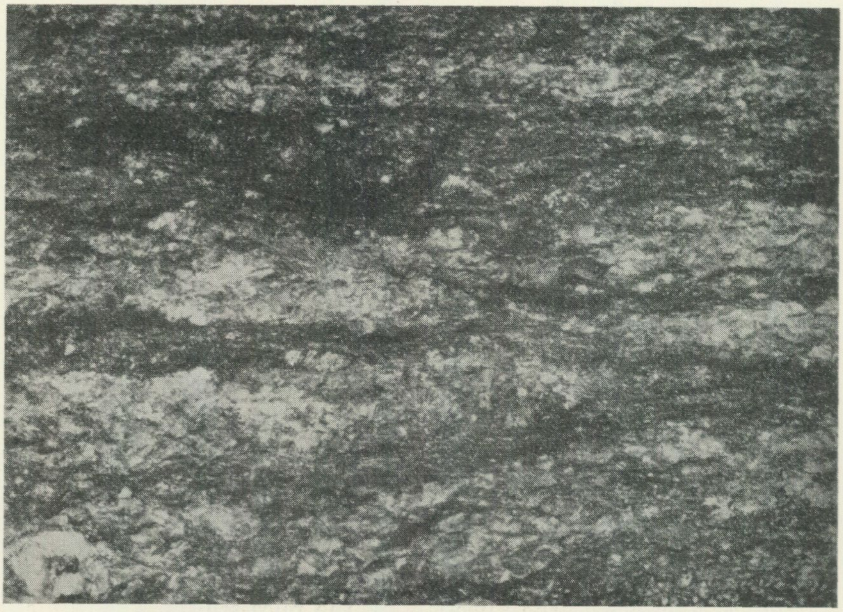


Fig. 17. Injected mica-schist with augen and schlieren of potassic feldspar. $^2/_3$ nat. size. W. of Lake Borka.

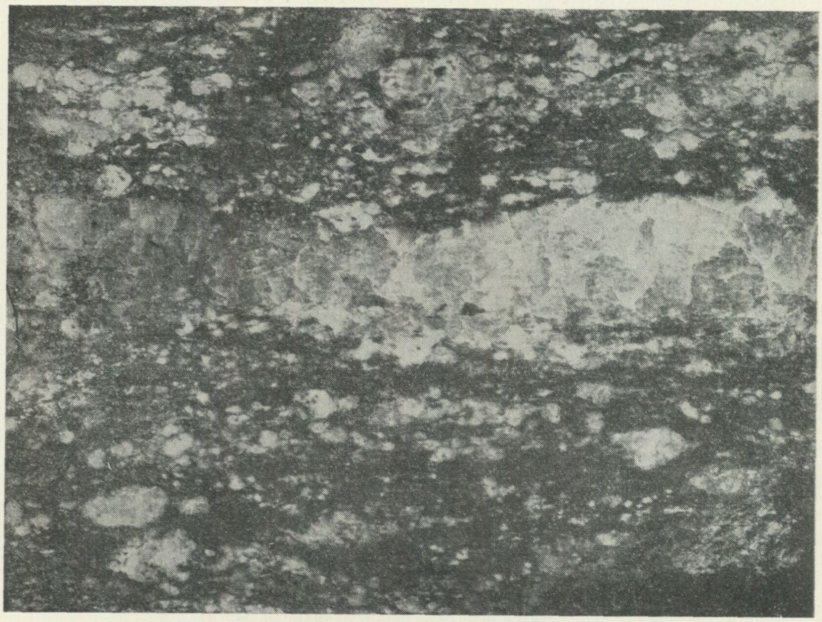


Fig. 18. Gneissic, injected mica-schist with augen of microcline (and a quartz vein). $^1/_2$ nat. size W. of Lake Borka.

the east, is more noticeable chiefly at the expense of chlorite. The transition from biotite-porphyroblastic phyllite to biotite-phyllite is indistinct in the field, because the rocks have the same texture and about the same grain size. The development of larger porphyroblasts, however, is soon distinct, and the rocks become more like mica-schists. Microscopically this is also noticed by the formation of small garnets. In this region we have the normal gradient of metamorphism with a first appearance of biotite and then of garnet. In some other districts (e. g. to the west of Muruhatten) it has been noticed that the garnet appears before the biotite. This depends chiefly on the fact that the biotite has been chloritized. Phyllitic rocks with porphyroblasts of chlorite are often observed in that case. The garnet has been much more resistant against the agencies of retrograde metamorphism.

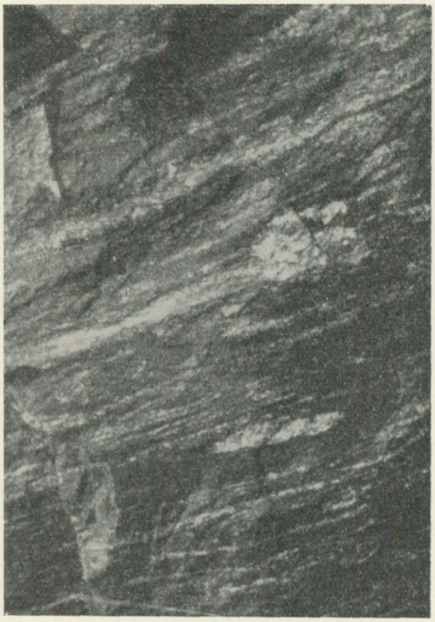


Fig. 19. Injected mica-schist with schlieren of potassic feldspar. About $^1/_5$ nat. size. N. of Lake Borka.

In some other parts of the same transitionary zone from the »köli» slates to the metamorphic »seve» schists, there are calcareous phyllites present, which are more sensitive to the metamorphism, and they have been more re-crystallized than the pelitic phyllites of the same area. Contrary to this the carbonaceous or graphite-bearing phyllites are distinctly more resistant against re-crystallization, and they may still look quite phyllite-like within the zone of the garnet mica-schists.

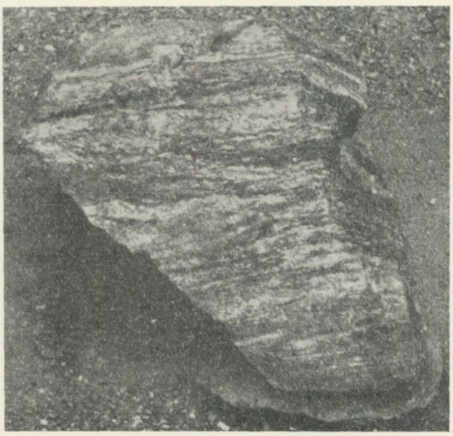


Fig. 20. Injection-gneiss. N. of Lake Borka. $^1/_6$ nat. size.

The transition from mica-schist to garnet-mica-schist is characterized by consecutive increasing size of the garnets, a porphyroblastic appearance of the muscovite (often intergrown with biotite), and soon also by a porphyroblastic appearance of plagioclase. The composition of the plagioclase varies between albite or albite-oligoclase and basic oligoclase, though it is on the average about An_{20}.

Rock types of the Borka region tabulated according to volumetric

Rock No.	25	26	27	28	29	30	31	32
	Chiefly sedimentary rocks							
	Biotite-phyllite		Mica-schist (Biotite-phyllite)			Garnet mica-schist		Slightly injected mica-schist
Average grain size	0.15 mm	0.2 mm	0.15 mm	0.2 mm	0.2 mm	0.2 mm	0.3 mm	0.5 mm
Locality	Borka		Lake Borka in N. W.	N. E. of Borka	North-western shore			
Quartz (weight %) . .	51.9	68.2	40.4	41.7	48.5	31.6	49.6	58.7
Microcline(-perthite)	—	—	—	—	—	—	—	5.2
Plagioclase	7.1	9.1	3.6	4.5	6.2	5.4	4.3	11.1
Myrmekite	—	—	—	—	—	—	—	—
Muscovite	17.1	18.7	34.2	23.8	19.6	25.7	21.8	16.5
Biotite	5.5	3.0	16.8	18.9	18.1	22.3	14.6	5.9
Garnet	—	—	2.5	2.8	3.9	10.6	8.8	2.2
Sillimanite	—	—	—	—	—	—	—	—
Cyanite	—	—	—	—	—	—	—	—
Epidote (orthite) . .	tr.	—	—	1.9	0.5	1.1	0.1	tr.
Iron sulphides		0.1	} 1.8	} 0.9	—	0.1	—	0.3
Magnetite	1.0	0.9			2.4	2.1	0.4	—
Rutile	—	—	—	0.8	—	0.3	—	—
Titanite	—	—	—	—	—	—	—	—
Apatite	0.1	tr.	0.2	0.4	0.7	0.2	0.4	0.1
Zircon	—	tr.	—	—	0.1	—	—	tr.
Tourmaline	tr.	—	0.2	0.5	tr.	0.4	—	—
Chlorite	13.8	—	—	—	—	—	—	—
Calcite	3.5	—	0.3	—	—	—	—	—
Carbon	—	—	—	—	—	0.2	—	—
Hornblende	—	—	—	0.3	—	—	—	—
Remarks	Phyllitic textured rocks	Phyllitic textured rocks. Extremely rich in quartz	Phyllitic textured rocks with some small garnets			Phyllitic textured rock with large garnets	Somewhat granular, recrystallized rocks	

In the phyllitic rocks the plagioclase is difficult to distinguish from the quartz, but by the increasing metamorphism the plagioclase grains will be larger than the quartz ones, and they also get a more distinct twinning than those of a lesser grade of metamorphism. — The size of the plagioclase does not increase so fast as that of the garnet which is also more poikiloblastic.

analyses with increasing degree of metamorphism toward the right.

33	34	35	36	37	38	39	40	41
Rocks of mixed origin								
Injected mica-gneiss	Injected mica-schist			Injection-gneiss	Augen-gneiss (injected)	Injection-gneiss		Garnet-cyanite-microcline-gneiss
0.6 mm	0.5 mm	0.5 mm	0.9 mm	0.7 mm	1.5 mm	1 mm	1 mm	2 mm
of Lake Borka				N. of Lake Borka	W. of Lake Borka	North of Lake Borka		
23.3	24.8	34.7	53.3	44.5	35.0	43.7	45.4	0.3
2.3	25.4	12.8	13.4	9.2	23.9	18.5	16.8	21.4
22.4	13.3	22.2	16.8	14.4	11.8	7.3	6.7	5.3
—	0.2	0.2	0.1	0.1	0.5	0.4	—	—
26.0	7.5	11.8	10.2	6.6	16.0	5.9	0.5	0.2
21.1	26.2	14.5	5.0	17.7	11.3	20.8	13.4	10.2
3.7	1.5	2.9	—	6.6	0.9	1.5	11.8	32.6
—	—	—	—	—	—	—	0.1	—
0.5	—	—	—	—	—	—	4.1	25.1
0.1	0.8	0.3	0.2	—	—	0.1	—	—
0.3	0.3	0.3	0.7	0.3	0.2	—	0.2	} 2.6
—	—	—	—	0.2	0.1	} 1.5	—	
tr.	—	—	—	0.2			0.4	2.0
—	tr.	0.1	—	—	—	—	—	—
0.1	tr.	—	0.1	0.1	0.1	0.2	0.6	0.3
0.1	tr.	0.1	0.2	0.1	0.2	0.1	—	—
—	—	—	—	—	—	—	—	—
0.1	—	0.1	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
Mica-schist with larger, porphyroblastic feldspars		Gneissic mica-schists		Homogenous but schistose, gneissic rock	Large augen of microcline in schistose rock	Granular, gneissic rocks with schlieren of darker materiel		Homogenous equigranular rock (Large addition of alumina and potassium to pelitic sediment, close to amphibolite)

The increasing grade of metamorphism will now be characterized by the injection of veins, or a formation of augen, of potassic feldspar. It is a microcline which often is finely perthitic. It has an uneven and varying appearance, often in streaks forming a kind of matrix around the other minerals or growing into porphyroblasts enclosing other minerals, especially quartz and plagioclase.

These minerals often show rounded grains, resorbed by the later crystallized microcline. The plagioclase, contrary to the potassic feldspar, generally forms evenly distributed minerals which make an impression of being primary components of the sedimentary rocks. Some show an antiperthitic growth and they

Fig. 21. Injection-gneiss. N. of Lake Borka. $^1/_6$ nat. size.

have probably originated through recrystallization with an addition of potassium. The particularly plagioclase-rich rocks probably correspond to a greater primary content of the plagioclase molecule in the sediments. In any case these feldspars were present in the rock before the introduction of the potassic feldspar.

An examination of the mineral composition of the rock series shows that an addition not only of potassium has occurred, but also of some aluminium, probably in the same proportion to the potassium as in the feldspar. In the

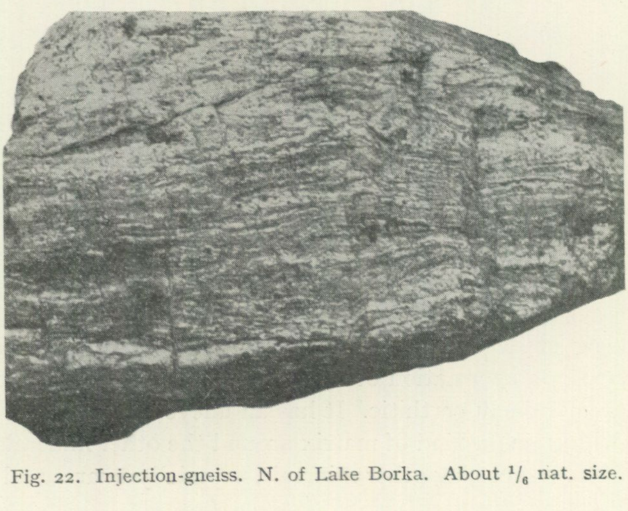


Fig. 22. Injection-gneiss. N. of Lake Borka. About $^1/_6$ nat. size.

outer metamorphic zone, where at first only biotite, but later also some muscovite has been formed, there has probably been an introduction of chiefly K_2O. The outermost zone with biotite porphyroblasts has probably got its biotite content by the crystallization of biotite out of sericite and chlorite through thermal metamorphism without addition of material from outside sources.

A study of the mineral table will also indicate that any marked addition of silica at the injection metamorphism is out of question, and that the content of quartz of the rocks has decreased. As veins and dikes of quartz in some places

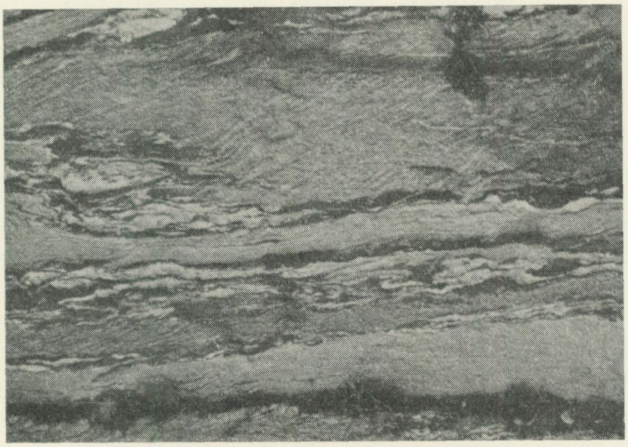


Fig. 23. Banded injection-gneiss. N. of Lake Borka. $^1/_5$ nat. size.

are rather common in the outer zone, mica-schists and phyllites, it may be that some silica has been precipitated in a zone outside of the chief injection zone.

The table shows that the content of apatite is rather constant in all the rocks, so it can hardly be regarded as introduced by the injections in this area, as has been described from other injection rocks. The zircon might, however, be regarded as chiefly introduced just as the sulphides (mostly pyrite and pyrrhotite). — The content of biotite is rather constant in the rocks. As to its grain size it does not belong to the larger or porphyroblastic minerals of the inner metamorphism zone. There is no great difference in colour between the biotite of the different zones. In the less metamorphic rocks it is generally greenish brown and in the injection-gneisses brown to reddish brown. Calcite only occurs in the least metamorphic zones, and it is chiefly replaced by epidote in the higher ones (clinozoisite to pistasite, often with a core of orthite).

The formation of myrmekite is not so abundant in the injection rocks of this region as in the Muruhatten area, partly depending on the lower plagioclase percentage of the rocks, but chiefly on the smaller occurrence of reactions in the lower temperature stages, which are characteristic for the Muruhatten region. The formation of myrmekite in the rocks of Borka is partly of the common, sponge-like plagioclase intergrowth at the borders of the larger microclines, partly it is a growth of vermicular quartz by the formation of mica at the expense of the microcline. Vermicular-like potassic feldspar penetrating the plagioclase has also been noticed.

Cyanite is only met with in the strongest injected gneissic rocks as porphyritic grains of the size of the garnet. It is generally somewhat transformed into mica as it is evidently an unstable product, which by reaction with microcline is converted into mica. Only in one case a slight transformation of cyanite into sillimanite as a predecesser to the transformation into mica has been observed.

The last rocks ot the table consist of homogenous rocks of the innermost injected zone. The garnet- and cyanite-rich gneiss is a quite uniform rock, chiefly composed of garnet, microcline, and cyanite. There has evidently been a strong addition of K_2O and Al_2O_3 when the primary content of quartz of the originally sedimentary rock has been made use of for the formation of the new minerals. These injection rocks are close to the amphibolites in the east, and reactions with these rocks have favoured the production of garnet, and partly also biotite at the expense of muscovite. As has been emphasized in the description of the Muruhatten region the content of garnet is always especially prominent in the injected rocks in contact with basic rocks (as also the formation of biotite out of muscovite). The amphibolites themselves have also been affected by the injections which will be shortly dealt with later on.

In the Borka region the stress is quite dominating, contrary to the conditions in the Muruhatten region, and strongly parallel-oriented rocks are thus predominant. There are not any large bodies of purely magmatic gneisses, but rather microcline infiltrated mica-schists which by the introduction of much K_2O have acquired a granite-like composition. The schists most enriched in microcline have got a lower content of silica than the less injected mica-schists, as they have primarily been rather quartz-rich phyllites. The content of SiO_2 of the rocks is thus decreased by the injections, chiefly supplying K_2O and Al_2O_3. The resulting rocks are, nevertheless, often richer in quartz than regular granites because of the great part of formerly pelitic to semipelitic material of the bulk composition of the rocks. Original plagioclase has often been greatly sericitized by the excess of Al_2O_3 at the introduction of potassium. Muscovite has also been formed in some rocks.

The content of garnet is relatively constant, with the exception of injected rocks close to amphibolites where the content of garnet may be rather high.

Cyanite is often found in the injection-gneisses, but not in the mica-schists which shows that this mineral is localized to the injected zone. It is thus a mineral formed by the combined action of stress and metasomatism. The cyanite is, however, an unstable product, and it may partly be transformed into mica by reaction with feldspar in the later stage of the injection-metamorphism. That we have not got sillimanite here instead of cyanite, as in the Muruhatten region, depends on the greater stress prevailing (stronger isoclinal folding and greater schistosity of the rocks) as compared with the more uniform pressure conditions of the Frostviken area. Where the stress prevails the formation of cyanite is favoured, but when the conditions are changed sillimanite may be formed out of the cyanite. In complete reactions both minerals are transformed into mica.

Compared with the Muruhatten region Borka is characterized by the injections of predominatingly potassic feldspar often forming porphyroblasts of microcline enveloping and resorbing older minerals. In the Borka region the primary sediments have been of a common pelitic character, while the former sediments at Muruhatten were psephitic rocks rich in plagioclase. The formation of the injection rocks of Borka is a soaking through of the rocks by metasomatic solutions without any appearance of regular intrusive rocks. In the outer zone some bed-like dikes of aplitic character are observed, but even those rocks have a heterogeneous composition and might be syntectic rocks.

The potassium-dominating injected rocks have only been found in this anticlinal zone of Borka or its continuation toward the S.S.W. or N.N.E. and not within the areas west of it. In the Borka region there have not been observed any pegmatitic or granitic bodies (as at Muruhatten) with transitions toward the trondhjemitic types of the same character as those (soda-rich) intrusives which are so common within the westerly phyllitic regions.

The successively increasing metamorphism from the west toward the injection zone east of Borka makes it probable that also the formation of biotite porphyroblasts in the youngest (silurian) phyllites W. of Borka depends on the thermal metamorphism issued from the injection zone, as the appearance of the porphyroblasts is quite conformable to the injection zone toward the N.N.E. and S.S.W. This makes it probable that the formation of the injection-gneisses is of Caledonian or late Caledonian age. Consequently also the injection rocks of the Muruhatten region ought to be of the same age.

Judging from the appearance of the injections of the Borka region, it may be conceived that the feldspathization of the rocks may have been developed by a sweating out of the rocks themselves in the innermost zone at a strong upward folding and thrusting of the complex with a simultaneous hightening of the geotherms, resulting in an upward squeezing of the dissolved substances (potassium being the most important component). The strong enrichment in K_2O in the present section of the crust shows, however, that we here chiefly have a precipitation of the substances, so that the main dissolution front may be searched below the present surface.

Within the Muruhatten region somewhat different conditions prevail. We have a more level development of the folding with a present erosion surface near the top of the injection complex. The injection-gneisses show a closer association with the granites, aplites, and pegmatites of that region. The trondhjemitic types might have been conceived as originated through anatexis of the plagioclase-rich sediments here present. Trondhjemitic rock types (including porphyries) are, however, common intrusives within the whole district, even far west of the Muruhatten region, and also west of the Borka region in Lappland. They also show consanguinity to more basic rocks, as has been pointed out by A. Högbom (14). The transitionary phases between the different rock types rather point to a differentiation suite gabbro-trondhjemite[1]-potassic granite, intruded in this order analogous with the conditions described by Goldschmidt (12). The injection zone may be the hearth of the intrusions of the later Caledonian epoch corresponding to the culmination of the folding with an elevation of the magma-front, in the Muruhatten area reaching earlier intrusion-suites of the epoch.

V. Reactions with basic rocks.

a. Reactions with peridotites.

As a detailed description of the metamorphism of the ultra-basic rocks of this region together with detail maps and sections is given in the earlier publication it will only be summarized and briefly discussed here.

The peridotites have originally been dunitic rocks with olivine as the only primary mineral observed, with the exception of a small percentage of (slightly chromiferous) magnetite. The olivine of the Muruhatten peridotites was of an intermediate composition with about 12—15 mol.% of fayalite, while the usual fayalitic percentage otherwise is about 8 mol.%. The peridotites occur as flat or lenticular bodies molded by folding with outcrops varying in length between a few meters to about 1 km.

The ultra-basic rocks are now greatly hydrothermally altered due to the pegmatitization of this region. The metamorphism has started with a formation of tremolite or actinolite at the borders of the bodies, generally showing a close connection with the intrusion of the pegmatites, and it is especially prominent at the contacts with amphibolites. The lime for the formation of the tremolite is thus partly derived from the amphibolites, and to a smaller degree from the acid intrusive rocks which have been decalcified as well as desilificated. A slight serpentinization in the form of chrysotile serpentine has occurred before the formation of tremolite, and it is hard to tell if it was the first phase of the same epoch of metamorphism, or if it was earlier formed.

The main serpentinization followed after the development of the amphibole, and it is also closely associated with the pegmatitization, starting from the outside with the strongest serpentinization at the walls and the roof of the bodies, and small lenses of ultrabasic rocks are often completely serpentinized. As the uppermost part of the peridotite often is more altered than the side walls, a greater transformation here might be confused with an alteration starting from the inside of the ultra-basic rocks. In such cases a detailed examination shows that it is the upper contact of the peridotite that is strongly transformed, and more dissected parts of the roof of the body show a slighter transformation.

Associated with the antigorite is often some chlorite which may be somewhat earlier formed. It is generally a penninite in the interior of the peridotite and a chlinochlore at the border. Often an intergrowth occurs between penninite

[1] Here are also included rocks with rather sodic plagioclases (oligoclase-albites).

and an antigorite-chlorite. The chlorite is chiefly associated with the wall rock, generally secondary after biotite or amphibole, but it is also a direct reactionary product.

The talc has been formed slightly later, and it is secondary to tremolite, serpentine, or olivine.

The last stage of the hydrothermal alteration is represented by the formation of carbonates (breunnerite or ankerite).

The border of the peridotite towards the surrounding rocks is generally enriched in talc and actinolite, particularly close to amphibolitic rocks. The contact surfaces of the ultra-basic are thus often transformed into soapstone or steatite composed mainly of talc with varying quantities of actinolite, chlorite, serpentine and — in certain parts — carbonate, breunnerite or ankerite. The soapstone mainly consists of two components: either chlorite and talc, or actinolite and talc. Breunnerite-bearing rocks may occur at the uppermost contact of the peridotite.

The wall rock of the soapstone is usually a chlorite rock, which is a complete chloritization of an amphibolite, or a mica-schist which partly may be a reactionary product. Chlorite schist is widely distributed along the contacts of the ultra-basic of Muruhatten, and may cover a wider zone than the soapstone. It is frequently a rather pure chlorite rock, with magnetite crystals as an accessory mineral. A chlorite rock with large garnets may also be typical. A vermiculite schist appears as a transition to the mica-schist.

Part of the chlorite rock is usually developed as an actinolite-chlorite schist, with long prisms of actinolite, sometimes several cm in length. Chlorite rock with anthophyllite and actinolite is also met with. Toward the soapstone, the chlorite-amphibole (biotite) schist passes into a talc-actinolite rock. Towards an amphibolite remnants of zoisite and ilmenite may be detected.

The following rock sequence can be given as a typical instance of a more complete type of transition: Dunite, serpentine-olivine-actinolite rock, talc- and actinolite-bearing serpentine, talc-actinolite rock, talc-chlorite rock, chlorite-actinolite rock, chlorite-anthophyllite-actinolite rock, chlorite rock, amphibolite or vermiculitic mica-schist.

The alteration products are better developed between the peridotite and the amphibolite than between the former and the mica-schist. The best developed soapstone deposits are localized to the appearance of pegmatites, aplites and tourmaline rocks. Where these rocks are best developed, the soapstone zones are the widest.

Migmatitic rocks occur which may be composed of four components viz. amphibolite, a little mica-schist, and pegmatite injections, all permeated by pneumatolytic solutions, with abundant precipitation of tourmaline. Biotite or chlorite is generally concentrated at the margin of the amphibolite towards the peridotite.

The rock analyses show that the addition of alumina by the pneumatolytic solutions has been considerable. Furthermore boron and water have been added. All the pneumatolytic injections observed are thus characterized by tourmaline, denoting solutions rich in boron. The chemical analyses of the rocks and the minerals show that lithium and fluorine were absent. The almost constant occurrence of some pyrrhotite, pyrite, or chalcopyrite indicates that sulphur has been introduced by the hydrothermal solutions.

The excess of alumina and deficiency of alkalies in the rocks may be a result of hydrolysis of the alkali-aluminium silicates in the pneumatolytic stage, the alkalies being removed.

Between the peridotite and the amphibolite the following zonal arrangement of reaction rocks is typical:

Serpentinized peridotite,
Actinolite- and talc-bearing serpentine,
Talc-schist with some actinolite and a little chlorite,
Talc-chlorite rock,
Chlorite rock,
Partly chloritized amphibolite,
Amphibolite.

The amphibolite and the chlorite rock often contain large tourmaline prisms. The tourmaline content of the amphibolite is considerable close to the injected pegmatites, concentrated at the margin of the amphibolite which is often developed as a biotite-tourmaline rock. The biotite, however, is generally chloritized in the tourmaline-bearing rocks, or is otherwise often developed as a vermiculite. The biotite is not stable at as low a temperature as the tourmaline. In some cases chlorite may have been developed directly as a reaction of amphibolite and peridotite on the appearance of the injections.

Direct transformation of greenish hornblende into actinolite has not been observed. Actinolite is thus found in the entirely chloritized rocks close to the peridotite, and seems to indicate migration of lime (or limesilicate) at the beginning of the chloritization of the amphibolite. At the transformation of the tourmaline-amphibolite, the order of the chloritization of the minerals is the following: hornblende — tourmaline — zoisite. Of the accessory minerals, garnet is observed in almost completely chloritized rocks.

The formation of actinolite or tremolite at the peridotite border might be ascribed to addition of lime and silica from the pneumatolytic injections, as the injected pegmatites are of a trondhjemitic character. The anorthite percentage of the plagioclases is, however, not high, and the development of actinolites at and in the peridotites is considerable as compared with the injected pegmatites. The main reason why the amphibolites are considered to have supplied most of the lime for the development of actinolite is the common presence of actinolite in peridotites when the latter is bordered by amphibolitic rocks. When amphibolites do not occur at the peridotite border, the formation of pale amphibole is less conspicuous.

Anthophyllite is not as common in the chlorite rock as actinolite. As to the occurrence of anthophyllite, it is evident that this is formed when mica-schists have also taken part in the reactions developing the chlorite rock. The anthophyllite was probably developed in an original biotite-schist.

The appearance of cummingtonite as a silicification product of olivine was looked for, but was never observed. Tremolite or actinolite is invariably formed.

The iron content of this amphibole primarily depends on the fayalite proportion of the original olivine of the peridotite. To a smaller degree it also depends on whether it was formed in the peridotite or in the chlorite rock outside the peridotite. In the latter case it is slightly richer in iron. No transformation of actinolite into tremolite as a more stable component at lower temperatures was observed.

The pure chlorite rock marks the border of the country-rock against the peridotite. Hydrothermal solutions have had easier access here, and the transformations were thus complete. If we compare the analysis of the chlorite rock from Muruhatten with that of the amphibolitic rocks,[1] it is conceivable that it is not a direct alteration product of the amphibolite, but rather a reaction product of the amphibolite with the peridotite under the influence of hydrothermal solutions. All the lime liberated has probably gone to the formation of actinolite in the peridotite. The mineral of the chlorite rock is clinochlorite, marking a higher alumina content than in the chlorite formed in the peridotite, which is generally a penninite, while the chlorite of the amphibolites is clinochlorite-prochlorite.

The alkalies were removed during the gradual transformation of amphibolite towards chlorite rock, but the lime, together with silica from the hydrothermal solution, migrated towards the ultra-basic and formed actinolite. This mineral is more abundant at the peridotite border than farther in. — Chloritization is intimately associated with the formation of actinolite in the ultrabasic, though continuing later. The chlorite is often more widely dispersed in the peridotite than the amphibole, but there is generally less of it. The slight chloritization of the olivine was directly succeded by serpentinization as the alumina content of the solutions was reduced. Serpentinization of the peridotite is generally more conspicuous than chloritization.

As the temperature fell still more, talc began to form, especially at the peridotite border, primarily by transformation of serpentine and olivine. At the original margin of the ultrabasic, even the actinolite was altered. As the transformation is very strong at the marginal part of the peridotite in contact with the chlorite rock, a pure talc-schist has often developed. In most cases it contains some chlorite, as this is not easily transformed into talc. Remnants of fibrous actinolite occur in the talc-rock forming actinolite-talc schists.

Talc decreases rapidly in quantity towards the center of the peridotite, where it is generally absent except for small solitary veins here and there.

In the Muruhatten region carbonatization (or addition of CO_2) evidently did not cause the formation of either serpentine or talc from the peridotite, but magnesia or lime-magnesia carbonate developed independently, though often in association with the formation of talc.

The addition of silica from the solutions, for the silicification of olivine and serpentine, must have been considerable. The quantity must have been several

[1] Cf. 6 pp. 188 and 180, 186.

times larger than that contained in the pegmatites observed at the contact of the peridotite. It was, however, not sufficient for the transformations that have occurred, as the injection gneisses and injected amphibolites are rather desilicated. The transformations might thus have been more extensive, if the injections had been greater.

At the contact of the peridotite with mica-schists the transformations are less conspicuous, and soapstones are often scarcely developed at all. Even the wall-rock mica-schist is less chloritized, generally showing remnants of biotite with the chlorite. It may be partly developed as a vermiculite-schist, with large garnet dodecaedrons.

By pegmatitization close to the border of the peridotites and the mica-schists a contact rock rich in biotite, and often also rich in almandite garnet, is produced. By reaction between the excess of MgO of the ultra-basic and the content of K_2O of the pegmatitic-hydrothermal solutions a light-coloured biotite is formed, of a greater size than that of the original mica-schists. The garnet seems to be formed slightly later, probably as an intermediate stage before the chloritization of the biotite (with removal of the alkalies). By this mineral formation it is evident that Al_2O_3 (in excess) migrates together with K_2O to the peridotite contacts. Some CaO from the pegmatitic solutions ($+ SiO_2$) migrates somewhat further to and into the peridotite, forming tremolite (or actinolite) by reaction with the olivine. The plagioclase of the pegmatites is altered to about An_{10} instead of the usual An_{16} (cf. the analysis of the contaminated pegmatite on p. 18). The pegmatite has been freed of most of its quartz and all potassic feldspar and it is generally a rock almost only consisting of acid plagioclase, with increasing biotite towards the peridotite, with more or less tourmaline and garnet as large crystals.

The reaction processes are much more pronounced when amphibolitic rocks also take part in the reaction, facilitating the production of pale amphibole and probably of biotite and garnet, due to the high content of CaO and also of Al_2O_3 and basic oxides. Tremolite is evidently very easily formed out of olivine by the addition of lime. The other reactions are thus facilitated by the earlier penetrations of the amphibole crystals. The wall rocks of the peridotite borders give an easy access to the later (magmatic) hydrothermal solutions on account of which the formation of chlorite and talc is enhanced.

b. Reactions with amphibolites.

1. Muruhatten area.

The amphibolites of the Muruhatten region are generally schistose to fibrous rocks interlaminated with mica-schists. They may chiefly have been sill-like intrusions or extrusive lavas, quite transformed before the intrusion of the granitic rocks of the region. Some occurrences of gabbroic amphibolites also occur. These are less metamorphosed both structurally and chemically, and are probably younger than the schistose amphibolites, though they are older than the granites.

The amphibolitic schists are rather monotonous in their composition, chiefly consisting of a green hornblende,[1] rather acid plagioclase, epidote, and titanite or rutile, with or without quartz. In order to show the usual type, and for the

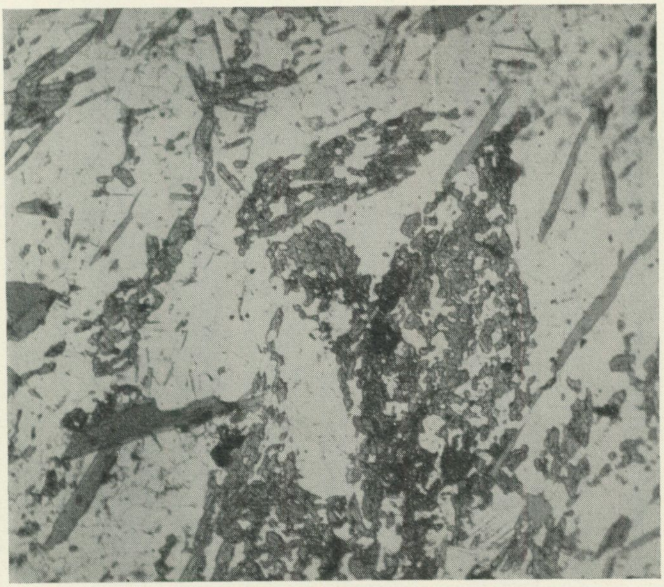


Fig. 24. Texture of pegmatitized, re-crystallized amphibolite.

convenience of comparisons later on, a composition of a common rock type has been calculated with the aid of volumetric analyses (two slices).

Table 42. Schistose amphibolite, W. of Muruhatten. Calculated.

SiO_2	48.8
TiO_2	1.6
Al_2O_3	13.2
Fe_2O_3	2.8
FeO(MnO)	7.1
MgO	9.8
CaO	12.1
Na_2O	2.8
K_2O	0.6
H_2O	1.2
	100.0 %

Mineral composition, weight percentage:	
Green hornblende	68.8
Plagioclase (An_{25})	19.9
Epidote	8.5
Titanite	2.6
Iron oxides	0.2
	100.0

Many amphibolites have, however, a slight percentage of quartz.

The plagioclase of these rocks have a relatively sodic composition evidently depending on the breaking down of an intermediate plagioclase with the for-

[1] The composition and optics of the hornblendes are discussed in a later chapter, p. 68.

mation of secondary epidote. The plagioclase is generally an oligoclase mostly with a composition between An_{30} and An_{20}. $Ab_{80}An_{20}$ seems to be the general limit of the breaking down of an originally more basic plagioclase, excepting when a marked influence of acid intrusions has occurred.

The epidote shows variations between clinozoisite and pistacite.

The injection of granitic rocks (aplites, pegmatites) in or close to the amphibolites has a marked influence on the structure and composition of the rocks. These amphibolites are completely recrystallized with less pronounced schistosity and often with a random orientation of the minerals. Figs. 24 and 25 shows

Fig. 25. Texture of pegmatitized, re-crystallized amphibolite.

the texture of two migmatitic amphibolites. The hornblende crystals are strongly poikiloblastic with a random orientation, often similar to the appearance of the amphiboles of the garbenschiefers. Compared with the gabbroic amphibolites the hornblende may be of a slightly paler variety.

The mineral composition of the rocks is altered by interaction with and addition from the granitic injections. A prominent content of biotite is always present (if not chloritized) and also some garnet. The percentage of plagioclase and quartz is increased, just as the amphibole content is reduced. Tourmaline and some sulphides are generally present, and titanite is replaced by rutile. The composition of the plagioclase is not much altered, but may be somewhat uneven. The percentage of epidote is less. It often shows a core of orthite.

The injection of the aplites is mostly followed by a hydrothermal alteration of the rocks with a production of chlorite, in the first place at the expense of biotite, then of amphibole and lastly of garnet. The iron and copper sulphides are generally precipitated at this stage.

The following table may give an idea of the variation in composition in different degrees of interaction. The four rocks 43, 44, 45, 46 are taken in one section, W of Muruhatten, and they are compared with the amphibolite 42 (p. 53) and the aplite 12 (cf. p. 19). The figures are in weight percentage.

These rocks show series of transitions from the aplitic injection toward the purely amphibolitic rocks. The injected aplite is also influenced by interaction with basic rocks resulting in a greater percentage of biotite, some garnet and tourmaline, and less of potassic feldspar and muscovite. The contaminated aplites and the amphibolites are possibly somewhat desilicated by the influence of the large peridotite body in the neighbourhood.

The biotite of these rocks is rather pale (yellowish to reddish brown). The secondary chlorite (opt. pos., with greenish colour, slight pleochroism, rather strong birefringence in anomalous colours) is of a clinochloritic to prochloritic composition. The tourmaline is of the same character as those described on p. 82.

Rock series showing different degrees of interaction. [1]

	12 Trondhjemite aplite	43 Aplite close to amphibolite (partly tourmaline-bearing)	44 Aplite at contact with amphibolite	45 Aplite contaminated by amphibolite material	46 Amphibolite reacted by aplite (hydrothermally recrystallized)	42 Amphibolite
Quartz	24 %	14.6	3.7	1.8	—	—
Plagioclase	57 %	47.8	61.0	64.7	28.5	19.9
Potassic feldspar	0.2	—	0.2	—	—	—
Muscovite	0.2	—	—	—	—	—
Biotite	16.0	21.0	17.8	7.4	5.4	—
Chlorite	—	8.8	4.7	0.3	4.7	—
Garnet	1.0	2.4	8.9	—	—	—
Tourmaline	0.5	—	1.3	—	—	—
Hornblende	—	—	—	23.6	59.3	68.8
Epidote (Orthite)	—	0.1	0.1	—	0.1	8.5
Titanite	—	—	—	—	0.4	2.6
Rutile	—	0.3	0.2	—	1.4	—
Sulphides	0.2	4.0	—	—	—	—
Ore minerals	—	—	1.5	2.1	—	0.2
Apatite	0.4	1.0	0.6	0.1	0.2	—
Zircon	tr.	—	tr.	tr.	—	—

[1] All tables in this paper showing volumetric analyses of rocks have figures recalculated into weight percent.

A uniformly migmatized amphibolite NE of Muruhatten has been analysed:

Table 47. Migmatitic amphibolite. North-eastern slope of Muruhatten.

Analyst N. Sahlbom.

SiO_2	56.87	9,431
TiO_2	0.60	75
Al_2O_3	14.77	1,445
Fe_2O_3	1.74	109
FeO	8.27	1,151
MnO	0.10	14
MgO	5.61	1,391
CaO	4.06	724
Na_2O	3.19	514
K_2O	0.56	59
Cu	0.50	78
P_2O_5	0.13	9
S	1.57	488
H_2O^+	2.34	1,299
	100.31	
H_2O^-	0.39	
— O for S	0.39	

Mineral composition (weight %)	
Plagioclase (oligoclase)	34.0
Quartz	22.0
Hornblende	19.0
Biotite	3.5
Garnet	3.5
Prochlorite	12.2
Tourmaline	0.3
Epidote-orthite	0.3
Apatite	0.3
Rutile	0.4
Chalcopyrite	1.5
Pyrrhotite	2.8
Iron oxide	0.2
	100.0 %

Norm		
Q	14.9	
Or	3.3	
Ab	27.0	
An	19.3	
C	1.8	
Σ Sal	66.3	
$FeSiO_3$	9.7	Hy
$MgSiO_3$	13.9	Hy
Mt	2.5	
Il	1.1	
Ap	0.3	
Pr	2.9	
Σ Fem	30.4	
Tonalase		

Niggli values	
si	170
ti	1.3
al	26
fm	51
c	13
alk	10
k	0.10
mg	0.49
c/fm	0.25

According to the norm this rock is similar to quartz-gabbros, augite- or mica-diorites etc., though it is poorer in MgO and has a high content of C, distinguishing the abnormal content of mica, garnet, and tourmaline, due to the metasomatic reactions and to the migmatitic origin of the rock.

The feldspar is fresh (neither sericitized nor saussuritized), but much penetrated by laths of amphibole and chlorite. Together with quartz it is often poikiloblastically enclosed in hornblende, garnet, and tourmaline. According to universal measurements ($\perp$ PM $8^1/_2°$, $\perp n_\gamma$ 2°, $\perp n_\alpha$ 78—79°) the composition corresponds to $Ab_{74}An_{26}$, though the rim of the plagioclase may be somewhat more sodic. This agrees well with the mineral calculation (3 rock slices) of the analysis which gave a composition of An_{24}.

The amphibole is a green hornblende with rather strong absorption but weak pleochroism and a large axial angle ($2V = +88°$). It has been analysed and is described further on. The garnet is an almandinite quite similar to one from a rock close by which had been analysed (referred on p. 79). Other rock specimens from another part of the same outcrop showed more tourmaline than the analysed one. The refraction indices and pleochroism colours of the mineral are almost the same as those of the analysed tourmaline referred on p. 82.

A comparison of this rock analysis with the aplite no. 12, the contaminated aplitic rock no. 10, and the amphibolite no. 42 is shown below (these rocks are not from the same section, but they are quite representative for the outcrops of this part of Muruhatten). The migmatite, 47, is almost intermediate in composition between the aplite and the non-injected amphibolite. The iron content is a little high, but this is quite typical for the metasomatically influenced, injected rocks (which almost universally have some enrichment in iron and copper sulphides also). Some potassium has been removed by the hydro-

Table 47 a. A comparison of the chemical composition and mineral constitution of common amphibolite (42) with migmatitic amphibolite (47), contaminated aplite (10), and slightly contaminated trondhjemite aplite (12).

Rock No.	12	10	47	42
	Trondhjemite-aplite, slightly contaminated	Contaminated aplite	Migmatitic amphibolite	Amphibolite
SiO_2	67.58	59.23	56.87	48.8
TiO_2	0.45	n. d.	0.60	1.6
Al_2O_3	16.69	20.50	14.77	13.2
Fe_2O_3	0.51	1.87	1.74	2.8
FeO	2.57	4.64	8.27	7.1
MnO	—	tr.	0.10	—
MgO	2.09	2.58	5.61	9.8
CaO	2.24	1.79	4.06	12.1
Na_2O	4.97	6.73	3.19	2.8
K_2O	2.20	2.52	0.56	0.6
H_2O	0.53	0.52	0.54	1.2
P_2O_5	0.04	n. d.	0.13	—
Cu	—	—	0.50	—
S	0.08	—	1.57	—
B_2O_3	0.05	—	—	—
Quartz	24.0	6.0	22.0	—
Plag.	57.0	65.0	34.0	19.9
Potassic feldspar	0.2	—	—	—
Muscovite	0.5	—	—	—
Biotite	16.0	22.0	3.5	—
Chlorite	—	—	12.2	—
Garnet	1.0	5.0	3.5	—
Tourmaline	0.5	—	0.3	—
Hornblende	—	—	19.0	68.8
Epidote	—	0.2	0.3	8.5
Sulphides	0.2	—	4.3	—
Iron oxides	—	1.7	0.2	0.2
Titanite, rutile	0.2	—	0.4	2.6
Apatite (Zircon)	0.4	0.1	0.3	—

thermal alteration of the rock. The lime content and probably also the silica has been lowered by interaction with the peridotite close by (cf. the discussion of the metamorphism of the ultra-basic rocks).

Two similar rock types, earlier analysed, will also be referred. They represent injected amphibolites in contact with peridotite, and they are more hydrothermally altered than the one above.

Table 48. Tourmaline-rich migmatite, Muruhatten.

Analyst N. Sahlbom.

			Mineral composition		Niggli values	
SiO_2	41.35	6,857	Plagioclase (An_{30-35})	33.7	si	95
TiO_2	1.62	202	Hornblende	15.6	ti	2.8
Al_2O_3	29.21	2,857	Tourmaline	12.6	al	40
Fe_2O_3	1.20	75	Muscovite	10.8	fm	35
FeO	6.22	726	Biotite	6.0	c	15
MnO	0.05	7	Chlorite	9.2	alk	10
MgO	6.77	1,679	Garnet	3.4	k	0.24
CaO	6.10	1,087	Epidote	6.3	mg	0.66
Na_2O	3.33	537	Ilmenite	1.8	c/fm	0.43
K_2O	1.60	170	Rutile	0.6	h	15.5
B_2O_3	1.15	166		100.0 %		
V_2O_3	tr.					
H_2O^+	2.01	1,116				
H_2O^-	—					
	100.61					
Sp. gr.	2.90					

The hornblende, tourmaline, garnet, and biotite are quite similar to those of the migmatite, no. 47. The optic properties of the hornblende are given on p. 69 (no. 69). The plagioclase is unusually basic in this rock. It is very much intergrown with other minerals.

This migmatite is more pneumatolytically-hydrothermally affected than no. 47, and it is stronger influenced by interaction with peridotite, signified by the low silica content. The transition toward the peridotite is distinguished by, at first an increase in chlorite, and then the appearance of actinolite and talc as the main minerals. One of the injected rocks of this locality, close by the amphibolitic migmatite, is the analysed one referred as no. 10 (p. 18).

Table 48 a. Tourmaline-zoisite amphibolite, Muruhatten.

Analyst R. Blix.

			Mineral composition (weight %)		Niggli values	
SiO_2	35.64	5,910			si	72.5
TiO_2	1.84	230	Zoisite	54.0	ti	2.8
Al_2O_3	27.81	2,721	Hornblende	11.5	al	33.5
Fe_2O_3	1.40	68	Tourmaline	13.1	fm	33.6
FeO	4.72	657	Chlorite	19.0	c	32
MnO	0.10	14	Rutile	1.1	alk	0.9
MgO	7.56	1,875	Ilmenite	1.1	k	0.07
CaO	14.65	2,612	Apatite	0.2	mg	0.69
Na_2O	0.41	66		100.0	c/fm	0.96
K_2O	0.05	5			h	28
B_2O_3	1.24	178				
P_2O_5	0.06	4				
H_2O^+	4.14	2,298				
H_2O^-	0.38					
	100.00					

As compared with analysis 48, 48a indicates a higher percentage of original amphibolite, with a greater hydrothermal alteration. The biotite is completely chloritized and the feldspar quite replaced by zoisite (the content of alkalies is thus lowered here). The zoisite is a β-zoisite with strong dispersion $\varrho > v$, birefringence about 0.005 with distinctly abnormal colours, grayish blue or brownish yellow, often with the bluish colour in the central part and the yellowish in the external. The bluish coloured zoisite has axial angles between $2E = 15^\circ$ and $2E = 36^\circ$, and the yellowish between 36° and 52° for white light (a measurement of $2V\gamma$ on one grain gave 14°). Refraction indices were determined at $\alpha = 1.708$ and γ about 1.713. According to an analysis by R. Blix the iron content of the mineral was FeO 1.08 % and Fe_2O_3 0.78 %.

The tourmaline is similar to those referred to above (cf. the analysed one, p. 82). The refraction indices were determined at $\alpha = 1.626$, $\gamma = 1.650$. The hornblende is of the same type as those of the other migmatitic amphibolites. This one has an extreme axial angle $2V\gamma = 84^1/_2$ °. It will be further described below, p. 69, no. 67.

Toward the peridotite the transition rock is a chloritite composed predominatingly of clinochloritic chlorite, and not quite 1 % magnetite. The chemical composition of the rock gave the following composition of the chlorite, with the mol.% in parentheses: SiO_2 30.86 (22.9), Al_2O_3 18.54 (8.1), Fe_2O_3 1.53 (0.4), FeO(Mn) 6.18 (3.8), MgO 30.20 (33.4), H_2O 12.69 (31.4). The refraction indices were determined as: $\alpha = 1.588$, $\beta = 1.591$, $\gamma = 1.596$, $\gamma - \alpha = 0.008$. The apparent optic axial angle is $2E = 23^\circ \pm 8^\circ$, and the interference colours slightly abnormal greenish gray.

The chlorite of the zoisite-amphibolite is more prochloritic, indicating a lower content of MgO and a higher of alumina. The axial angle 2E is about 40°. According to a recalculation from the amphibolite analysis its composition may be about: SiO_2 30, Al_2O_3 $21^1/_2$, Fe_2O_3 2, FeO $8^1/_2$, MgO 25, and H_2O 13 %.

All three amphibolite-migmatites are in about the same tectonic position close to the large Muruhatten peridotite, and they represent amphibolites invaded by trondhjemite-granitic intrusions. The acid intrusions themselves are found as lenticular bodies of an aplitic texture. They are more or less contaminated by reaction with the amphibolites. They are thus rather rich in micas, the more reacted ones have biotite as the sole mica, as muscovite is replaced by biotite at an extended reaction with the femic rocks. The salic rocks are often surrounded by an aureole enriched in tourmaline, micas, chlorite, and garnet toward the basic rock. Sulphides are mostly precipitated at about the same time as the formation of chlorite. These minerals have been formed here because of the excess of the femic elements available for their crystallization.

Smaller bodies of amphibolite are completely re-crystallized under these conditions, transformed to migmatitic rocks by the influence of the pneumatolytic-hydrothermal rest-solutions of the salic injections.

The migmatites 47, 48, 48a are more or less of this type. The quite similar optic properties (and chemistry) of their minerals indicate that the original amphibolites as well as the injected material must have been of quite the same character, only differing in size and degree of reaction. The composition of the migmatite no. 48 may have been affected by the presence of some mica-schist at the upper part of the former amphibolite, separating it from the peridotite.

A similar migmatitized amphibolite at Junsternäset, N. of the Muruhatten region, has got more addition of aplitic-pegmatitic material, and it is thus more »diorite»-like in composition, averaging: plagioclase $>$ biotite $=$ quartz $\geq$ hornblende $>$ garnet $>>$ apatite $=$ tourmaline $\geq$ rutile $>$ orthite. The plagioclase is a basic oligoclase, An_{23}—An_{30}, averaging An_{29}. The hornblende, garnet (cf. 6, p. 198), and biotite are similar to those of the Muruhatten migmatites, and the tourmaline is a little more bluish in pleochroism colours. The primary amphibolites have been of more insignificant size, and they are now completely transformed.

2. *Lillfjället.*

An occurrence of a schistose, gabbroic amphibolite intruded by a granite pegmatite has been particularly examined. One part of the outcrops is sketched in fig. 26. The pegmatite is a homogeneous, potassic-dominant graphic rock,

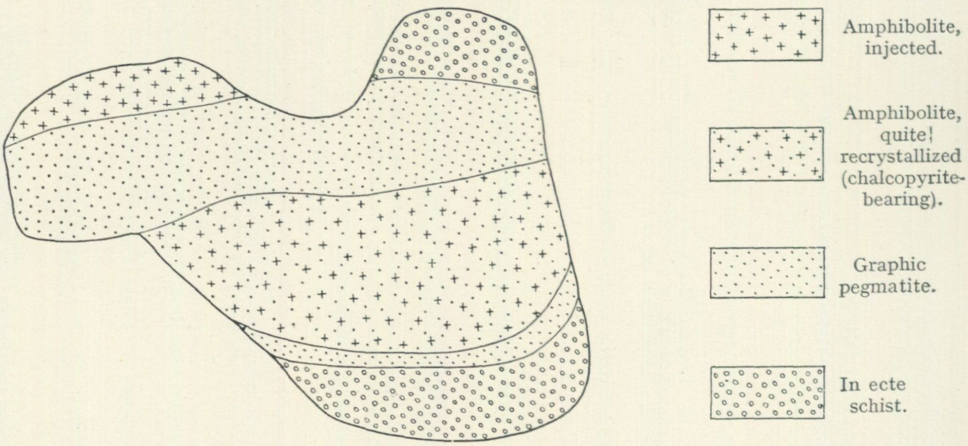


Fig. 26. A sketch of a pegmatite-injected amphibolite. Lillfjället. Scale of 1 : 100.

a sample of which has been analysed (represented by no. 49). Pegmatite and schlieren of quartz have been intruded in the schistose and partly banded amphibolite and its border rock, mica-schist. The outcrops of amphibolite extend further away on the left hand side of the sketch, though they are less injected here. The amphibolite in the center of the figure is enveloped by pegmatite. It has been quite re-crystallized showing a homogeneous rock outwardly reminding of a diorite, as illustrated by the photo, fig. 27. It is somewhat schlieric toward the margins with much larger size of the amphiboles and a greater percentage of quartz. The next outcrop on the left-hand of the figure has schlieren of quartz in it, but it is less recrystallized, and it has still much augite and labradorite which are almost completely transformed in the

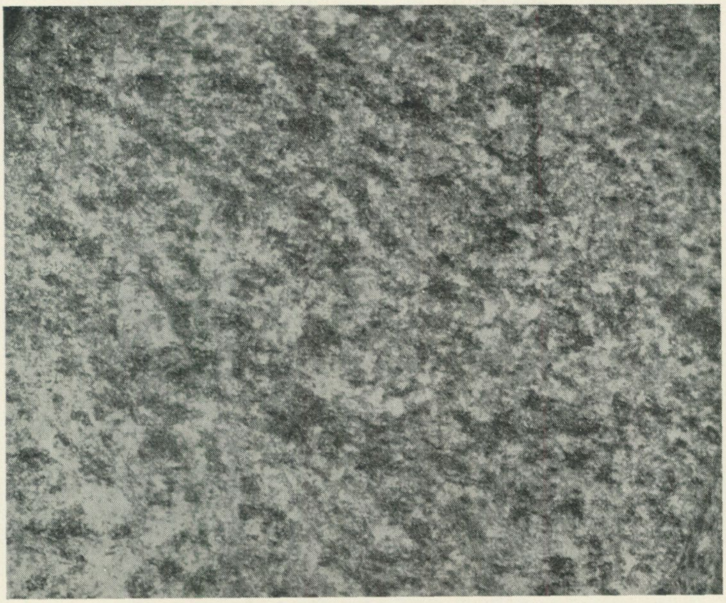


Fig. 27. Recrystallized amphibolite. Lillfjället. 1/2 nat. size.

re-crystallized rock of the central part of the sketched outcrop. A sample of this homogeneous rock has been analysed.

Table 49. Quartz-epidote amphibolite. Lillfjället.

Analyst N. SAHLBOM.

SiO_2	67.04	11,118
TiO_2	0.42	52
Al_2O_3	11.37	1,112
Fe_2O_3	4.05	254
FeO	4.32	601
MnO	0.13	18
MgO	2.55	632
CaO	6.60	1,177
Na_2O	0.75	121
K_2O	0.54	57
P_2O_5	0.19	13
S	0.64	199
CuO	0.83	104
H_2O^+ 105	0.50	277
	99.93	
H_2O^-	0.04	

Mineral composition[1] (weight %)	
Quartz	47 %
Hornblende	15
Sericitized (and saussuritized) plagioclase	4.5
Sericite	4.5
Transformation products of pyroxene (spinel 2.3, epidote 1.7 and chlorite 2.0 %)	6
Epidote	18.9
Titanite	0.3
Apatite	0.5
Titanomagnetite	1.3
Chalcopyrite	2.0
	100.0 %

Norm		
Q	42.8	
Or	3.2	
Ab	6.3	
An	26.0	
Σ Sal	78.3	
$CaSiO_3$	2.3	Di 4.3
$MgSiO_3$	1.5	
$FeSiO_3$	0.5	
$MgSiO_3$	4.8	Hy 6.9
$FeSiO_3$	2.1	
Il	0.8	
Mt	5.9	
Pr	1.2	
Ap	0.4	
Σ Fem	19.5	
CuO	0.8	
H_2O	0.5	
	99.1	

Niggli values	
si	260
ti	1.2
al	26
fm	42
c	28
alk	4
k	0.32
mg	0.36
c/fm	0.67

[1] According to the slices the content of quartz and plagioclase was slightly less, and the latter was hard to recognize.

The amphibole is a strongly greenish blue hornblende, to be described later (p. 69). The epidote is a pistacite with a birefringence 0.040—0.044, corresponding to about 32 % iron epidote. Remnants of an earlier augite are found as greenish spinel-pigmented dots of probably epidote with chlorite and sometimes some titanite. The chief difference from the gabbroic amphibolite is the great addition of quartz, the transformation of the plagioclase and pyroxene, increasing the content of epidote and hornblende.

The reaction with the potassic pegmatite is slight as there is only formed a few percent of sericitic muscovite and no biotite, probably because of the absence of pneumatolytic solutions accompanying this type of pegmatite injections. The earlier, alkali-intermediate injections have always a stronger reactionary effect on surrounding basic rocks, and they are generally tourmaline-bearing which these potassic injections are not.

Comparison with two quartz-injected but less transformed rocks (50 and 51) shows following figures:

	No. 49	No. 50	No. 51
Quartz	47 %	48 %	55 %
Plagioclase	4.5	10.1	18.8
Hornblende	15	9	4
Diopside-augite	—	16.5	8
Epidote	20.6	13	7.4
Titanite	0.3	1	1.3
Sericite	4.5	—	0.9
Chlorite	2.0	0.2	0.1
Spinel	2.3	—	0.1
Apatite	0.5	—	0.2
Sulphides & magnetite	3.3	2.2	4.2

The plagioclase of these rocks is a labradorite (An_{59}—An_{60}), and the pyroxene an ordinary diopside-augite ($2V\gamma = 59°$, $c : \gamma = 44°$).

The original non-injected rock has probably been a gabbro or quartz-gabbro. An estimation of the mineral composition of this rock gives following figures (no. 52): quartz 5.2 (weight %), labradorite 45, augite 30.5, hornblende 15, titanite 2, magnetite 1.9, apatite 0.4 %. The composition of the hornblende[1] is according to the optic data about: SiO_2 43, TiO_2 1, Al_2O_3 12.5, Fe_2O_3 6, FeO 12.7, MgO 9, CaO 11.5, Na_2O 2, K_2O 0.3, H_2O 1 %. The calculated composition of this estimated rock compared with the recrystallized amphibolite (no. 49), and the same after deduction of 40 % silica (49 a) will give a fair view of the chemical transformations:

	52	49	49 a
SiO_2	51.5	67.04	45.01
TiO_2	1.3	0.42	0.70
Al_2O_3	17.1	11.37	18.92
Fe_2O_3	2.9	4.05	6.75
FeO	4.9	4.32	7.21
MnO	—	0.13	0.22

[1] Compare the optic figures of the amphiboles from this locality and the data of the analysed hornblendes, referred on pp. 69, 72, 73, and the diagrams, figs. 28 and 29.

	52	49	49 a
MgO	5.9	2.55	4.43
CaO	13.4	6.60	11.00
Na_2O	2.2	0.75	1.25
K_2O	0.3	0.54	0.90
P_2O_5	0.2	0.19	0.32
S	—	0.64	1.07
CuO	—	0.83	1.38
H_2O	0.3	0.50	0.84

The differences in composition are not great. Some lime and soda (and possibly a little magnesia) has been carried away during the transformations and a little potassium has been taken up by interaction with the pegmatite. Iron and copper have been supplied as sulphides. The transformation of the plagioclase and the pyroxene has disengaged some silica. The plagioclase has been saussuritized, and the pyroxene has partly been transformed into hornblende, partly into epidote, chlorite, and some spinell and a little titanite. The high iron content of the epidote indicates some addition of iron here also.

3. *Lillfjällsgruvan.*

Lillfjällsgruvan is a small mine or cavity situated in the eastern slope of Lillfjället. It was completely excavated during the author's visit. It lies at the outer border of the Lillfjället injection-gneisses as an offset from the main injection complex at a boundary between an amphibolite and a mica-schist.

These rocks have been completely re-crystallized, with larger grain size of the minerals, now showing a consecutive transition between the two rocks. An addition of quartz and sulphides (chiefly chalcopyrite) has probably occurred from outside sources (from the pegmatitic to trondhjemitic injections which are generally followed by sulphide-bearing hydrothermal solutions in this region). The reaction between the rocks is complete, so it is hard to tell where the amphibolite vanishes and the mica-schist begins. A table showing the mineral composition of seven consecutive rock types (in weight %) will give a fair view of the development of the rocks.

Rock no. 54 represents the original amphibolite, now re-crystallized with but little change of the composition besides injected veins of quartz. The bluish green hornblende is represented by no. 77 in the discussion of the amphiboles on pp. 67—73. It is partly intergrown with a pale amphibole which, according to its optic properties $2V\gamma$ 76° and $c:\gamma = 20°$ should be a cummingtonite with a content of about 50 % $FeSiO_3$ according to N. Sundius[1]. The chlorite is a penninite with a distinct pleochrosim: bluish green to pale greenish yellow, and a low birefringence, partly with anomalous bluish, partly with anomalous greenish (yellowish black) colours (both negative and positive). It is secondary chiefly to the hornblende, and to a smaller degree to the garnet, though this

[1] Q. J. 1931 p. 320.

Table 53. Amphibole-bearing rocks from Lillfjällsgruvan.

	54	55	56	57	58	59	60
	Recrystallized amphibolite, quartz injected	Large-grained, hornblenditic amphibolite (rich in chalcopyrite)	Hornblenditic amphibolite	Micaceous, hornblenditic amphibolite	Staurolite-rich, migmatitic mica-schist	Migmatitic mica-schist	Anthophyllite-rich mica-schist
Quartz	47.8	—	2	tr.	27	41.7	31
Plagioclase	6.1	1	tr.	tr.	—	—	—
Green hornblende	20.9	74	91	82	2	1.8	—
Anthophyllite	—	—	—	—	9	21.1	37
Cummingtonite	1.5	—	—	—	—	—	—
Garnet (almandinite)	11.2	2	—	—	—	—	—
Staurolite	—	—	—	1	27	15.0	8
Biotite	—	—	—	8	27	19.3	17
Chlorite	8.5	1	tr.	2	1	0.2	$3^1/_2$
Muscovite	—	—	—	tr.	—	—	—
Cyanite	—	—	—	—	—	0.1	1
Pistasite	0.8	2	—	—	—	—	—
Clinozoisite-orthite	—	—	$2^1/_2$	2	$^1/_2$	0.1	—
Copper-and iron sulphides	2.6	20	4	4	6	0.2	2
Titanite	0.5	—	—	—	—	—	—
Rutile	0.1	—	$^1/_2$	1	$^1/_2$	0.3	$^1/_2$
Apatite	tr.	tr.	—	—	tr.	0.1	—
Zircon	tr.	—	—	tr.	—	—	—

chlorite is more chlinochloritic. The plagioclase is somewhat uneven, probably a decalcified feldspar.

Rock no. 55 is a skarn-like, hornblenditic amphibolite, rich in chalcopyrite. The bluish green hornblende of this rock is represented by the amphibole no. 76 (p. 69). The rocks nos. 56 and 57 have successively paler hornblendes, represented by amphiboles nos. 75 and 73 (p. 69). The last one has been analysed (p. 70). Rock no. 57 may be regarded as the contact rock between the original amphibolite and the mica-schist.

The next rock is more like a mica-schist in appearance, and it is distinguished by a high content of staurolite and biotite. The biotite of these rocks is of a pale colour with a weak pleochroism: γ brown to reddish brown $> \alpha$ pale greenish yellow. The anthophyllite which now appears together with the green hornblende has an axial angle about $2V\gamma = 79°$. — The last two rock types represent the original mica-schist to a greater part. They are richer in anthophyllite ($2V\gamma = 75 — 79°$) and have also some cyanite.

The anthophyllite is often present in metamorphic mica-schists at contact with amphibolite or peridotite, but they are never present in the basic rocks themselves. The cummingtonite has never been seen in the ultra-basic rocks or their metamorphism products. It is a typical product of skarn rocks, developed in sulphide deposits in Sweden, also characterized by country rocks enriched in magnesia and iron.

The rocks of Lillfjällsgruvan have evidently been enriched in iron and magnesia as seen by the great content of dark green hornblende, staurolite, and anthophyllite. The plagioclase of the original amphibolite has to the greatest part been turned over into hornblende by the enrichment in magnesia and iron. By the same metasomatic action the original mica-schist has been enriched in staurolite and anthophyllite, two minerals typical of metamorphosed Al-rich rocks poor in lime. Cyanite is also typical for injected or metasomatically altered rocks of this region.

The normal mica-schist as the end member of the series was also present. It is a bedded muscovite-bearing mica-schist, but it has not been sliced.

The enrichment in sulphides, particularly chalcopyrite, is typical for the earlier injection-bodies characterized by the preponderance of acid plagioclase over potassic feldspar. Sulphide enrichment has thus been found at the margins of peridotites and amphibolites close to injection bodies at many places, and also in migmatites. Small ore bodies have also been found at the borders of similar intrusive rocks (of trondhjemitic or leuco-trondhjemitic type) to the west and north of this region.

4. Borka.

The injection metamorphism of the amphibolites of the Borka region is hard to study because of the differentiated banding of the rocks. They have not been closer studied. Some different types were, however, recognized:

1) Quartz- injected amphibolites, but slightly transformed, with quartz, transformation products of pyroxene, oligoclase, actinolitic hornblende, and clinozoisite as chief minerals, often with a prominent content of sericitic muscovite, mostly secondary to plagioclase. Other minerals as garnet, biotite, calcite, chlorite, titanite or rutile, apatite, and iron sulphides are generally present.

2) Injected amphibolites transitionary to the former type with a prominent content of microcline, besides oligoclase, green hornblende, quartz, and garnet, with more or less diopside-augite, biotite, calcite, titanite, epidote, ore minerals, and apatite. These rocks have been injected principally with an addition of potassic feldspar. The reaction between the different components mixed is very slight.

3) Strongly banded amphibolites with a diffuse appearance of the injected material and consecutive transitions between the different layers of the rocks. More amphibolitic bands have hornblende, quartz, and plagioclase (oligoclase to labradorite) as main minerals, with garnet, epidote, biotite, apatite, titanite, and often some augite. Some types have more garnet, biotite, and often scapolite. More salic parts of these rocks are almost devoid of hornblende and show rather much quartz, and often some cyanite. A common type shows the following

mineral proportions: Quartz = plagioclase $\geq$ biotite $>$ garnet $>$ scapolite $>$ ore grains = apatite $>$ clinozoisite-orthite = cyanite = zircon $>$ rutile $\geq$ muscovite. The distinctly injected rocks show an increasing percentage of microcline, and more of the micas. A volumetric measurement of one sliced rock gave the following composition: andesine 22 %, quartz 18, microcline 18, muscovite 17, biotite 10, garnet 10, iron sulphides 1, scapolite 1, calcite 1, cyanite 0.5, rutile 0.5, apatite 0.5, myrmekite 0.2, orthite 0.2, and zircon 0.1 %.

4) Some amphibolites in the injected zone show an enlargement of the grain size of the minerals, particularly the hornblende. They are often hornblenditic in appearance, similar to those described from Lillfjällsgruvan. The amphibolites of the outer part of the injection complex are generally not injected themselves, but they may show a re-crystallization of the rock with a more crystalloblastic habit and a larger size of the minerals.

VI. The paragenesis of the pegmatite and migmatite minerals.

The paragenetic relations of some of the migmatite- and injection minerals of the Muruhatten region will be summarized here, and the green hornblendes will be closer described.

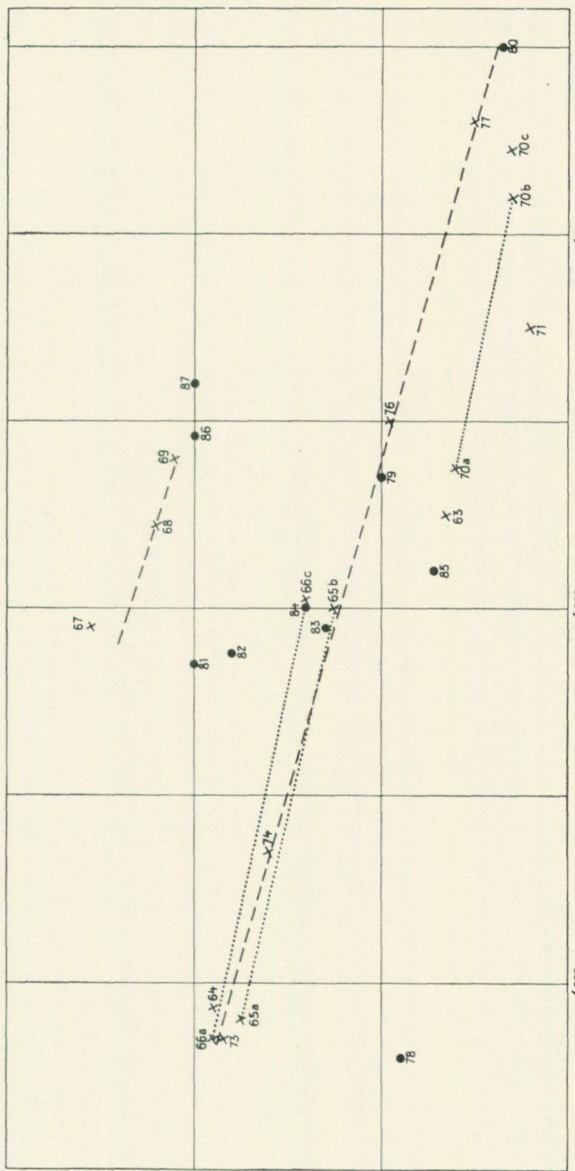
Table 61. Paragenetic table of the main pegmatitic-reactionary minerals of the Muruhatten region.

	Late magmatic phase	Pegmatitic phase	Pneumatolytic to pegmatitic hydrothermal phase	Hydrothermal phase
Quartz	—	—	—	—
Potassic feldspar	—	—	—	
Oligoclase	—	—	—	
Muscovite	—	—	—	—
Biotite	—	—	—	
Green hornblende (not primary)		—	—	
Anthophyllite			—	—
Tremolite (and actinolite)			—	—
Tourmaline		—	—	—
Garnet		—	—	—
Sillimanite			—	—
Cyanite			—	
Epidote (orthite, zoisite)			—	—
Chlorite			—	—
Titanite		—	—	
Rutile			—	—
Magnetite (not primary)		—	—	—
Iron and copper sulphides		—	—	—
Calcite				—

The preceding table (61) shows the interval of stability of the chief pegmatitic and reactionary minerals according to the opinion of the author.

a. The amphiboles.

Anthophyllite (gedrite) has been observed in metasomatically altered mica-schists at contacts of peridotites and amphibolites as a typically reactionary



× Examined hornblendes • Quoted hornblendes

Fig. 28. Green hornblendes of the Muruhatten region (compared with similar hornblendes). Tabulated after intermediate refraction index $\frac{\alpha+\gamma}{2}$ and axial angle $2V\alpha$.

Green hornblendes of

	62	63	64	65 a	65 b	66 a	66 b	66 c
Locality	W. of Muruhatten		Muruhatten					
Type of hornblende	Pale green	Blue-green	Pale-green	Common green hornblende				
Type of rock	Schistose amphibolite			Amphibolite in contact with aplite		Aplite injected amphibolite		
Pleochroism	Very weak	Strong	Very weak	Weak	Weak	Weak	Weak	Intermediate
α	yellow. green	yellow. green	yellow. green	yellow. green	yellow. green	yellow. green	yellow. green	yellow. green
β	green	olive-green	green	green	green	green	green	green
γ	(bluish) green	greenish blue	bluish green	(bluish) green	(bluish) green	(bluish) green	green	bluish green
Refraction- α	—	1.653	1.637	1.635	1.648	1.636	—	1.648
indices γ	—	1.674	1.662	1.663	1.672	1.661	—	1.673
Birefringence	—	0.023	0.026	—	0.023	0.023	0.023	0.022
2 $V\alpha$ (mean value)	78°	76½°	89°	87½°	82½°	89°	86°	84°
Ext. $C:\gamma$	15°	16°	16°	14°	15°	—	14½°	15½°

mineral within the original mica-schist, and it does not occur within the amphibolite or peridotite side of the margin, where instead green hornblende or actinolite-tremolite may be found. It must be the deficiency of lime in the mica-schist which has favoured the formation of anthophyllite in this rock. At the contact to basic rocks both anthophyllite and the other amphibole may be seen in the same rock specimen. A little actinolite or hornblende have several times been observed in the mica-schist together with anthophyllite.

According to the axial angles of the anthophyllites the minerals developed in the mica-schists in contact with peridotites are poorer in iron than those in contact with amphibolites.

The green hornblendes.

In the examination of the amphibolite-migmatites the green hornblendes have also been investigated. The table above gives an abstract of the optic properties of the particularly investigated hornblendes. Two of these, nos. 68 and 73 have been analysed.

As a comparison 11 analyses are quoted, nos. 78 to 88 (pp. 72—73), of similar amphiboles according to the optic properties, mainly the refraction indices and the optic axial angles.

The schistose amphibolites of the region have green hornblendes ranging from almost colourless to strongly bluish green. Nos. 62 and 63 are two common types. 62 is rather like 78 (quoted from Beskow), even in the slice. 63 is similar to 85 (Heritsch) and 79 (Beskow). Some hornblendes are distinctly

the Muruhatten region.

67	68	69	70 a	70 b	70 c	71	72	73	74	75	76	77
			Lillfjället				Lillfjällsgruvan					
Green hornblende with strong absorption, weak pleochr.			Blue-green hornblende				Green hornblende		Blue-green hornblende			
Amphibolite-migmatite			Quartz-epidote-amphibolite (recrystallized gabbroic amphibolite)				Metasomatically recrystallized amphibolite in contact with mica-schist					
Weak	Weak	Weak	Very strong	Very strong	Very strong	Very strong	Weak	Intermediate			Very strong	
yellow. green	yellow. green	yellow. green	green. yellow	green. yellow	green. yellow	green. yellow	yellow. green	yellow. green	yellow. green	yellow. green	green. yellow	green yellow
green	green	brown. green	grass green	grass green	grass green	grass green	green	grass green	grass green	green	green	grass green
(bluish) green	bluish green	green	green. blue	green. blue	green. blue	green. blue	(bluish) green	(bluish) green	bluish green	bluish green	(green.) blue	(green.) blue
1.648	1.6515	1.653	1.6525	1.662	1.660	1.655	—	1.636	1.642	—	1.655	1.6625
1.671	1.673	1.675	1.675	1.6825	1.682	1.680	—	1.661	1.665	—	1.675	1.6835
0.023	0.023	0.023	—	0.021	0.021	0.021	—	0.023	0.022	—	0.021	0.020
$95\frac{1}{2}°$	92°	91°	76°	73°	73°	72°	89°	$88\frac{1}{2}°$	86°	83°	$79\frac{1}{2}°$	75°
$16\frac{1}{2}°$	14°	16°	$17\frac{1}{2}°$	17°	18°	—	17°	16°	17°	$15\frac{1}{2}°$	$16\frac{1}{2}°$	17°

zonary similar to 83 (Du Rietz). The hornblende no. 64 comes from a schistose amphibolite that is somewhat affected by aplite intrusion. It has a high axial angle, rather characteristic for this region.

The hornblendes of the injected amphibolites and migmatitic amphibolites have been particularly studied (as well as the rocks described earlier in this paper). The hornblendes have also been affected by the metasomatic reactions generally in a very regular manner. In order to show the variation in optic properties the hornblendes of the region have been plotted in a diagram with refraction indices, here for convenience $\frac{\alpha + \gamma}{2}$, on the abscissa, and the optic axial angle $2V\alpha$ on the ordinate, fig. 28, p. 67. Both refraction indices and axial angles have been quoted with their mean values as being more proper, because the analyses will generally give mean values of the composition of many grains of the mineral. The value $\frac{\alpha + \gamma}{2}$ will also give somewhat more constant figures than either refraction index alone. Coherent mineral series, generally from the same rock, or from a section of the same outcrop, have been connected with lines in the diagram.

The three hornblendes 67—69 are taken from three different rocks, but these are located in the same tectonic position, all being injected amphibolites close to or in contact with the large Muruhatten peridotite, described on pp. 56—59. Two other outcrops of migmatitic amphibolites in the neighbourhood

Analyses of 2 hornblendes by N. Sahlbom.

(Picked out material separated in Clerici's solution.)

	73 Lillfjällsgruvan			68 Muruhatten		
	Weight %		Mol. %	Weight %		Mol. %
SiO_2	48.64	8,066	46.7	42.41	7,033	43.1
TiO_2	0.29	36	0.2	0.65	81	0.5
Al_2O_3	8.94	875	5.1	12.15	1,189	7.3
Fe_2O_3	1.54	96	0.6	4.47	280	1.7
FeO	8.78	1,222	7.0	12.49	1,738	10.6
MnO	1.16	163	0.9	0.19	27	0.2
MgO	16.42	4,072	23.6	14.79	3,668	22.4
CaO	12.64	2,253	13.0	11.15	1,988	12.2
Na_2O	0.49	79	0.5	0.96	155	0.9
K_2O	0.27	29	0.2	0.24	25	0.2
H_2O^+	0.69	383	2.2	0.26	144	0.9
F	0.00	—	—	0.00	—	—
	99.86		100.0	99.76		100.0
H_2O^-	0.15					
α	1.636 (1.633—1.639)			1.6515		
γ	1.661 (1.659—1.664)			1.673		
$2V_\alpha$	$88^1/_2°$ ($88-90^1/_2$)			92°		
$C:\gamma$	16°			14°		
$\gamma-\alpha$	0.023			0.023		
Sp. gr.	3.12			3.19		

of the analysed one (no. 47) have quite similar hornblendes as the analysed mineral (68) according to axial angles and pleochroism (rocks nos. 48 and 48 a). Amphiboles of about the same type are those quoted as nos. 81, 86, and 87. This type of hornblende is characterized by a high content of alumina, rather high ferrous and a relatively low of ferric iron. This chemical character is distinguished by a high value of the axial angle $2V\alpha$, being more than 90° in the Muruhatten hornblendes of this type. According to the supposition of the author the original amphibolite has formerly had an iron-rich hornblende of the more normal type, viz. not so poor in ferric iron in proportion to ferrous (as it now has), of the bluish green hornblende type (as e. g. nos. 63, 71, 77), common among the amphibolites of the Muruhatten region. By the metasomatic reactions following the pegmatite-aplite injection the character of the amphibole formed is somewhat altered. As has been pointed out in the description of the reactions at the border of some peridotites and amphibolites in this paper, an enrichment in alumina has often occurred resulting in a crystallization of such Al-rich minerals as garnet, biotite, tourmaline, zoisite, chlorite etc. It is thus probable that also the amphibole formed is somewhat higher in alumina than the original one was. The reactions with the near- by peridotite which is particularly poor in ferric iron has probably been the cause of the relative diminishing of the Fe_2O_3 content of the reactionary amphibole. It is also typical that the hornblende with the largest axial angle comes from the most transformed rock.

The hornblende no. 86 was referred by Kunitz[1] as the end member of the pargasite series because of its content of fluorine, but as seen by the other similar amphiboles with a high axial angle as nos. 68, 87, 81, 82 which are devoid of fluorine, this content is not the chief ingredient governing the optic properties of this kind of amphibole. It is at present impossible to say to what degree the fluorine may influence the axial angle (cf. the diagram, fig. 29 p. 75).

The amphiboles 65 a and 65 b are from a slightly contaminated amphibolite, and nos. 66 a, 66 b, and 66 c from another one close by. The more influenced part of the amphibolite will get an amphibole slightly paler with lower refraction indices and slightly higher axial angle. They have been kind of diluted by the reactions, chiefly a decreasing of their iron content.[2] The mineral series from different rocks show almost parallel lines of variation (or differentiation lines).

The hornblendes from the re-crystallized amphibolite of Lillfjället described on pp. 60—63, are typical, bluish green hornblendes, 70 a, b, c from the same rock and no. 71 from a somewhat less metamorphosed rock. 70 a is taken from the amphibolite most enriched in quartz. It is re-crystallized in large garben-like amphiboles. The series 70 is roughly parallel with the series 65 and 66, but represents hornblendes richer in iron. The bluish green amphibole no. 63 is close to 70 a in the diagram, and it is similar in colour and pleochroism. Further away the series 70 points to the hornblende no. 85 (having a somewhat lower content of alumina than the corresponding part of the Lillfjällsgruvan series above comparable with the analysed hornblendes nos. 79, 83, 84). As no. 71 falls below the differentiation line of series 70, it might be conceived that the minerals of the more reacted rock (of series 70) has been subjected to a greater change in composition, e. g. an increase in the alumina content or a decrease in the ferric iron.

The hornblende series of the Lillfjällsgruvan rocks show a differentiation line almost rectilinear. No. 77 with the highest refraction indices and the lowest axial angle represents the least transformed amphibolite, and nos. 76, 75, 73 in this order represent the approach of the margin towards the metamorphosed mica-schist. Of the hornblendes of the mica-schist 72 is similar to the analysed one (73), while no. 74 is somewhat stronger in colour with larger refraction indices and a lower axial angle. The mother rock of this mineral has only a slight content of green hornblende, but a large percentage of anthophyllite. This rock is thus not quite comparable to the others.

[1] N. J. 1930, BB 60, p. 211.

[2] The available analyses of green hornblendes show that the Al_2O_3 content on the average is proportionate to the iron content.

Molecular percentage and optic data

	78	79	80	81	82
	G. Beskow Sv. Geol. Und. Ser. C. No. 350, 1929.	G. Beskow S. G. U. Ser. C. No. 350, 1929, p. 97	G. Beskow S. G. U. Ser. C. No. 350, 1929, p. 158	H. Backlund cf. G. F. F. 1935 p. 179	V. E. Barnes Am. Min. 1930 p. 414
SiO_2	44.9	44.3	44.1	45.0	43.4
TiO_2	0.7	0.6	1.0	0.5	0.6
Al_2O_3	5.8	9.5	8.0	8.1	6.6
Fe_2O_3	0.7	1.5	2.6	0.7	1.7
FeO	8.0	7.9	11.7	8.9	6.3
MnO	—	0.1	0.1	0.2	0.3
MgO	19.1	12.7	11.6	19.0	21.7
CaO	12.1	11.5	11.8	12.5	12.4
Na_2O	2.6	2.3	3.8	2.6	2.4
K_2O	0.3	0.3	0.4	0.2	1.2
H_2O	5.8	9.3	4.9	2.3	2.5
F	—	—	—	—	0.9
	100.0	**100.0**	**100.0**	**100.0**	**100.0**
α	1.638	1.6515[1]	1.665[1]	1.645	1.6511
β	—	—	—	—	1.6589
γ	1.658	1.6755[1]	1.685[1]	1.672	1.6665
$2V\alpha$	79°[1]	80°[1]	73½°[1]	90°	88°
$C:\gamma$	15°	15°[1]	19.5°	—	23°
$\gamma-\alpha$	0.020	0.022	0.020	0.023	0.015
Sp. gr.	3.16	(3.109)	3 283	3.162	—

That the hornblendes show decreasing refraction indices, mainly indicating lower iron content toward the mica-schist depends on reaction between the two rocks. That these rocks which are more transformed than the amphibolites of the hornblende series 70 a—b—c, show a hornblende series with larger axial angles may depend on a greater change of the minerals due to greater metasomatic transformations, i. e. resulting in a higher content of alumina of the Lillfjällsgruvan amphiboles. The line of differentiation of the Lillfjällsgruvan hornblendes almost coincides with the optic properties of two amphiboles from S. Storfjället (Beskow), nos. 79 and 80. These are bluish

[1] Determined by S. GAVELIN and T. DU RIETZ.

of 11 green hornblendes (quoted).

83	84	85	86	87	88
T. Du Rietz G. F. F. 1929 p. 504	Tilley Min. Mag. 1937, p. 565	H. Heritsch Z. K. 86 A. 253, 1933	Kunitz N. J. B. B. LX 1930 p. 211	Th. G. Sahlstein Med. om Grön. 1935, No. 5 p. 22	Kunitz N. J. B. B., A 1930 p. 207
38.9	42.0	42.4	42.1	42.2	42.0
1.6	0.5	0.4	1.1	0,2	0.8
6.8	10.1	5.7	6.9	11.2	6.4
2.4	1.0	1.5	1.0	1.8	1.3
7.6	7.8	11.7	12.0	6.8	12.4
0.4	0.1	0.1	0.2	0.2	—
21.5	17.7	14.0	16.7	23.5	16.8
12.1	11.8	11.7	12.4	11.0	11.9
0.9	1.7	0 6	2.4	1,2	1.3
0.3	0.5	0.9	0.6	0.3	0.3
7.5	6.8	11.0	2.0	1.6	6.8
—	—	—	2.6	—	—
100.0	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
1.646 (mean)	1.648	1.651	1.6545	1.658	1.659
—	—	1.659	1.6655	—	—
1.673 (mean)	1.672	1.673	1.6747	1.674	1.681
83° (mean)	84°	77° 6′	90°	90° approx.	65° 38′
17.5°	19°	25°	18° 30′	24°	16° 30′
0.024	—	0.022	0.020	—	0.022
—	3.20	3.15	—	3.170	3.234
Strongly zonary, opt. data intermediate values			Other optic values earlier quoted by Ford A. J. S. 1914, 37 p. 181		

green hornblendes of quite the same pleochroism as nos. 76 and 77 from Lillfjällsgruvan which fall in between the two from S. Storfjället on the diagram. Their chemical composition may thus be similar (though the alumina content of no. 79 is extraordinarily high). Toward the left the refraction indices—axial angle line of the Lillfjällsgruvan series passes close under the amphiboles nos. 83 and 84 which lie very close to the basic end members of the Muruhatten amphiboles series 65 and 66. Deducing from this, these amphiboles ought to have a composition about 6½ mol.% Al_2O_3 and 2 % Fe_2O_3 for this part of the Lillfjällsgruvan amphibol series, and not very different for the Muruhatten amphiboles. The end member of the series, no. 73, shows a mol. composition of 5 % Al_2O_3 and less than 1 % Fe_2O_3 which is according to expectations. The composition of the hornblendes nos. 64, 65 a, and 66 a of the injected amphibolites of Muruhatten should have similar compositions as the optic properties are rather like those of no. 73.

In order to ascertain the influence of alumina and ferric iron on the axial angles of the green hornblendes, all those analysed minerals with determines, values of refraction indices and axial angle available, including the tremolited have been plotted in a net, fig. 29, in the same way as the diagram fig. 28. Upon calculating the composition of the amphiboles the axial angle $2V\alpha$ is rather well proportionate to the value $Al_2O_3 + \frac{TiO_2}{2} - Fe_2O_3$ (mol.%) when the imagined continuation of the tremolite series (actinolites free from Al_2O_3, TiO_2 and Fe_2O_3, or with the Al and Ti percentage equalized by the same value of Fe) is taken as base line. This line inclines a trifle more toward the right part of the diagram than the differentiation lines of the hornblende series discussed above according to the calculation of the available analyses. Parallel lines are drawn on the diagram indicating the values $Al_2O_3 + \frac{TiO_2}{2} - Fe_2O_3 = 0$, $+ 2$, $+ 4$, $+ 6$, $+ 8$. At each analysis this calculated value (in italics) is stated. The agreement of the analyses is not quite satisfactory, but the values indicate the drawing in a rough way.

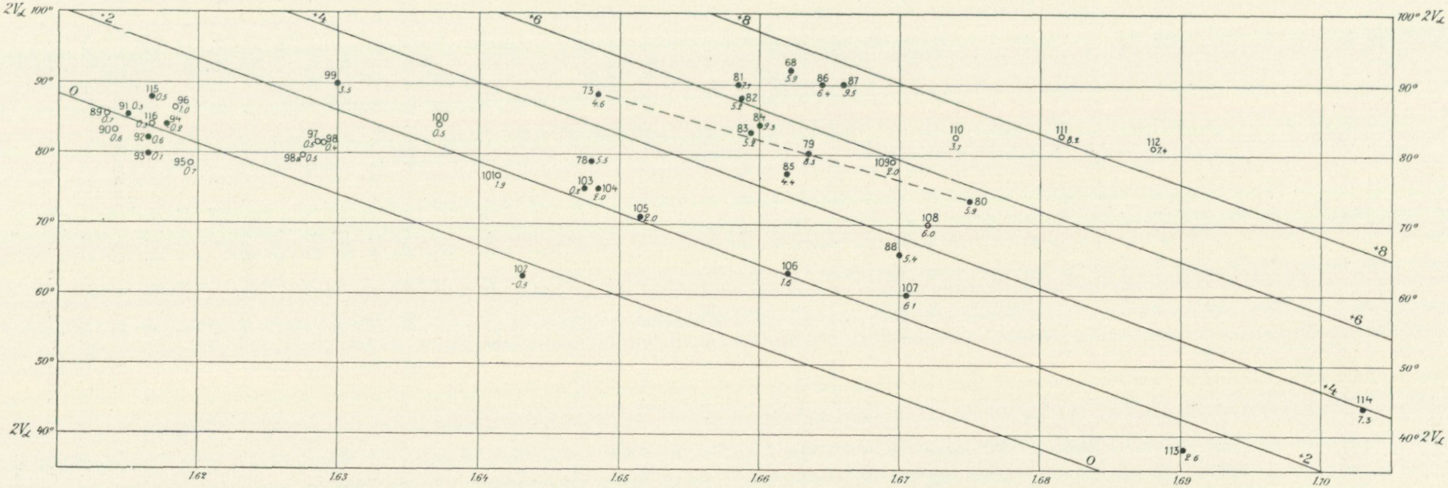
The composition of the green hornblendes is very complicated, and the other components of the minerals, not figured, probably also somewhat influence the axial angle. The diagram is also very susceptible as both the determination of the refraction indices and the axial angle determine the position of the mineral. It of course also depends on the reliability of the state of oxidation of the iron.

Analyses of minerals generally show the intermediate composition of many grains of the same mineral which may have somewhat different composition as well as varying optic properties. The optic figures given should thus be the intermediate values of many measurements of the same material as that analysed. As optic measurements are often made on only one or two mineral grains the result may be misleading.

In the diagram the less certain minerals quoted are specially marked (circles). Some have only the axial angles calculated from the refraction indices. In some the figures given do not seem quite reliable, etc.

At the right end side the diagram might be filled out with new analyses of iron-rich hornblendes as such minerals often have been described, though they are either without complete optic determinations or not analysed. Most amphiboles of this kind described are dark, bluish green hornblendes falling below the continuation line of the Lillfjällsgruvan mineral series. Such hornblendes are described for instance by P. Geijer[1] from the pegmatites of Stockholm and Österskär, and by the author[2] from the quartzdiorite of Rådmansö

[1] G. F. F. 1913, p. 147.
[2] G. F. F. 1929, p. 519.



• Rather reliable amphiboles ∘ Less reliable amphiboles

Fig. 29. Green hornblendes tabulated according to intermediate refraction index $\frac{\alpha + \gamma}{2}$ and optic axial angle $2V_\alpha$.

(with $\alpha = 1.671$, $\gamma = 1.689$, $2V\alpha = 59°$, and also a still darker variety, erroneously called hastingsitic).

For the convenience of the earlier discussion of the Lillfjällsgruvan hornblendes the straight line indicating the mineral series of this locality has been marked out on the general diagram also.

A table of quoted analyses is given below.

Tremolite-actinolite.

The tremolite-actinolite minerals are only found within the metamorphosed parts of the peridotites or at their margins.

The composition of the mineral generally depends on the original iron content of the primary olivine. It has thus about the same percentage of the iron-silicate as in the olivine or a little more. 14 % of the iron component (mol.%) is a common figure for the actinolite of Muruhatten, but it is generally less at other places.

As to the origin of the tremolite-actinolites the reader is referred to the earlier paper of the author (6) (summarized in this paper on pp. 48—52).

The lime-poor amphiboles, viz. cummingtonites and anthophyllites, have never been found within the peridotites or their metamorphic products, though the anthophyllite has often been observed in mica-schist close to the peridotite. The cummingtonite has only been found at one place, viz. in a metamorphosed amphibolite enriched in copper and iron sulphides. The lime-bearing amphibole is thus the easiest formed and most stable one within the ultra-basic rock. The lime is supplied from outside sources.

The tremolite-actinolite minerals have not been observed as a last amphibole formed by the continued low temperature metamorphism of the amphibolites. It seems rather as if the Al-rich hornblende is more stable than the tremolite-actinolite.

b. The feldspars.

The plagioclase of the schistose amphibolites is rather acid, generally an oligoclase. As these rocks are epidote-bearing amphibolites, they have originally probably had more basic feldspars, about andesine to labradorite according to the indications of less metamorphosed varieties. The main metamorphism of the amphibolites, producing their general schistosity, has occurred before the intrusion of the granitic-pegmatitic rocks. The contemporary breaking down of the basic plagioclase has resulted in an oligoclase, generally about An_{22}, which seems to be rather stable, as a further reduction of the anorthite component only occurs in special reactions, for instance at the contact with peridotites. The quartzitic mica-schist of the region generally also carries an oligoclase, about An_{20}—An_{25}, but as this rock does not carry other lime-bearing minerals as epidote or amphibole, except as accessories, this feldspar content must be original, perhaps furnished by breaking down of igneous rocks having this kind of plagioclase.

Hornblendes quoted in diagram fig. 29, p. 75.

The analyses figures given, are mol. %.

	89	90	91	92	93	94	95	96	97	98
	Ford, A. J. S. 1914 p. 180—187	Ford, A. J. S. 1914 p. 180	Kunitz, N. J. B. B. 60 1930	Barnes, Am. M. 1930 p. 411	Sundius, Z. Kr. B 43, 422 1933	Du Rietz, G. F. F. 1935 p. 215	Du Rietz, G. F. F. 1935 p. 215	Ford, A. J. S. 1914 p. 180	Ford, A. J. S. 1914 p. 180	Ford, A. J. S. 1914 p. 180
TiO_2 . . .	—	—	—	0.05	0.03	—	0.05	0.09	0.06	—
Al_2O_2 . . .	0.69	0.65	0.28	0.61	0.23	0.07	0.70	0.91	1.34	0.64
Fe_2O_3 . . .	0.01	0.06	—	0.04	0.12	0.23	—	—	0.83	0.26
FeO . . .	0.43	0.15	0.18	0.16	—	0.91	1.68	0.39	3.51	4.06
MnO . . .	0.03	0.05	—	0.01	1.15	0.27	0.12	—	—	0.36
α	1.6000	1.5992	1.603	1.6024	1.604	1.6036	1.607	1.6022	1.6162	1.6173
β	1.6155	1.6132	1.616	1.6183	—	1.6188	1.620	1.6192	1.6304	1.6330
γ	1.6272	1.6246	1.627	1.6307	1.629	1.6319	1.632	1.6347	1.6412	1.6412
$2V\alpha$ . . .	85° 30′	83° 23′	85.5°	82°	79.3°	84° 9′	78.5°	86° 29′	81° 30′	81° 38′
$C:\gamma$ . . .	—	20°	15°	15 1/2°	—	17° 18′	17.5°	16° 38′	14° 47′	15°
$\gamma-\alpha$ . . .	0.0272	0.0254	0.024	0.0283	—	0.028	0.027	0.0325	0.0250	0.026
Sp. gr. . .	—	—	3.027	—	2.998	—	—	—	—	3.047
	2V calculated	2V calculated					Fe_2O_3 n. d.	2V calculated	2V calculated	2V calculated

	99	100	101	102	103	104	105	106	107	108
	Jones, Uni. Toro. Studies. 1930	Ford, A. J. S., 1914 p. 180	Ford, A. J. S. 1914, p. 180	Winchell, Am. M. 1931 p. 259	Kolderup, Bergens Mus. Aarb. 1924—25. No 1	Washington & Merwin Am. Min. 1923. 8 p. 36	S. Gavelin, G. F. F. 55, 1933 p. 476	Winchell, Am. M. 1931, p. 259	Kolderup Berg. Mus. Aarb. 1924—25. No. 1	Marchet, T. M. P. M. 38, 1926 p. 500
TiO_2 . . .	0.29	0.19	0.87	0.22	0.11	1.35	0.25	0.27	0.06	1.45
Al_2O_3 . . .	4.12	1.42	2.35	0.77	1.71	2.09	1.85	3.62	7.42	6.89
Fe_2O_3 . . .	0.76	1.04	0.89	1.77	1.56	0.78	—	2.11	1.34	1.61
FeO . . .	4.51	5.01	4.18	6.38	6.34	4.66	13.09	9.68	13.42	12.70
MnO . . .	0.20	0.53	0.27	0.25	0.13	0.03	0.31	0.32	0.13	0.15
α	1.618	1.6237	1.6280	1.6341	1.637	1.636	1.640	1.6539	1.660	(1.660)
β	1.631	1.6382	1.6442	1.6472	—	1.650	—	1.6656	—	(1.676)
γ	1.642	1.6503	1.6547	1.6522	1.658	1.660	1.663	1.6702	1.681	(1.684)
$2V\alpha$ . . .	90°	84° 8′	76° 58′	62°	75°	75°	71°	63°	60°	70°
$C:\gamma$ . . .	16°	—	13° 35′	21°	15.5°	16°	18.5°	32°	18.6°	—
$\gamma-\alpha$ . . .	—	0.025	0.0267	0.0181	—	—	0.023	0.0163	—	0.024
Sp. gr. . .	3.147	3.111	3.127	—	—	—	—	—	—	3.254
		2V is calculated				Indices are high	Indices seem low			

	109	110	111	112	113	114	115	116	98 a
	Deer, G. M. 1937 p. 359	Duparc & Pearce, B. Soc. Min. XXVI 131, 1903	Kunitz, N. J. B. B. A. 1930	Kunitz, N. J. B. B. A. 1930	Barnes Am. Min 1930 p. 410	Wolff J. G. 37, 1929 p. 9	Johansson Z. K. 73, 1930 p. 31	Kreutz Sitz. Kais. Ak. Wis CXVII H. VII	Kreutz Sitz. Kais. Ak. W. CXVII H. VII
TiO_2 . . .	1.13	1.34	2.84	3.22	0.76	4.12	—	—	—
Al_2O_3 . . .	2.40	6.79	8.87	7.57	5.64	7.03	0.7	0.6	0.6
Fe_2O_3 . . .	0.99	3.81	2.07	1.81	3.44	1.78	0.2	0.3	0.1
FeO . . .	11.33	8.65	5.03	4.96	13.68	23.76	1.3	1.7	3.8
MnO . . .	0.24	—	0.08	—	—	0.82	0.4	—	0.2
α	1.659	1.6627	1.670	1.675	1.6804	1.693	1.6036	1.6065	1.6139
β	1.669	1.6765	—	—	1.6980	1.711	1.6171	1.6210	1.6297
γ	1.680	1.6856	1.693	1.701	1.700	1.713	1.6299	1.6319	1.6410
$2V\alpha$ . . .	79°	82° 30′	82° 45′	81°	38°	43 1/2°	87° 56′	84° 05′	79° 49′
$C:\gamma$ . . .	24°	17°	8°	11–12°	20°	20–21°	18.3°	16° 54′	16° 31′
$\gamma-\alpha$ . . .	—	0.0228	0.023	0.026	0.0196	0.020	0.0263	0.0254	0.0271
Sp. gr. . .	—	—	3.178	3.213	—	3.422	3.025	3.031	3.041
	Indices are high		Basaltic hornblendes						

The plagioclase of the intrusive granitic rocks is a more sodic feldspar. In the trondhjemitic (or leuco-trondhjemitic) rocks it is an oligoclase varying between An_{12} and An_{20}, An_{16} being the average type. It is generally more sodic in the potassic-richer intrusives, being about An_{15} in the intermediate rocks and passing down to pure albite in the pegmatites with about An_{8} as the average value.

Trondhjemitic to alkali-intermediate intrusives in contact with peridotite have sometimes by reactions with ultra-basic rocks been decalcified and may thus have a plagioclase down to about An_{8}. The lime has gone to the formation of tremolite in the peridotite.

By metasomatic reactions in the pneumatolytic-hydrothermal stage the oligoclase of the rocks has very often been sericitized indicating a deliberation of the potassic component of the mineral. In some other transformations the plagioclase is completely or almost consumed by reactions under the formation of hornblende, biotite etc. Albite has, however, not been formed in this transformations.

The potassic feldspars occurring in some rocks, viz. in the granitic to pegmatitic rocks and in the injection-gneisses, are of common types, generally microcline and microcline-perthite, but sometimes also orthoclase. Some porphyroblasts of the »augen»-gneisses often remind of perthites, because of their enveloping older crystals of quartz and plagioclase.

The composition of the microcline of a pegmatite has been calculated from the rock analysis: SiO_2 65.7, Al_2O_3 18.2, CaO 0.1, BaO 0.1, Na_2O 2.8, K_2O 13.0 % (cf. p. 23). The microcline of the granites have a slightly higher content of the albite molecule, as the refraction indices are a little higher.

The appearance of microcline twinning is largely an effect of stress as the more tectonized rocks generally have a microcline and the less schistose rocks often untwinned potassic feldspar. A more schistose part of the same rock may thus show an undulous and indistinct appearance of microcline twinning, while the more homogenous rock part has an untwinned feldspar. The same is often the condition of the occurrence of perthite also. In a schistose rock it often appears as uneven, indistinct spots arranged parallel with the schistosity. The less schistose parts of the same slice may be without the perthite. One common type is exemplified by the photo, fig. 9, p. 21.

The injection rocks of Borka which were formed under a greater stress than those of the Muruhatten region have always a microcline as their potassic feldspar.

c. Garnet.

Most of the rocks of the region are rather rich in garnet, especially the migmatites and contact rocks, often with large, idiomorphic garnets reaching a size up to 4 cm in diameter. It is always of a brownish red colour, being similar in all rocks. It is generally poikiloblastic, enveloping smaller grains of quartz, plagioclase, magnetite, biotite etc.

An analysis of garnet will be quoted here (6, p. 190):

Table 117. Garnet from Muruhatten.

Analyst R. BLIX.

			Mol. %
SiO_2	37.21	6,171	42.52
TiO_2	0.14	17	0.12
Al_2O_3	20.97	2,052	14.12
Cr_2O_3	0.02	1	0.01
Fe_2O_3	0.04	2	0.01
FeO	32.65	4,545	31.33
MnO	2.02	285	1.96
MgO	2.74	680	4.69
CaO	3.67	654	4.51
Na_2O	0.14	23	0.16
K_2O	tr.		
H_2O^+	0.15	83	0.57
H_2O^-	0.10		
	99.85		100.00

Sp. gr. 4.145 ± 0.002 (BLIX).

Refraction index:
(determined by K. LUPANDER, Helsingfors, on prism.)

$\lambda = 579\,\mu\mu$ n = 1.8083
546 = 1.8107
436 = 1.8311
± 0.0003

The analysis corresponds to:

	Mol. %	Weight %
Andradite	0.1	0.1
Almandite	73.8	75.0
Spessartite	4.6	4.7
Pyrope	11.0	10.5
Grossularite	10.5	9.7

A similar garnet from Junsternäset has also earlier been analysed (cf. 6, p. 198). All the garnets observed in the region seem to be of the same almanditic character. This garnet is evidently a mineral that is often formed in the injection of mica-schists, and it is particularly abundant in the pneumatolytic-hydrothermal transformations of the amphibolites, and at the mica-schists in contact with peridotite. In the injected mica-schist, large garnets are often present. In the common mica-schists they are less abundant and of much smaller size. The author has often observed that they increase in abundance and particularly in size, when approaching the injected schists. The garnet has evidently been formed in the re-crystallization of the schists under the influence of the pneumatolysis from the pegmatitic solutions. The composition of the garnet does not necessarily indicate an addition of material, as the garnet has a similar composition as the biotite, only a higher percentage of iron, which probably partly has been supplied by the solutions (or re-deposited) as the rocks otherwise also point to an addition of iron, seen for instance by the occurrence of much magnetite etc. The alumina content of the rocks has often been increased at the same time, as many other Al-rich minerals for instance tourmaline, epidote, Al-rich hornblende, cyanite, etc., have also been formed.

In the continued hydrothermal transformation of the garnet-bearing rocks the biotite has generally been chloritized before the garnet, and garnet-chlorite schists have been formed, often with much magnetite. In the continued transformation of the rock even the garnet is chloritized but seldom completely. In the strongly, hydrothermally transformed rocks rich in sulphides garnet is often present.

The garnet is especially abundant in the contacts towards the amphibolites, and in the injected amphibolites themselves. The garnet-amphibolites further northeast of this region seem to be formed by metasomatic transformations emanating from granitic intrusions. A similar origin of garnet amphibolites has also been pointed out by H. Backlund (4).

d. Sillimanite and cyanite.

Sillimanite and cyanite have been observed in many injected rocks and injection-gneisses, and they have evidently been formed by the injection metamorphism as these minerals have not been observed in other rocks. The cyanite has been formed by the combined action of stress and metasomatism in the first phase of the injection metamorphism. In the Muruhatten rocks it has generally been partly converted into sillimanite, probably as the stress has been reduced. Sillimanite is thus more stable when the tectonic movements are less active. By continued metasomatism the sillimanite has been converted into mica, as the former is not a stable mineral beside microcline. The sillimanite is often quite enveloped in biotite or muscovite which may have protected it against further transformation.

In the Borka region cyanite has been observed in the most injected rocks, but hardly any sillimanite. That cyanite alone was formed here depends on the great stress which had prevailed in this region and prevented the formation of sillimanite. It is thus partly transformed directly into mica.

Sillimanite and cyanite have been formed in the injection or metasomatism of normal mica-schists which were not exceptionally rich in alumina. As they are not found in non-injected schists of the regions investigated it is conceivable that they have been formed by metasomatism in the first stage of the metamorphism, probably before the chief supply of potassium was added. The study of the rock slices indicates that they were relatively stable under the main injection metamorphism, though the cyanite was probably less stable than the sillimanite in the Muruhatten region. In the later hydrothermal transformations these minerals were not stable any longer and were transformed into mica.

J. L. Stuckey discusses the origin of cyanite and points out the replacement origin of some occurrences, also some referred by others. Cyanite blades often cut across the structure of the rocks, indicating perfect replacement. He writes further: »The extended literature on pegmatites indicates that they have originated from igneous magmas and their formation involves a long series of replacements. Their minerals have been derived from the original solutions and not from the inclosing rocks — — —. A careful review of all the available evidence points to the formation of the cyanite deposits of North Carolina by metasomatic replacements by hot solutions given off by the quartz veins, pegmatites, dikes, and their parent magmas.» The present author does not go so far, but believes that these minerals were formed as reaction products under the combined action of stress and metasomatic-magmatic solutions chiefly by re-crystallization of the parent rocks of the minerals. Some alumina have been supplied by the solutions, but it is not quite certain to what degree.

e. Rutile.

Rutile is a frequent accessory constituent in all metasomatically transformed rocks of the region, particularly in the amphibolites.

It is partly a transformation product of earlier titanite which is scarce in these rocks, and it is common as secondary precipitations in biotite and especially in chlorite at the transformation of biotite, just as titanite otherwise is. Rutile also seems to be more stable than titanite at low temperatures. It is particularly common in the transformed rocks in contact with peridotites due to the fact that the lime content of the rocks partly has migrated toward the peridotite to form tremolite. The rutile has often been enveloped in secondary iron oxides, sometimes to the exclusion of the rutile.

The rutile generally occurs as minute, allotriomorphic grains somewhat spindle-like, recognized from the titanite by its stronger redbrown colour, higher refraction and birefringence.

f. Tourmaline.

Tourmaline is often found in the Muruhatten region as aureoles around pegmatitic and aplitic rocks when in contact with basic or ultra-basic rocks. It has thus been observed as genuine rocks of tourmaline $^1/_2$ m in thickness separating aplite from peridotite, and also as a similar rock separating an injected granite from an amphibolite (cf. the profiles and the photos in the earlier paper by the author, 6, pp. 175, 177, 177, 183, 193, 195, and 198). The tourmaline crystals are generally several cm long and about $^1/_2$ cm in width, almost black in hand specimen but light-coloured in thin section, showing a pleochroism, E greenish yellow and O in different shades of green generally olive green, often also with a bluish green core. Sometimes it is more bluish in colour. It is often distinctly zonary with a core of much deeper colour than the margin.

Much of what is said about garnet also is true of tourmaline, though it is not so universally distributed as the garnet. That tourmaline generally is found at contacts with basic rocks depends on the excess of basic oxides available there for the development of tourmaline out of the boron content of the solutions. A slight tourmaline content is characteristic for the trondhjemitic type of intrusions themselves just as their nearest environment, but the content is strongly increased at the contact of basic rocks. The potassic pegmatite injections on the other hand are not characterized by any appearance of tourmaline.

The analysed composition of a tourmaline from Muruhatten will be quoted (6, p. 178).

Table 118. Tourmaline from Muruhatten.

Analyst R. Blix.

			Mol. %
SiO_2	36.70	6,086	38.0
TiO_2	1.38	172	1.1
Al_2O_3	30.97	3,030	18.9
Fe_2O_3	1.73	108	0.7
Cr_2O_3	0.03	2	—
FeO	2.94	409	2.6
MnO	no tr.		
MgO	8.83	2,190	13.7
CaO	1.63	291	1.8
Na_2O	2.49	402	2.5
K_2O	0.21	22	0.1
Li_2O	no tr.		
P_2O_5	no tr.		
B_2O_3	9.50	1,364	8.5
H_2O^+	3.49	1,937	12.1
H_2O^-	0.17		
F	no tr.		
	100.07		100.0

Sp. gr.	3.250 (Blix)
$N\varepsilon Na$	1.6256
$N\omega Na$	1.648.

The refraction lines of the polished surfaces observed on the refractometer were not quite distinct, at least not that of $N\omega$, evidently owing to zonal growth of the crystals. According to the formulas of F. Machatschki[1] the composition of the tourmaline corresponds to (Na_2Ca) (Mg_8Al_{19}) $B_9Si_{18}H_{11}O_{93}$ (B_2O_3 is a little too low and water a little too high for this formula).

The pleochroism is E pale greenish yellow, O olive green.

Another tourmaline from a neighbouring rock gave the indices: $\varepsilon = 1.626$, $\omega = 1.650$ with the immersion method.

VII. Tectonic evolution of the region.

The Muruhatten—Lillfjället area is located at a bending of the general strike of the Caledonian axis. Its main direction is NNE to SSW, but in this region the general strike is about E—W with an overturning of the folds toward the south (as otherwise generally toward the eastsoutheast), cf. the map of the district (6, plate 3). This turning of the general trend of the Caledonian rocks which is still perceptible on the Norwegian side of the border is probably the cause of the marked intrusions of salic rocks of the Muruhatten region as compared with the conditions north of it.

[1] Z. Kr. 70, Vol. 3, 1929, p. 211.

The folding of the region is rather constant with frequent culminations and depressions of the pitching axis. This general structure of the folding may be typified by the drawing of the folding complex of Muruhatten (6, plate 5), though the curving of the pitching here is closer (and of smaller dimensions) because of the stiffness of the peridotite body.

The trondhjemitic or Na-dominant intrusions are quite conformable with the folding, though they may show intrusive contacts against the earlier igneous rocks viz. the amphibolites and the peridotites. They are generally somewhat granulated, and they have evidently been intruded under stress. Many of these intrusions are localized to tectonic lines of weakness, as the borders of earlier intrusions of peridotite and amphibolite in the mica-schists. These have thus been stabilized and protected against the following more potassic dominant intrusions.

The alkali-intermediate salic intrusions are also visibly influenced by stress (cf. microphotos, figs. 15 and 16), but not so much as the trondhjemitic types, and they are consequently never completely granulated and generally show a more granitic texture than the trondhjemites, though they are also more or less cataclastic.

The potassic dominant intrusives, of a rather pegmatitic type, are decidedly less influenced by the tectonic movements, and they are often quite unmetamorphosed (cf. the analysed pegmatite, p. 23). They may, however, show an undulousity of the grains and some crushing of the margins of the porphyritic feldspars. These rocks have evidently been intruded in the later phase at the culmination of the folding, and they are thus partly schistose and partly non-schistose. Some rocks of this type have cut across more schistose trondhjemitic types.

Later than the folding and younger than all the rocks of the region are horizontal movements forming planes of mylonitization with complete crushing of the rocks.

To the northeast of the region (for instance in the neighbourhood of Gäddede) there are finely grained gneisses, generally interlaminated with amphibolites. These fine-grained schistose rocks (almost leptite-like) have a composition similar to the trondhjemitic rocks averaging: oligoclase (about An_{14}) $\geqq$ quartz $>$ muscovite $\geqq$ biotite $+$ chlorite $\geqq$ pistasite $>$ apatite $=$ titanite. As they are conformable with the amphibolites and are cut through by pegmatitic rocks, they are probably older than the trondhjemitic rocks of the Muruhatten region. The amphibolites are intrusive in the graywacke-like mica-schists N.E. of Gäddede. These mica-schist are rather rich in acid plagioclase, possibly originating from older plagioclase dominant igneous rocks.

From Muruhatten toward the northwest acid intrusives of the trondhjemitic type are met with in several localities, and rocks of the same character are common as intrusives in the youngest phyllitic rocks (silurian) further away, here often as porphyries with transitions toward granitic-textured rocks. Table 119 gives an abstract of the composition of some occurrences.

Table 119. Mineral composition of some acid igneous rocks intrusive in the silurian "köli"-rocks.

(W.N.W. to N. of the Muruhatten region.)
Weight percentage.

	a	b	c	d	e	f	g	h
Locality	Bratt-åsen, Blå-sjön	W. of Björk-vattnet	W.N.W. of Björk-vattnet	Close to the Norwegian boundary			S. of Björk-vattnet	Gaska-tjuolt, Ankar-vattnet
Type of rock	(Leuco-)trondhjemite			Oligoclase (albite-oligoclase) porphyry				
Plagioclase (An_{10}—An_{15}, average An_{12})	59.8	51.4	56.4	—	—	—	—	—
Plag. phenocrysts	—	—	—	10.7	6.1	11.5	15.0	14.3
Quartz	30.2	30.3	25.4	—	—	—	—	—
Quartz phenocrysts	—	—	—	10.2	16.0	11.1	9.2	16.3
Plag.-quartz matrix	—	—	—	70.0	68.4	69.6	33.0 plag. + 27.0 Q	51.2
Biotite	6.0	—	—	7.2	3.7	5.3	0.2	—
Chlorite (secondary to biotite)	1.5	13.2	4.8	—	—	—	8.5	—
Muscovite (sericitic)	1.2	—	—	1.0	2.6	—	5.2	9.0
Epidote	0.3	1.5	7.2	0.5	0.2	0.2	1.1	9.0
Calcite	—	—	2.9	—	2.4	—	—	—
Sulphides	0.7	3.5	3.3	—	—	2.3 (sulphides + ore minerals)	0.8 (sulphides + ore minerals)	—
Ore minerals (chiefly magnetite)	—	—	—	0.4	0.6			0.2
Garnet	0.3	—	—	—	—	—	—	—
Apatite	tr.	0.1	tr.	—	tr.	—	—	—
Zircon	tr.	—	—	—	tr.	—	—	—

The plagioclase of the rocks is generally a trifle more sodic than those of the Muruhatten region.[1] Some of the rocks are rather schistose, especially the porphyries, others have well preserved textures with hexagonal quartz crystals and idiomorphic feldspars. As seen by their position it is probable that they were intruded at the folding of the phyllite complex. As there are continuous series of small intrusives all the way from the Muruhatten area they must all be considered as contemporary.

That the potassic dominant intrusives only are found in the east must depend on the anticlinal uplift of this part of the mountain range whereby these rocks have been exposed by erosion.

[1] The dike rocks of the trondhjemitic type are often a trifle more sodic than the plutonic ones (The earlier [ordovician] extrusive rocks are still more sodic).

A short summary of the magmatic evolutions of the region may be given as follows: At an early epoch of the Caledonian basic and ultra-basic rocks were intruded in pelitic and psephitic sediments. There were probably also extrusive rocks. Some soda-dominant salic rocks were associated with the basic ones. By tectonic movements the rocks were metamorphosed resulting in a re-crystallization and a marked schistosity of the amphibolites and probably in a slight serpentinization of the peridotites. At a folding of the region a new suite of igneous rocks were intruded beginning with gabbroic rocks followed by trondhjemitic to leuco-trondhjemitic rocks, and in the culmination of the folding by potassic dominant rocks. At the last anticlinal uplift of the region the country rocks were strongly injected by potassic pegmatites mainly resulting in a feldspathization of the schists.

In the central part of the injected complex the rocks have chiefly had an addition of K_2O and Al_2O_3 with a marked decrease of the alumina deposition outwards. Some silica has been precipitated in the outer circle of the injected complex.

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