PETROGRAPHY OF THE
LEVANG PENINSULA
(KRAGERØ, NORWAY)

BY

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Abstract.

An area within the archean Bamble formation, southern Norway, has been mapped. A description of the rock types occuring in the area is given. The Levang oligoclase granite in the southern part of the mapped area is surrounded by banded gneisses, with quartzites and zones rich in sillimanite.

The gneiss has been reworked in the upper part of the migmatite zone. Its mineral facies is one of a lower temperature than the amphibolite facies, presumeably the epidote-amphibolite facies.

The whole complex has much in common with the Swedish leptite formation.

The more complicated geology of the northern part of the area has not been treated. The rocks of this part are only mentioned to give an idea of the geological surroundings of the Levang rocks.

Introduction.

The geology of the Kragerø region (fig. 1) has been studied since the 19th century. Among the first interested in the geology here were Kjerulf and Dahl, 1861, who studied the Valberg gabbro, and the granites and banded gneisses on the Levang peninsula, on a journey along the SW-coast. An englishman, Robert Forbes, 1857, also made a journey in these parts, and was specially interested in the quartzite-amphibolite-formation and the gabbro at the Valberg peninsula, The apatite deposits have been described by Sjögren, 1882, J. H. L. Vogt, Reusch, and Brøgger. More recently much work has been done on the complicated geology of the Kragerø region, but there are still many unsolved problems. In two great papers on hyperites, 1933 and also on nodular granites 1934, Brøgger has dealt with a part of this area. In his work on the pegmatites of Sørlandet. O. Andersen (1931) has treated some of the pegmatites of the area, mapped by Barth and Marstrander.

Holtedahl and Andersen (1922) have described dolomites here, and O. A. Broch has surveyed the area Kjøllebrønn—Kil—Blankenberg. He considered his map a preliminary sketch, and wanted the mapping to be done over again. The map proved, however, to be very good. My mapping in 1939 was done for The Geological Survey, dr. A. Bugge being the geologist in charge of the field work. Dr. Bugge had made a brief survey of the area in 1922, and one of the analyses was made from material collected by him. In the summer of 1939, Barth and A. Bugge went over parts of the area, and their conclusions have thrown light into many of the problems which seemed insoluble to a beginner. Without the help of professor Barth, I should never have been able to follow these things up.

Outline of Geology.

The Kragerø region forms a part of the Bamble formation and in many respects it shows great similarity to a more south-westernly part of the same formation, which has been recently thoroughly studied by J. Bugge. This is particularly the case for the southern part of The Kragerø region with its banded gneisses and granites, while the northern part has features that can not be paralleled with rocks examined by J. Bugge. It is the petrology of the Levang peninsuia that will be treated in this paper. The northern part of the Kragerø region is merely brought in to show the geological surroundings. A treatment of these parts with their numerous rocks and rock types would demand a more thorough mapping. The rocks of the Kragerø region are metamorphous, and their mode of origin has been much discussed, as has been that of the whole Bamble formation. This especially applies to quartzites, but also to the banded gneisses and the amphibolites in which cases the sedimentary vz. the eruptive mode of origin has been debated.

All over the region there is banded gneiss, and the other rocks form zones, lenses, or irregular bodies in this rock, which mainly consists of gneiss, amphibolite, and amphibolitic schist, in all states of chemical and mineralogical transition.

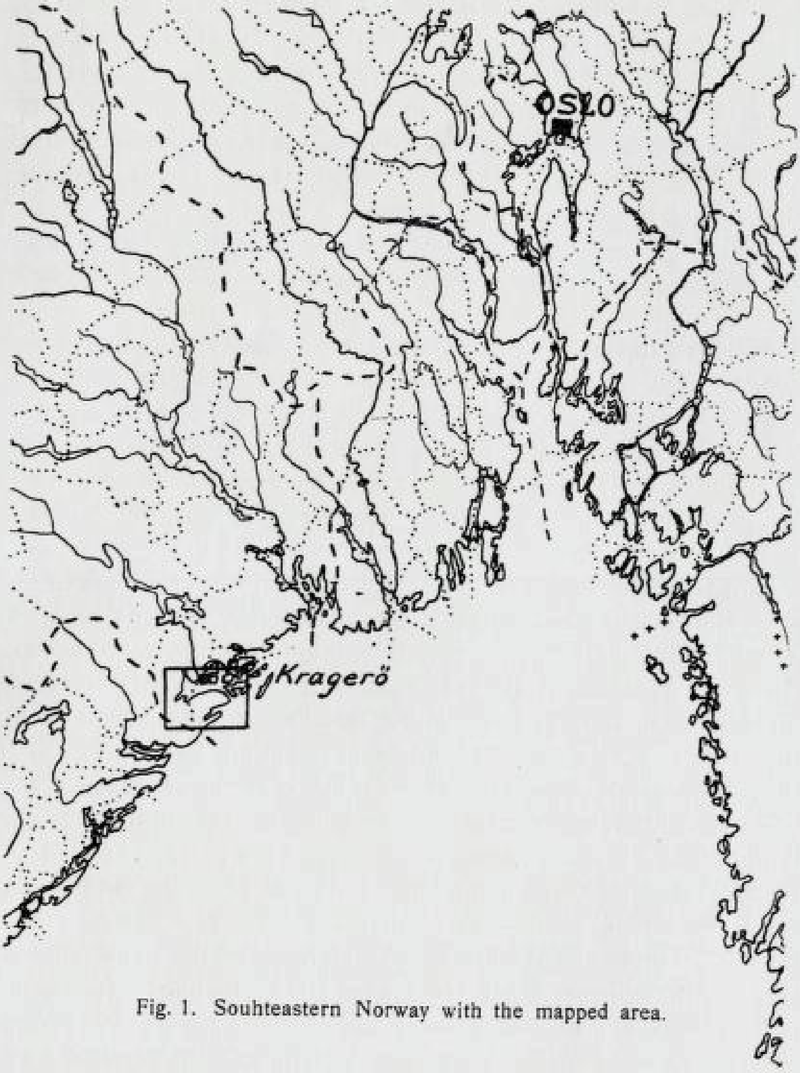

Fig. 1. Souhteastern Norway with the mapped area.

The gneiss has zones of granitic composition, bands of quartzite with or without sillimanite, fahl-bands, and bands rich in lime. The strike of the bands is NE—SW like the rest of the Bamble formation.

The large Levang-granite in the southern part of the area forms a longish lens in the strike direction. This lens consists of a pink granite of more or less marked gneissic structure. 15 km long and 4 km broad, evenly thinning out towards NE. Towards SW it has a long appendix bending back along the side of the granite. In the banded gneiss south and north of this granite there are several smaller granitic bodies of the same type. The banded gneiss north of the Levang granite has a somewhat different character from that to the south. As a rule it contains more mica. Further north it occurs only as single zones in the series of quartzites and amphibolites. These amphibolites partly have a gabbroid character, partly they pass through amphibolitic schists to amphibolitic mica schists. The quartzite is in parts rich in mica, and in some places it passes into granites. The area between Kilsfjorden and Valberg has a complicated geological structure: Amphibolites predominate. On Haugstranden and Valberg in the midst of great amphibolite-massifs occur hyperites that pass into amphibolites by gradation. Towards its selvage the amphibolite becomes schistose.

Between Kalstad and Valberg quartzite alternates with amphibolite, amphibolitic schist and amphibolitic mica schist. In banded gneiss at Blankenberg, extending towards Kragerø in the neighbouring amphibolite, lies the peculiar albitic rock, the Kragerite. In parts it contains rutil.

Between Kammerfoss and Sanssouci there are sheets of dolomite, following the strike direktion of the amphibolite, in some places several meters thick, or as little patches. Dolomite occurs also at Knipen, just north of the Levang granite, and at Risøy and Gumøy, east of the mapped area.

The southern part of Skaatøy consists of the usual banded gneiss, the northern part of gneiss richer in mica with zones of amphibolitic schist. The strike of the gneiss streamlines plastically along the sides of the Levang granite, straightening out towards east into the main strike direction of the Bamble formation. All over the area pegmatites abound. In the southern part of the area there are some diabase dikes.

The Levang granite.[1]

Mineral composition.

The Levang granite is a medium to coarse grained, pink, granite, consisting of quartz, microcline, microcline perthite, oligoclase, biotite, hornblende, and some clinozoisite, with apatite, zirkon, sphene, rutile, and iron ore as accessory minerals. In some places garnet. Molybdenite has been found as impregnation. Only biotite, hornblende, clinozoisite, and the accessory minerals show crystal outlines.

Quartz. Undulating extinction. The grains have irregular boundaries and fill spaces between other mineral grains. Quartz seems to be a late, probably the latest component crystallized. It has few inclusions. The granite is everywhere rich in quartz, though the quantity varies somewhat.

Microcline, showing chequered design, is fresh, and the grains have irregular shapes. Obviously it has crystallized later than the plagioclase which it often includes. Along the contact between the two minerals myrmekite may occur. The chequered microcline may or may not be perthitic. As a rube microcline dominatis over plagioclase, but in certain areas the proportion is reversed.

Plagioclase is an oligoclase, usually with composition ca. An_{20}, but it may vary between An_{17} and An_{30}, seldom An_{35}. The composition of the plagioclase was determined in sections, normal to α and normal to (001) and (010), and by maximal extinction, usually by two of the methods together. In some cases it was determined with the Federow stage.

A profile through the granite, taken along a road cutting across the eastern part of it, was studied to see whether the variation in the composition of the plagioclase had anything to do with the distance from the boundaries of the granite. No regularity was found. Most of the plagioclase was An_{20} through the whole profile. The plagioclase of the western part of the massif, however, seemed often to exhibit a more basic composition. In those sections plagioclase usually predominated, as at Eikeland (An_{33}) and Marijusteshei (An_{30}).

[1] See Plate I at the end of the paper.

But more frequently microcline predominates also in the western part, and the plagioclase has then a composition of An_{20}. Also in the eastern part there occurs granite rich in a more basic plagioclase. The differently composed parts of the granite cannot be separated on the map. The two types pass into each other, and in the field the whole Levang granite gives a homogenous impression. The plagioclase is seldom completely fresh. It is usually partly saussuritized. Untwinned plagioclase frequently occurs. Thus the granite is rather rich in oligoclase, which is usual for Archean granites e. g: Granite of the Orijärvi region (Eskola 1913), The Smedjebacken region, (Lundquist and Hjelmquist 1937), The Lina granite in the Gälli-vare ore region (Geijer 1930), and Canadian granites (Haliburton and Bancroft areas) (Adams and Barlow).

Biotite is the predominating dark mineral. It is rich in iron with pleochroism:

α — Yellow
β — Dark brown
γ — Dark brown

Mean index of refraction; $1,676 > \beta > 1,672$. It is usually fresh, but in some places it is a little chloritized. The orientation of the biotite which is easily seen macroscopically, is not so noticeable in thin sections, since comperatively little biotite is present.

Hornblende does not appear in all sections. The distribution is uneven. Some sections have numerous large grains, others have tiny flakes. The hornblende is quite fresh. It is dark, in many sections nearly opaque, and strongly pleochroic.

α — light yellowish green
β — dark grass green
γ — greenish blue black

The optical angle is small and varying but difficult to determine with the Fedorow stage, owing to the dark colour of the minimal. It is decidedly smaller than that of the usual hornblendes. Angles ranging from 20° to 60° have been measured in the mineral.

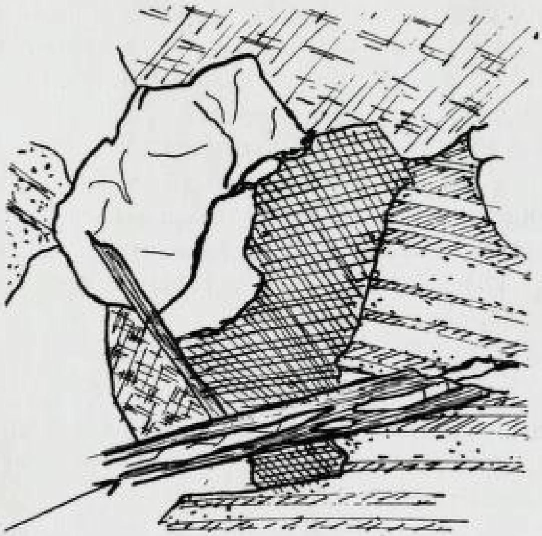

Fig. 2. Clinozoisite along the cleavage planes of biotite.

The indices of refraction β and γ are about equal.

$$1{,}719 < \beta, \gamma < 1{,}716 \text{ strong dispersion } \rho > \upsilon$$
$$1{,}690 < \alpha \gtreqless 1{,}695$$

The extinction angle varies, $c:\gamma = 9^\circ, 16^\circ, 20^\circ, 22^\circ$, and 27° were measured in different parts of the granite.

The optical data of this hornblende are similar to those given by Larsen and Berman for hastingsite. Epidote minerals occur in the granite. Clinozoisite is distributed throughout a great part of the granite, but is not found in all sections, Some epidote occurs.

Clinozoisite occurs mostly as greater or smaller grains or euhedral crystals in the rock. It also occurs as intergrowth with biotite, where it seems to grow along the cleavage planes. In this way sometimes a stronger-coloured mineral of similar optical properties also occurs, that seems to be epidote. It is not possible to determine it with certainty in those narrow stripes (fig. 2).

Some crystals are metamict, especially in the centre. This is due to a Ce-content that is not great enough to give pure orthite. The crystals are in these cases yellowish, nearly colourless, and should thus be clinozoisitic. It may also be epidote, bleached by the influence of Ce. Both cerepidote and clinozoisite with a core of orthite are found in similar rocks (Orijärvi). Biotite and hornblende are often gathered in small dark patches, and clinozoisite and cerepidote often occur together with them. The clinozoisite, which is biaxial positive, has variable extinction. Refractive index:

$$1{,}727 > \gamma > 1{,}722, \text{ strong dispersion } \rho < \upsilon.$$

It occurs also outside the granite in the gneiss and in hydrothermal veins, partly in large crystals, On one of these the density was determined: 3,37.

When epidote minerals occur in near connection with biotite, it is possible that they are metamorphic after hornblende. The epidote minerals also occur as parts of saussurite.

Garnet occurs in certain parts of the granite, sometimes in large crystals. It is almandine, refraction:

$$1{,}782 < n < 1{,}801.$$

The accessory minerals are evenly distributed. Around the euhedral zirkons situated in biotite the pleochroic haloes are conspicuous.

Sphene is not found in all sections. In some it forms large crystals, in others it lies around iron ore, as leucoxene. It may then be supposed that the ore mineral is ilmenite, while in other cases it may be magnetite. In some sections hematite occurs in thin, red, translucent flakes.

Rutile is common, and was found in many sections.

The chemical composition. Facies.

For chemical analysis a sample was taken of a normal rock in the middle of the granite. Analyst B. Bruun

SiO_2	68.43
TiO_2	0.55
Al_2O_3	15.03
Fe_2O_3	0.80
FeO	3.80
MnO	0.01
MgO	0.72
CaO	2.90
Na_2O	3.70
K_2O	3.28
H_2O +	0.63
P_2O_5	0.10
F	traces
Cl	0.10
	100.08

Norm:

Q	24.48	
Or	19.54	
Ab	31.56	
An	13.95	
C	0.20	
	sal	89.73
En	1.80	
Fs	5.42	
Ap	0.30	
Il	1.16	
Mt	1.16	
	fem	9.84
H_2O		0.63
		100.20

Niggli:

si	302
al	39
fm	22
c	14
alk	25
k	0.35
mg	0.22
qz	101

The ACF-values of Eskola are: A=33, C=27 F=40. If the values are plotted in an ACF-diagram of the amphibolite facies (K_2O-surplus) they fall within the area where plagioclase and biotite, if there is enough water, should be the stable minerals (fig. 3). Almandine also is stable here.

But now epidote-minerals, and some chlorite occur. The plagioclase is usually a little saussuritized. This sugests that the granite was formed at a somewhat lower temperature than that of the amphibolite facies, and approaches epidote-amphibolite-facies. In a subfacies of the latter the usual green hornblende is replaced by a strongly bluish green hornblende (Eskola 1939 mentions barroisite), clinozoisite, and chlorite.

Bluish green hornblende and clinozoisite, and a little chlorite occur in the Levang granite besides biotite, but neither the actinolite-greenstone-facies of Th. Vogt or the prasinite facies of Angel suits the requirements (Eskola 1939). Barth (1929) mentions that the mineral facies of the Archean rocks of South Norway resemble the epidote-amphibolite facies of Becke, i. e. the temperature is lower than in Eskolas amphibolet facies.

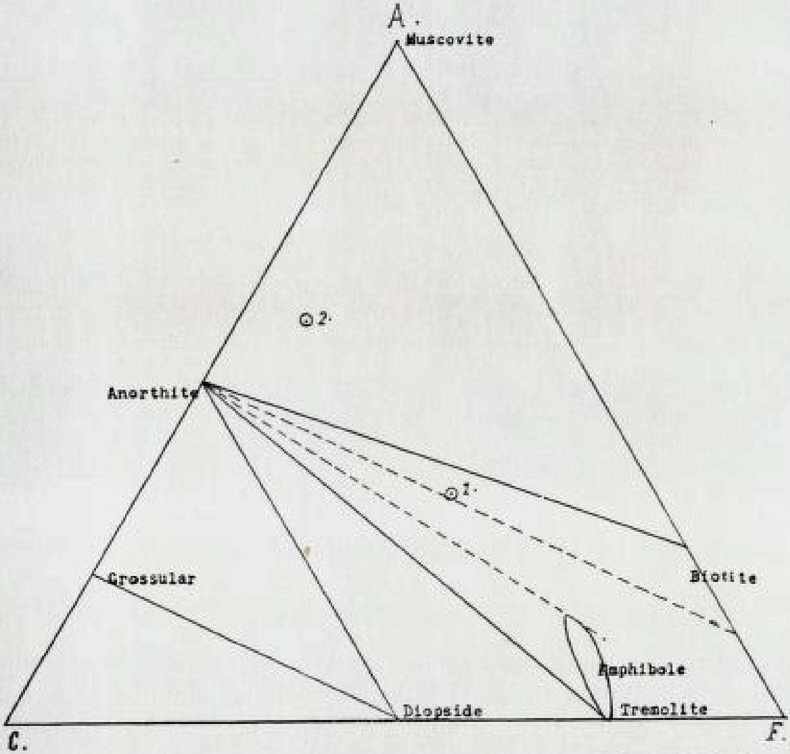

Fig. 3. ACF-diagram for amphibolite-facies. 1. Levang granite. 2. Gneiss.

Foliation and fissures.

The Levang granite is foliated along the whole area a little weaker in the centre, but there are also a few small, unfoliated, coarse-grained parts. The rock must be called a gneiss granite. It is here called granite for short.

The structure is clearly seen on the map, on the surface of the rock in the field, in hand specimens, and in thin sections Quartz and microcline are somewhat stretched in the direction of the structure, but it is the arrangement of the dark minerals in planes, especially the biotite, that makes the structure so conspicuous. Along these planes the rock cleaves most easily. The direction of the planes is always more or less vertical with dips towards the north. The surface of the rock consequently shows a striation whose direction varies a little in the different parts of the granite.

Foliation must have been generated during, possibly after, the original crystallisation of the granite, as a result of regional metamorphism and recrystallization. This vertical foliation suggests an upward movement of the granite. There are other tectonically determined cleavage directions in the granite. The most dominating goes vertically in direction north-south. Another common cleavage is horizontal. Balk (1937) mentions that if an eruptive body has a flat roof, the pressure of the overlying rock, different from the pressure farther down in the batholite, may cause this to split up horizontally, and that differences in temperature during the consolidation also may give such results. These three cleavage directions were found everywhere. There are also other directions. But as they are many and varying, it is difficult to coordinate the cleavage directions that belong together from place to place. No further comments will be offered regarding the directions of the forces that have been at work. The foliation of the granite is always conformable to the boundaries towards the neighbouring rock.

Boundaries of the granite.

The boundary, which is sharp, runs straightly and evenly around the long, lense-formed body. It marks a visible change in the landscape because of the different resistance towards erosion offered by the granite and by the surrounding rocks. The granite does not send out apophyses into the neighbouring rock, and in a few places only the clear boundary is disturbed by greater pegmatitic dikes, which frequently include fragments of amphibolite from the adjacent rock. The boundary is conformable to the direction of the banded gneiss.

The NE end of the lense extends into the sea. It is possible that the granite at the islands of Rauane is a narrow continuation of it, but it seems more probable that it is a small independent granitic body like several others around the greater Levang granite. In the SW part the boundary has a more complicated course. The queer shape of the curved western termination

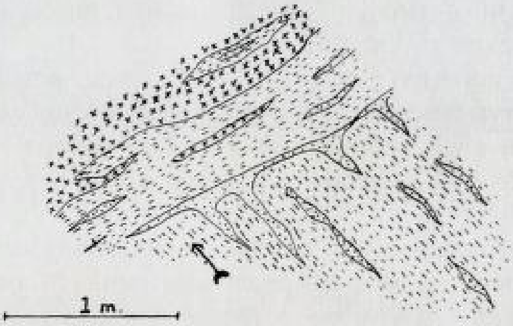

Fig. 4. Boundary between granite and gneiss, in the apex of the angle between the main granite body and the appendix in the southwestern part of the granite area. Here, too, the foliation of the granite follows the boundaries. The gneiss, beeing strongly folded with the folding axes dipping under the granite, is dissected by small pegmatite veins at the boundary. Only in a narrow zone along the boundary itself the schistosity of the gneiss is conformable to it, as a result of the contact. Here, the granite sends small apophyses along the schistosity planes, and partly includes gneiss, whose schistosity is them conformable to the foliation of the granite.

must be tectonically explained. The arched structure that stands out in the topography west of the Levang granite, has its center in the western end of the granite. The arc conforms to the strike thus making the boundaries of the granite parallel to the strike.

The part of the adjacent rock lying between the appendix and the lense itself, has its schistosity comformable to the boundaries of the granite on both sides. It bends along the appendix. But in the apex of the angle it is different. See fig. 4. There is a similar case east of the farm Leivatn, where the granite also cuts the strike of the surrounding rock the same way. About 200 m east of the boundary the granite lacks foliation. Thus, changes that may have taken place in the direction of the strike in the granite can not be traced directly. At a locality north of Finsbudalen, where the granite penetrates into the gneiss, the amphibolite changes its strike, and the irregular small folds along the boundary are cut by pegmatite. These three localities are the only ones where the boundary of the Levang granite cuts the main strike direction of the gneiss.

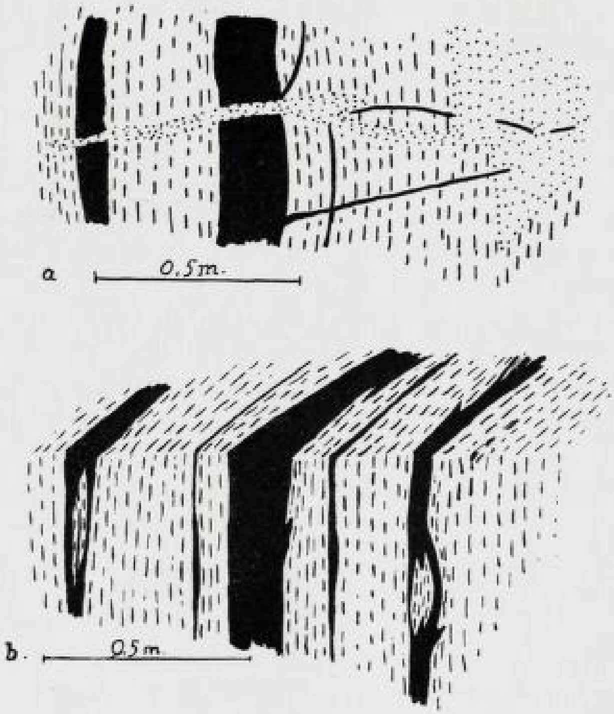

Fig. 5, a and b. Schlieren (black) of amphibolite in the Levang granite, near the boundary at Viborgtjern. Dotted: Pegmatite.

Inclusions.

The boundaries of the granite are sharp. On can put one's finger on the spot where the granite begins. In some cases the marginal rock may be a little more grey than normally or more finely grained, but in thin sections no great difference can be seen.

Near the boundary schlieren of amphibolite are frequently (fig. 5) encountered. They vary from a few cm to several dm in width. They represent parts of the neighbouring rock, which they often closely resemble. It is more difficult to explain some narrow stripes — 1—0.5 cm wide — of amphibolite, that in some places cross the foliation direction. The schlieren are often cut by small pegmatite veins. In some places pegmatitic bodies accompany the edge of the dark schlieren. They occur in the outer parts of the granite. Farther towards the centre inclusions of another type occur. These are pieces of amphibolitic schist and amphibolitic micaschist that can be 2—3 km long and several hundred meters wide, but most of them are smaller, ca. 0.5 km long and 50—100 m wide. The schistosity is parallell to the foliation of the granite. The inclusions usually lie in the direction NE—SW, but exceptions exist, for instance at Eidsvann.

The apexes of the longish inclusions often pass by gradation into granite. The granite then sends apophyses into the inclusions, and small fragments of granite rich in amphibole and mica make a transition between the two rocks. In some places there are great feldspar bodies at the end of the inclusion (for instance at Løvdalen, where feldspar is quarried). Along the schistosity planes the boundary is usually sharp.

In one amphibolitic mica schist inclusion a fold is preserved. The axis of folding dips a little towards SW. Elsewhere the schistosity planes are vertical. The great inclusions have everywhere about the same petrographical character. The smaller fragments, especially in the pegmatite, often consist of more massive amphibolite. (Fig. 6).

Besides these inclusions there are parts in the granite rich in small dark patches, representing partly assimilated inclusions. The granite groundmass between the patches often has a colour somewhat different from the normal granite, usually more grey. At one locality (at the road just south of the Løvdalen school) these patches are small grains of about ½ cm's diameter. They consists of amphibole, biotite, ore minerals and garnet, and around each grain there is a light rim. It looks like an advanced assimilation of an inclusion. Lighter parts in the granite, containing garnet, are also due to inclusions, almost completely assimilated. They look like hazy patches, and the phenomenon resembles the "ghostly remains" referred to by Swedish petrologists.

The effect of a granite magma on the inclusions (Bowen 1928) is a reactive solution and a reactive precipitation. In-

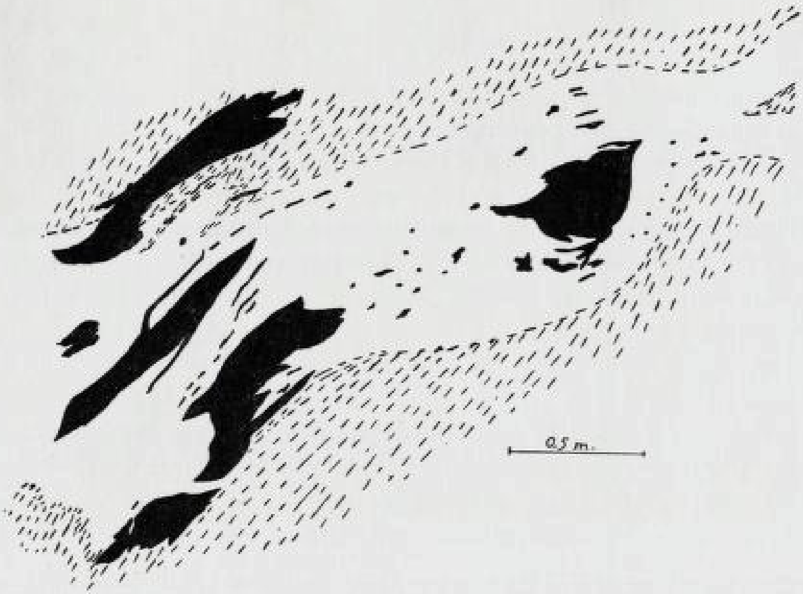

Fig. 6. Amphibolite inclusions (black) in the central part of the Levang granite (striped). White: Pegmatite.

clusions of acid composition are assimilated, and only a few constituents will remain unsolved, for instance an Al-surplus, going into garnets. Basic inclusions, amphibolites for instance, will not be assimilated, but will react more or less completely with the magma and form the minerals which are in equilibrium with the magma at the given moment.

The inclusions of the adjacent rock that will be preserved are the dark ones, and their petrographic homogeneity may be due partly to their reaction with the magma. They mainly consist of hastingsite-like hornblende, common biotite, ore minerals, plagioclase, and quartz. The inclusions are specifically heavier than granite, and may constitute downfallen fragments of a batholith roof, which later took part in the movements of the granite.

The smaller granitic bodies.

In the gneiss around the Levang granite lie some small granite bodies, supposedly congenetic with the Levang granite.

They are the Mørjeheia granite just north of it, the Umdalen granite, Øysang granite, and Portørgranite south of it. Farther north lies the Tømmeraas granite which perhaps should rather be seen in relation to a granite north of the mapped area. The Marijustesheia granite shows no direct contact with the Levang granite, but still it is most certainly a part of it. The Mørjeheia granite is a red, medium-grained microcline granite, whose mineral composition is much the same as that of the Levang granite. The rock is hypodiomorphous and has a foliation conforming to the strike of the side rock. In the centre the granite is not foliated. The red colour of the rock is due to feldspar, which has a stronger colour here than in the Levang granite

South of the Levang granite lie the Øysang, Umdalen, and Portør granites with about the same composition. They are microcline granites rich in quartz and poor in mica. The plagioclase is difficult to determine as the small and few grains usually are changed into saussurite or sericite, but it seems to be an oligoclase.

The Marijusteshei granite is mentioned under the Levang granite. It is a granite rich in plagioclase with An_{27}—An_{29}.

Foliation is also conspicuous in these granites, conformable to the boundary and the strike of the surrounding rock. The Øysang granite is less foliated than the others.

Apart from the Portør granite, which has som dark patches along the border, I have not found inclusions in these granites. The absence of hornblende may have a connection with this. The great similarity between these granites suggests a common origin.

The Tømmeraas granite has quartz, microcline, plagioclase (An_{30}), biotite, and muscovite but no hornblende. The biotite has partly been changed into chlorite. It looks as if this has happened while the biotite crystallized, since the green and brown parts follow planes of growth of the crystal. It farther contains clinozoisite, zirkon, apatite, and iron ore. The granite has sharp boundaries, and foliation parallel to them.

Fig. 7. Banded gneiss, Levang peninsula.

The Gneiss.[1]

The Gneiss on the Levang peninsula is a banded gneiss. It consists of alternating dark and light bands. In the southern part of the peninsula it is of constant type, but nearer the Levang granite its character changes. North of the granite there is banded gneiss along the northern shore of the peninsula at Taatøy, Brattøy, Djupsundholm, at Blankenberg and some places as part of the quartzite-amphibolite formation.

The normal banded gneiss

consists of medium grained gneisses, amphibolites, amphibolite schists with some mica, and all transitions between them interwoven with pegmatitic material. The thickness of the bands range from a few cm to several meters (fig. 7). The light bands consists mainly of quartz, plagioclase, (oligoclase or andesine composition) and varying quantities of hornblende, often biotite, and more seldom muscovite. Accesory components are apatite, zirkon, sphene and iron ore. Tourmaline is found

[1] See Plate II at the end of the paper.

in some places. Mineralogically the difference between light and dark bands lies in the different quantity of hornblende and biotite and of light minerals. The boundary between light and dark bands is sharp.

The parallel structure of the gneiss is conspicuously exhibited macroscopically as well as in thin sections. It is parallel to the boundary towards the granite. The structural elements of the gneiss are vertical or have a steep dip towards north, more seldom towards south. Folds in the gneiss occur on the Levang peninsula and at Blankenberg. The strike of the banded gneiss swings around the smaller inclusions of granitic bodies. In a zone from Levang over Bjørkekjærr to Leivann, granitic bands are constituent parts of the gneiss. This zone posibly represents an area of more intense granitization.

The bands possibly represent effusives, tuffs and other deposits, and later intruded basic rocks, corresponding to conditions in the Swedish leptite formation. This banded gneiss differs from the Swedish leptite formation in having very little limestone. Limestone is found however in the more southern part of the Bamble formation, the Arendal area, where J. Bugge (1939) has compared it with the limestone of the leptite formation.

The Swedish leptites are frequently ore bearing, but on the Levang peninsula no ore is encountered. A narrow band containing pyrite, 5—6 m long, in the direction of the bands is all, apart from a fahl-band near the granite, some 200 m long and 1—5 dm wide, in the strike direction.

The pegmatites

occur mostly as dikes along the bands, and also as pygmatic veins in the gneiss. Irregular bodies, partly of considerable size, are also encountered. Pegmatitic material also occurs in numerous small patches everywhere in the gneiss without visible supply channels. The quantity of pegmatite is evenly distributed over a great area and does not increase noticeably near the granite. Some of these pegmatites originated during the migmatization at comparatively low temperature from the pore solution of the gneiss.

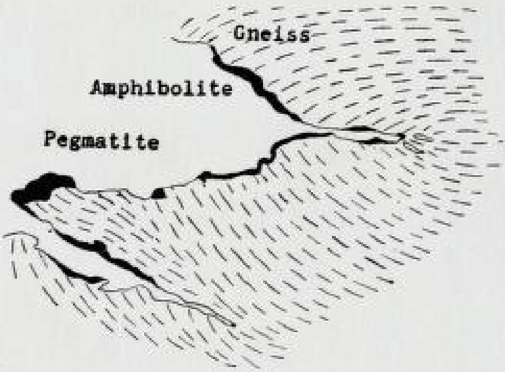

Fig. 8. "Surreitic structure", indicating a lateral secretion of the granitic components from the gneiss, and gathering of the pegmatitic material in veins and patches.

By a molecular interchange the granitic components could migrate in the gneiss and gather in pegmatitic veins and patches. In this way a small part only of the pegmatite was formed for the gneiss does not seem to have been so deep in the zone of migmatization. More pegmatitic material was supplied from the underlying gneisses, whence the ichor slowly rose.

Various structural patterns indicate that a "lateral secretion" has taken place from the adjacent rocks. By molecular interchange the pegmatitic material was removed from the rocks and the dark minerals were arranged in directions resembling power-lines around a magnetic field. "Surreitic structure" Holmquist (1920). Fig. 8.

The greatest pegmatitic bodies probably represent residual solutions squeezed out from the underlying granitic magma of which the Levang granite is a part, and which originated as a migma. It did not necessarily constitute one single magma. There may have been several sources from which the granitic material gathered together. Pegmatites of this type are treated by O. Andersen in his work on feldspar (1931). On the Levang peninsula these pegmatites seem to consist of microcline perthite and quartz. Graphic structure is usual. Biotite occurs in most of them and reduces the economic value.

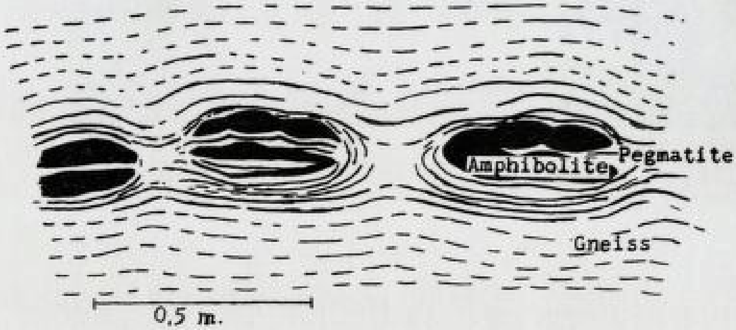

Fig. 9. Boudinage in banded gneiss.

Boudinage

is a common stucture in the gneiss. The amphibolites have been less elastic, so that during stretching they have cracked into framgents, while the light bands have expanded and shaped themselves plastically around the fragments. Between the dark fragments pegmatitic material has leaked in, and also sent apophyses along the sides of the lense like fragments, a usual phenomenon in areas where the pegmatitic material has been mobile (Wegmann 1932). (Fig. 9.)

The zone of gneiss around the granite.

In a zone of varying width 300—400 m surrounding the granite, the gneiss is somewhat darker, a little richer in mica and in parts more coarse-grained. Concentric zones of other types of rock are also met with. Outwards from the granite, the arrangement of the several surrounding rock zones is similar over great parts but the order is not quite the same north of and south of the granite. Three profiles have been surveyed from the boundary of the granite and outwards. One profile was taken at Finsbudalen, one at Langvarp, and one at Stabbestad.

I followed the individual zones through the profile and found that they generally kept their distance from the boundary rather constant. Nearest to the boundary there is usually amphibolite or amphibolitic schist with some mica and little

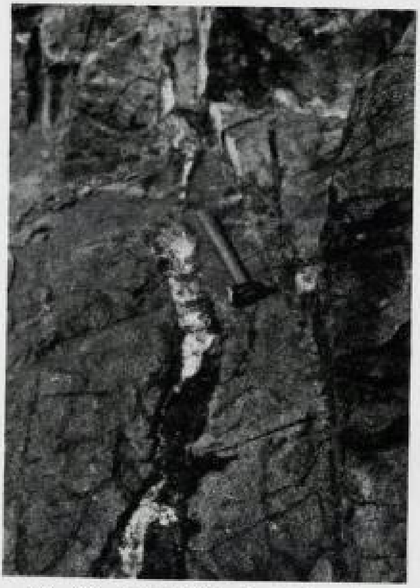

Fig. 10. Amphibolized calcite vein, south of Vafoss.

quartz and plagioclase. Next to it come lighter rocks with varying amounts of hornblende and mica causing lighter and darker bands. In a distance of 100 to 200 m from the granite there is on the north side two bands of quartzite. South of the granite quartzite does not occur in this regular way. It appears here in a narrow stripe from the outer part of Stølestranda, to Fiane, and in an oblong body at Hønnebø. In connection with quartzite there is on the north side stripes of granitic composition that often pass into quartzite. In the south there are also granitic stripes at a certain distance from the main granite, and at Fiane they can be seen to pass into quartzite. Beyond these stripes there is on the northern side a zone of amphibolite, and biotite schists with greater or smaller porphyroblasts of garnet. On the southern side garnet porphyroblast rocks occur inside the granite-quartzite zones, distributed over a greater width and also quite close to the boundary.

The most remarkable of these rocks is the sillimanite gneiss that accompanies the boundaries of the Levang granite on all sides. It is sillimanite-bearing quartzite and granite, the peculiarly eroded surface of which can easily be followed in the field.

Calcite occuring north of the Levang deserves mentioning, allthough its mode of origin is very different from the above mentioned calcite. At the railway line, about 2 km south of the Vafoss railway station calcite veins are clearly seen to have been metasomatically altered into amphibolite. Only in the central parts of the vein calcite is preserved. Narrow veins are completely amphibolitized. Fig. 10. Limestone is found at

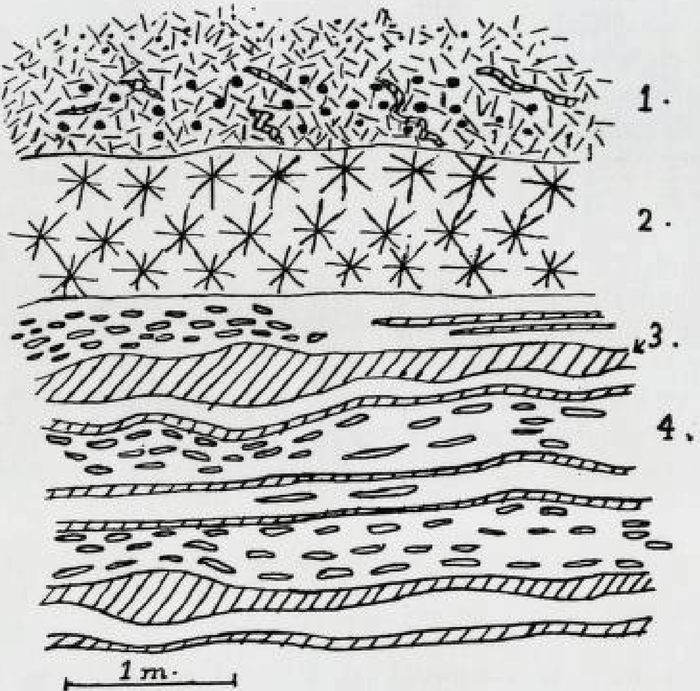

Fig. 11. Anthophyllite- and sillimanite-bearing gneiss on the southern shore of Tåtøy. 1. Amphibolite with garnet porphyroblasts and pegmatite veins. 2. Anthophyllite crystals. 3. Pegmatite. 4. Gneiss with sillimanite nodules.

Stabbestad in a small patch in the sillimanite gneiss. South of the granite another small patch of pure limestone occurs about 1 m long and 0.5 wide. At two places the granitic gneiss itself contains crystals of calcite possibly of primary origin.

Near the boundary there occurs at several places both north and south of the granite, anthophyllite in great crystal masses partly changed into biotite, together with quartz, and in one place cordierite. The anthophyllite rock is also found on Skaatøy, Taatøy and Knipen. Fig. 11.

The part of the gneiss enclosed in the western part of the granite is very homogeneous. It is a delicately folded amphibolite mica schist with slightly varying quantities of light minerals. The rock is quite like the inclusions in the granite and is possibly influenced by the granite ichor in the same way as these.

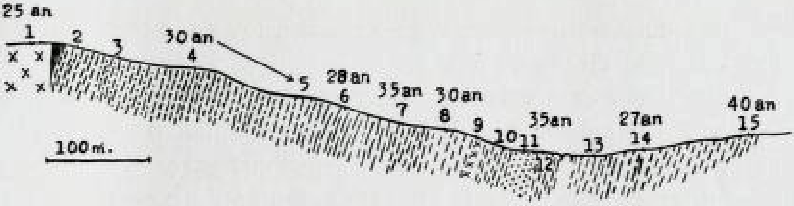

Fig. 12. Profile, Finsbudalen.

Profiles throug the gneiss.

Finsbudalen. Fig. 12.

1. Granite, here comparatively rich in plagioclase An_{25} with hastingsitic hornblende. Black: a pegmatite dike.
2. Medium-grained amphibolite gneiss. The predominant component is common hornblende, in parallel orientation. It grows in well formed crystals in a more fine-grained groundmass of quartz and saussuritized plagioclase. Some biotite in greater crystals (pleochroism: α — yellow, β — brown, γ — brown).
3. Amphibolite with great garnet-porphyroblasts with inclusions of quartz and magnetite. The usual accessory minerals, zirkon, apatite, and iron ores are found throughout the whole profile.
4. Lighter amphibolite-rich gneiss. Crystals of common hornblende (pleochroism α — yellow, β — grey-green, γ — brownish-green; extinction angle $c/\gamma = 13°$) are sub-parallely oriented, as in the rest of the profile, in a ground mass richer in quartz and saussuritized plagioclase. There is some diopside and a little chlorite. In conneetion with the iron ore, some leucoxen.
5. Amphibolite gneiss. Common hornblende, optical angle $2V = 70° - 80°$, pleochrosism α = yellowish-green, β — green, γ — brownish-green, extinction angle $c/\gamma = 11°$, forms large crystals, partly porphyroblasts. The ground mass is quartz, plagioclase (An_{80}), strongly saussuritized. Some grains of chlorite, and biotite (pleochroism α = yellow, β — greenish brown, γ — greenish brown) a little calcite.
6. Light, gneiss rich in mica with predominant plagioclase (An_{28}), a little saussuritized quartz, rather much biotite

(pleochroism α — yellow, β — reddish brown, a little muscovite, and chlorite.

7. Next follows a relatively finely grained amphibolite schist, with hastingsitic hornblende. It has a small optical angle, (pleochroism α — light green, β — greyish green, γ — brownish green), some parts of it are colourless. Extinction angle c/γ — 24°. Refraction $1.669 < \beta, \gamma < 1.673$, $1.660 > \alpha > 1,654$. Larsen gives $\beta = 1.670$, $\alpha = 1.654$, $c/\beta = 32°$. The quartz has undulating extinction and the plagioclase is fresh (An_{85}).
8. Light, quartz-rich gneiss with plagioclase (An_{80}), common hornblende, faintly pleochroic, grey-green, extinction $c/\gamma = 9—10°$, a little less biotite, partly cloritized.
9. Red granite with sillimanite nodules, ca. 350 m from the boundary. It forms a band of 10—20 m without sharp boundaries. It has quartz and microcline, little plagioclase, myrmekitic structure. Partly cloritized biotite (pleochroism α — colourless, β — brown, γ — brown). In the groundmass between the nodules no sillimanite needles.
10. Amphibolite- micaschist with hastingsitic hornblende (pleochroism γ — yellowish green, β — bluish green, γ — dark green, optical angle small, extinction angle $c/\gamma = 19°$). Little and strongly sericitized quartz and plagioclase. The biotite is partly chloritized. There is epidote growing along the cleavages of some of it.
11. Grey quartzite with sillimanite needles. The quartz has not undulating extinction. A little biotite (pleochroism α — colourless, β — bluish green, γ — green). There is also muscovite.
12. Amphibolite gneiss, with large crystals of common hornblende, (pleochroism α — yellow, β — grass-green, γ — bluish, bluish green, extinction c/γ — 20°) in a groundmass of small quartz and plagioclase (An_{85}). Little biotite, (pleochroism α — yellow, β — yellowish brown, γ — yellowish brown). There are some small crystals of rutile. In this rock there is a small area of a strange rock that possibly represents former limestone. It consists mainly of epidote and garnet, with some quartz and saussuritized

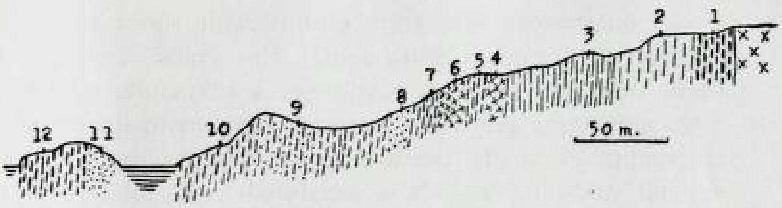

Fig. 13. Profile, Langvarp.

plagioclase, a little calcite, muscovite, sphene, and the usual accessory constituents.

13. Light gneiss with a little sillimanite. After this, light and dark bands alternate. In thin section no important changes can be noticed. But in the field it can be seen that one has now passed into the normal banded gneiss. The plagioclase changes rapidly and irregularly from band to band.

Langvarp. Fig. 13.

1. Massive amphibolite gneiss. Common hornblende occurs in fresh crystals, and so does sphene, which is rather abundant. The groundmass of light minerals is thoroughly saussuritized and sericitized.
2. Rather homogenous ligh gneiss about 40—50 m across. It is rich in comparatively fresh quartz and plagioclase, and has common hornblende and dark biotite with parallel orientation. A little sillimanite sparingly occurs. Apatite and zirkon.
3. A more biotite-rich gneiss with little hornblende, where the quartz and the plagioclase is more saussuritized. Apatite and zirkon.
4. A red, finely grained granite. It has quartz, microcline, and microcline perthite, little and strongly sericitized plagioclase, myrmekitic structure. The biotite has pleochroism α — yellow, β — greenish brown, γ — brown. There is a little muscovite and chlorite. Apatite and zirkon.
5. A narrow band of quartz-rich gneiss with partly chloritized biotite separates this from
6. a granite that partly has sillimanite nodules, but otherwise is normal, with biotite a little chloritized. This passes

into a quartz-rich sillimanite granite with some rutile in addition to the other constituents. This granite can be said to be transitional to the next zone: a sillimanite quartzite

8. The sillimanite quartzite carries in addition to quartz and sillimanite in single needles or in bundles only a little sericite and chlorite. It is separated from zone 7 by a narrow septum of a light quartz-plagioclase-gneiss with biotite.
9. Coarsely grained amphibolitic gneiss with some biotite quartz and plagioclase. Some of it has amphibolite porphyroblasts, some garnet porphyroblasts.
10. Gneiss rich in white mica,
11. Sillimanite quartzite, and at the end of the profile an
12. amphibolite of the same type as that from the outer parts of the Knipen amphibolite opposite it (plagiolase and hornblende).

The plagioclase varies much also in this profile. It ranges between An_{25} and An_{40}, The hornblende is always a common hornblende.

The same types are found in the direction of Stabbestad.

Stabbestad.

Nearest to the granite there is a dark, massive amphibolite. The plagioclase has an exceptional composition An_{55}. There is no quartz. The hornblende is hastingsitic, and there is some diopside, Extinction $c/\gamma = 37°$.

On the outside of this unusual rock there is a light gneiss with quartz, plagioclase, common hornblende and some biotite. It is followed by a still lighter, rather coarsely grained gneiss. Its quartz has not undulating extinction. Plagioclase, biotite and common hornblende are the other constituents.

Next comes gneiss richer in common hornblende. The plagioclase is An_{38}.

In some places biotite has epidote along the cleavages. About 100 m from the main granite comes a broad band of granite with sillimanite nodules. It has quartz, microcline, biotite and zirkon. It is red, medium grained and hypidiomorphous.

Next is a quartzite band that at some places has sillimanite nodules. The quartzite is coarsely grained with small grains of sericitized plagioclase.

In a light gneiss on the outside of the quartzite a small occurence of crystalline limestone with a rim of skarn is encountered. It carries diopside partly changed into hornblende and chlorite and cordierite.

A band of quartzite follows, before an amphibolite-rich gneiss begins.

Still further out there is a broad zone of amphibolite-biotite schist with large garnet porphyroblasts. The schistosity bends around the garnets, and the last mobile part of the rock, the quartz, has filled out on the sides in the direction of schistosity. The refractive index of the garnet is $1.782 < n < 1.801$. The refractive index β of the biotite is $1.645 < \beta < 1.650$.

The refractive indices of the hornblende are $1.680 < \beta$, $\gamma < 1.686$ and $1.660 < \alpha < 1.665$.

Mineral facies of the gneiss.

An analysis was made by me of a sample of light granite-like band at Levang school.

			Norm:		
SiO_2	76.76	Q	46.31		
TiO_2	0.15	Or	14.57		
Al_2O_3	12.89	Ab	25.25		
Fe_2O_3	1.28	An	8.08		
FeO	0.77	C	2.35		
MnO	traces				
MgO	0.05			sal	96.56
CaO	1.62				
Na_2O	3.00	en	0.10		
K_2O	2.40	fs	0.26		
H_2O+	0.74	il	0.22		
$H_2O\div$	0.13	mt	1.86		
P_2O_5	0.01			fem	2.44
CO_2	0.57	H_2O			0.87
	100.37	CO_2			0.57
					100.44

Niggli:

si	495.00
al	49.00
fm	11.00
c	11.00
alk	29.00
k	0.35
mg	0.04
si	212.00
qz	285.00

The mineral composition is quartz, plagioclase of composition An_{28}, orthoclase, and a little microcline, a little biotite, chlorite, and muscovite, and some grains of calcite and clinozoisite. Accessory minerals are apatite, zirkon, and iron ore. In an ACF-diagram of the amphibolite facies it falls within the field of plagioclase, muscovite, and biotite, the ACF-values beeing: A-59, C-33, F-8. The presence of clinozoisite and chlorite indicates that the rock is Hable in a facies representing a somewhat lower temperature, like the Levang granite (fig. 3).

Metasomatosis.

In the neighbourhood of the granite some metasomatic contribution of material has taken place. The more volatile components as a rule have passed on, and are no more found in the rock. The fact that more biotite occurs around the granite than elsewhere in the banded gneiss, would seem to indicate that the gneiss ordinarily contained little water, but that the granite added enough to it for the crystallization of biotite. It seems also reasonable that there has been added some K? and Si. The formation of anthophyllite can be explained through a metasomatic exchange of alkalies for Ca and Mg (Orijärvi Eskola 1913). Bowen mentions (1928) that a Mg surplus hardly can be explained as metasomatically added by volatiles from a magma, since Mg is but little volatile. Eskola (1913) agrees in considering Mg as not originating from the magma, but suggests a derivation from Mg-rich rocks, where Mg has been carried away by volatiles, and redeposited. Adams and Barlow consider anthophyllite as limestone changed by addition of granitic emanations. Brøgger (1933) mentions anthophyllite and gedrite which occur in garben schist at Skaatøy. He considers this rock as an amphibolite that has lost CaO and alkalies through the influence of the oligoclase granite, and thus has become enriched in Mg. Gedrite occurs in large crystals at Knipen and Hansjøhei.

The amphibolite gabbro at Knipen is partly metosomatically altered to scapolite — hornblendestone. The refractive indices of scapolite:

$1.575 < \gamma < 1.581$, $1.555 < \alpha < 1.558$ give the composition Ma_{38} Me_{62}

Thus there has been an addition of Na and Cl presumably from the granite.

The sillimanite gneiss.

Some of the most remarkable features in the geology of this area are the sillimanite-bearing quartzites and granites along the boundaries of the Levang granite, on the islands in Kilsfjord, and farther east, at Borøy and Skaatøy. The rocks have been throughly studied by Brøgger (1934) and are also known from other areas: The Arendal region (J. Bugge) at Snarum (J. Schetelig, according to Brøgger, 1933), and in Holleia (the writer).

Brøgger has published the following analyses of granites with sillimanite nodules from Fiskerodden Bærø (1934):

	Analyst dr. Heidenreich average of the rock	Groundmass	Sillimanite nodule
SiO_2	77.75	77.39	79.25
TiO_2	traces	traces	—
AL_2O_3	11.83	11.29	14.79
Fe_2O_3	1.68	1.33	2.74
FeO	0.39	0.39	0.48
MnO	traces	traces	traces
MgO	1.03	0.97	0.07
CaO	0.56	0.59	0.09
Na_2O	0.96	1.61	0.17
K_2O	5.41	6.61	1.86
H_2O	0.69	0.63	0.89
P_2O_5	0.03	0.03	0.07

He describes the granite as a fine grained, fresh rock. The groundmass consists of about equal amounts of quartz and microcline with less oligoclase, biotite and a little muscovite occur, accesories: apatite, magnetite and zirkon, sometimes tourmaline.

The sillimanite nodules have a core of fine grained quartz with sillimanite needles swimming about, often packed together to a felt-like mass. Muscovite also occurs sometimes in small quantities. Muscovite and sillimanite show a weak and imperfect schistose orientation. Tourmaline, magnetite, apatite and zirkon occur in small amounts. Around the core there is a rim mainly consisting of muscovite, less quartz and no sillimanite. The muscovite gathers in comparatively great flakes around the core, which therefore is easily loosened from the matrix.

The granite often passes into quartzite in part very pure. This is clearly seen in a profile at Fiane.

The sillimanite rock here usually has lenticular sillimanite nodules with a silky sheen. (Fig. 14, see also Pl. II, Figs. 3 and 4).

1. Light, biotite-rich sillimanite gneiss with quartz, plagioclase, biotite and magnetite, and streaks of sillimanite needles, that float in the schistosity direction of the gneiss in and between the quartz grains.
2. The gneiss passes into a mica-rich, strongly foliated granite, with quartz, microcline (fresh), biotite and muscovite with sphene, apatite and hematite as accessory minerals. It has sillimanite nodules here and there, but there are no sillimanite needles in the groundmass.
3. The granite passes into a more acid granite, still containing sillimanite nodules. The groundmass consists of quartz, microcline, little and strongly sericitized plagioclase, some biotite and muscovite, apatite and zirkon.
4. This passes into a quartzite that partly has sillimanite either as clear nodules or as shadows in a lighter colour with a silky sheen. The quartzite has a few grains of microcline and strongly sericitized plagioclase and biotite and muscovite. Tourmaline occurs, and zirkon, apatite and hematite.

This quartzite can be followed in a broad stripe eastwards unto the sea. It is mostly a very pure whitish grey quartzite. Some places alongside or within it there are chunks of hydrothermal quartz, white or pale pink. At one place a quartz of

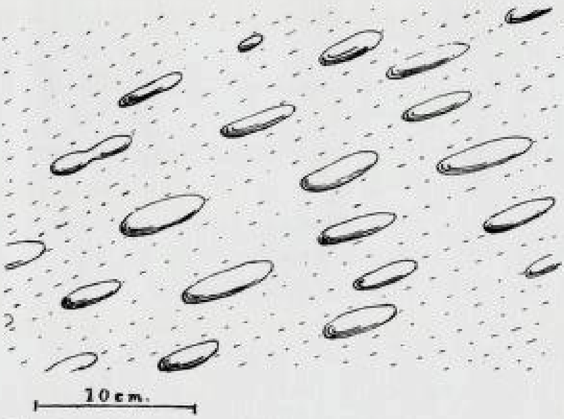

Fig. 14. Sillimanite nodules on a weathered surface.

probably hydrothermal type includes a fragment of amphibolite, about 1 m long. The quartzite is quarried on a large scale on the island of Langholmen. The granitic stripe in the gneiss can be retraced west of Leivann. Between the farms Tallakseng and Myren it has great quantities of sillimanite arranged in sheets. It is a hypidiomorphous, medium to coarse grained, red granite, some places with pegmatitic development. It has equal amounts of quartz and microcline; the microcline is partly changed into sericite. Biotite (with inclusions of hematite) and muscovite occur. Zirkon and apatite are accessory minerals. West of Skarvann there is a great deal of quartzite, granite often occuring in connection with it. Sillimanite nodules occur frequently in both rocks.

Eskola (1932) has explained such pure quartzites as residues after a granite when orogenic movements have squeezed out the lowest melting components. Even if this may have been the origin of the quartzites, the neighbouring granite, that partly passes into it can scarcely be supposed to possess an analogues mode of origin. The granite is more easily explained as formed from subsequently added granitic material. The granite occurs between the quartzite bands and between them and the main granite. The granitic material may have been arrested on its way up by the less penetrable quartzite. One reason for this supposition is the different mode of occurrence of the sillimanite in the two rocks. While in the quartzite and in the gneiss it forms bands or single crystals, associated with quartz or muscovite, it forms in the granite always nodules, never single crystals in the matrix. The absence of sillimanite in the matrix may be explained as a result of the dissolving effect of the intruding ichor, which would be able to completely dissolve the small dissiminated crystals while the larger sillimanite nodules would be preserved.

Sillimanite formes at a rather high degree of metamorphism in rocks of Al-surplus under the conditions of both regional and contact metamorphism. According to Harker (1932) it forms needles and prisms that have a tendency to gather in lenticles or streaks where the crystals have the same orientation. They often form a feltlike dense mass. They are then usually included in quartz or muscovite. This description corresponds to the occurrences of sillimanite in the quartzite on the Levang peninsula. Some authors have tried to explain the Al-surplus as pneumatolytically added material (E. G. Geijer 1930) as AlF_3. Harker (1932) however says that under such conditions one should expect to find topaz instead of sillimanite. The Al-surplus also may have been in the rock all the time.

If the quartzite is considered as a metamorphic sandstone the sources of Al may be layers richer in clay. The formation of sillimanite demands a higher degree of metamorphism than the mineral facies of the gneiss would seem to suggest. It is possible therefore that the gneiss with slowly decreasing temperature attained equilibrium at a lower facies, while the rather inert sillimanite remained as an unstable relic.

The association between the granite and sillimanite rocks may be tectonic. The granite might have been arrested on its way up in an anticline against a layer of arenaceous rock with small amounts of argillaceous material.

If this is true all the sillimanite quartzite would belong to the same horizon in the series and the peculiarities of the rock would be due to the chemical composition of this horizon rather than to the influence of the granite.

This explanation is rendered improbable, however, by the fact that similar rocks occur around archean granites also in other places.

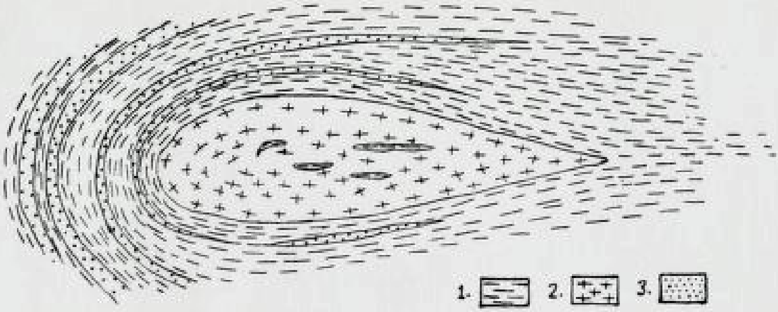

Fig. 15. Section through the Levang granite, parallel to the surface.
1. Gneiss. 2. Granite. 3. Quartzite.

Summary of Conclusions.

The banded gneiss with its quartzites possibly represents a supracrustal complex, a sedimentary series deposited at a time of intense volcanic activity. The complex seems to have been intruded by basic rocks, mostly along the sedimentary planes. The different character of the banded gneiss in the south and the quartzite-amphibolite-formation in the north may be due to different conditions during deposition in different epochs. The age relation cannot yet be given, but it seems possible that the quartzite-amphibolite-formation schould be the younger. The substratum of the series is not known. In a profile between Rollag and Tinnsjø one can see the Bamble formation overlain by the Telemark formation (Brøgger 1933).

The following hypothesis represents an endeavour to render a possible explanation of the deformation of the series. Orogenic movements made the series fold. Thus parts of it sank into the migmatitic zone, and were more or less remelted. A migma originated. The lowest melting constituents, with granitic composition, were specifically lighter than the overlying rock, and had a tendency to rise into the overlying crust, possibly diapiric (in the sense of Wegmann). The migma became a magma that could fill anticlines during their formation till their walls became steep, as batholitic intrusions. Detached fragments of the walls and downfalling fragments from the roof, formed inclusions. (Fig. 15, 16, and 17).

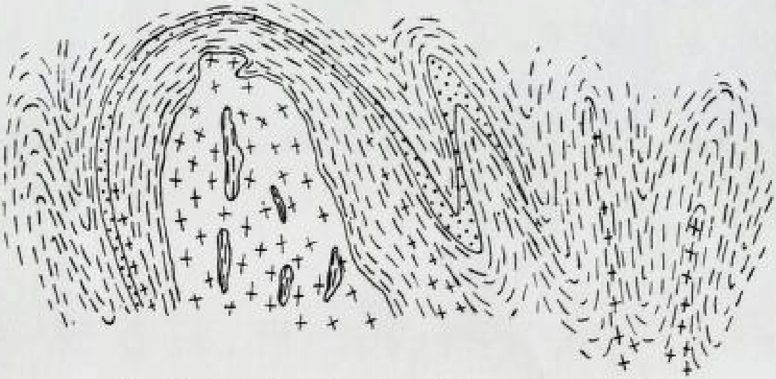

Fig. 16. Vertical section through the Levang granite.

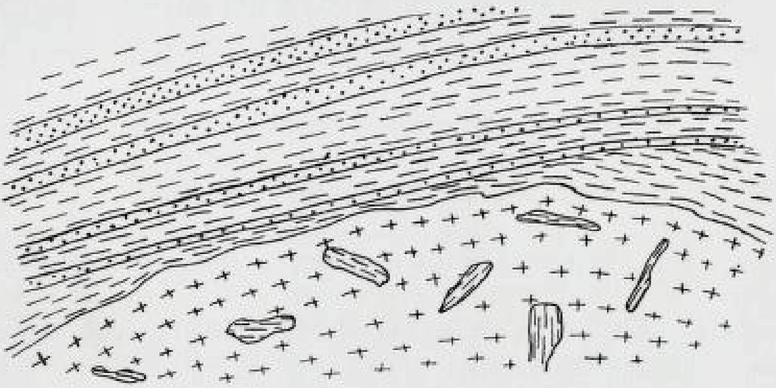

Fig. 17. Vertical section through the Levang granite.

It was a syncinematic intrusion. The granite, though intruding as a true magma, still had no direct connection with the "urmagma".

The gneiss around the intrusion shows signs of having been migmatized.

Metasomatic influence has been of importance; the mother liquor of the granite with its high content of water and volatiles was squeezed into the adjacent rock over great areas by the orogenic movements.

Later some diabas dikes cut through the rocks. Some fissures probably are caused by still later movements. Faults in connection with these have not been encountered.

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PLATES

Plate I

Fig. 1. Granite with myrmekite structure. Levang granite.

Fig. 2. Garnet in the Levang granite. The crystals are often spongy and full of fissures. This appearence is usual if the magma on cooling gives occasion for stress, rendering garnet unstable.

Fig. 3. Clinozoisite in the Levang granite. Core of orthite. The crystal is only in part metamikt.

Fig. 4. Gneiss with sillimanite and garnet.

Plate II

Fig. 1. Amphibolitic gneiss.

Fig. 2. Gneiss.

Fig. 3. Sillimanite needles in muscovite and quartz.

Fig. 4. Sillimanite needles, mainly in quartz.

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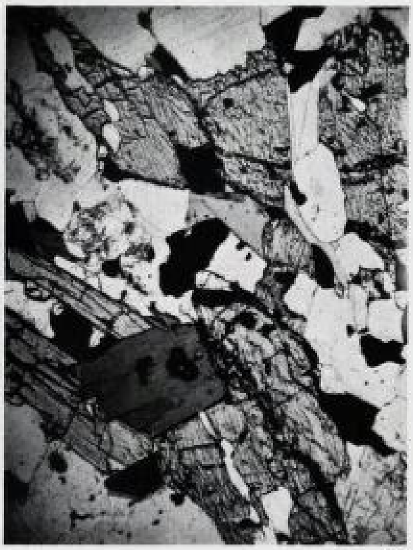

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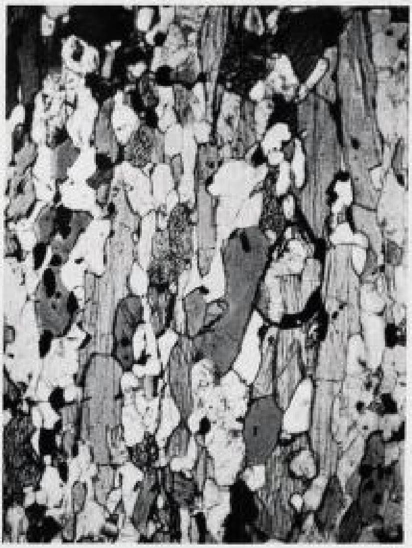

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