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Sammendrag

Generell berggrunnskartlegging i et omrade sör for Russünes i Saltdal. Skildring av de enkelte bergartsformasjoner, stratigrafi, tektonikk og metamorfose.

GEOLOGY AND PETROLOGY OF THE REGION SOUTH OF RUSSÅNES

SALTDAL, NORWAY

W. F. STEENKEN

In grateful remembrance to your hospitality in the summer of 1955.
W.F. Steenken,

GEOLOGY AND PETROLOGY OF THE REGION SOUTH OF RUSSÅNES

SALTDAL, NORWAY

W. F. STEENKEN

GEOLOGY AND PETROLOGY OF THE REGION SOUTH OF RUSSÅNES

SALTDAL, NORWAY

ACADEMISCH PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD VAN DOCTOR
IN DE WIS- EN NATUURKUNDE
AAN DE UNIVERSITEIT VAN AMSTERDAM
OP GEZAG VAN
DE RECTOR MAGNIFICUS DR M. W. WOERDEMAN
HOOGLERAAR IN DE FACULTEIT DER GENEESKUNDE
IN HET OPENBAAR TE VERDEDIGEN IN DE
AULA DER UNIVERSITEIT
OP WOENSDAG 3 JULI 1957
DES NAMIDDAGS TE 4 UUR

DOOR

WILLEM FREDERIK STEENKEN
GEBOREN TE AMSTERDAM

MOUTON & CO · 'S-GRAVENHAGE

Aan mijn ouders

Aan mijn vrouw

PROMOTOR: PROF. DR H. A. BROUWER

Bij het beëindigen van mijn academische studie maak ik gaarne van deze gelegenheid gebruik om mijn dank te betuigen aan allen, die tot mijn wetenschappelijke vorming hebben bijgedragen, in het bijzonder aan mijn hooggeschatte Promotor.

CONTENTS

SAMENVATTING

(Dutch summary)

Dit proefschrift omvat de resultaten van het geologisch en petrologisch onderzoek van een gebied gelegen ten zuiden van het gehucht Russånes, in de Noorse provincie Nordland, tussen 66° 50′ en 66° 55′ N.B. en tussen 15° 4′ en 15° 24′ O.L. Het landschap bezit een middelmatig relief en vertoont meestal afgeronde gebergtevormen.

In het onderzochte gebied komen metamorfe sedimentaire- en stollingsgesteenten voor. De volgende formaties werden onderscheiden:

De graniet-gneis formatie. – Deze formatie dagzoomt over een groot oppervlak in het zuiden en zuid-westen van het onderzochte gebied en bestaat voor het overgrote deel uit licht gekleurde, middenkorrelige kwarts-veldspaat gesteenten.

Een onderverdeling werd gemaakt in: *Granietische gesteenten, glimmer-arme mikrokliengneizen* en *biotiet-rijke mikrokliengneizen.* De granietische gesteenten bevatten als hoofdbestanddelen kwarts en veldspaat (mikroklien en albiet-oliogoklaas). In geringere hoeveelheden komen biotiet en titaniet voor. De ongerichte granietische gesteenten gaan naar boven toe geleidelijk over in de glimmer-arme mikrokliengneizen. Wat hun samenstelling betreft lijken deze mikrokliengneizen sterk op de granietische gesteenten; als nevenbestanddelen bevatten ze echter ook muskoviet en granaat. Behalve een gerichtheid van de glimmer treedt in deze gesteenten een gebandheid op door variatie in het gehalte aan kwarts en veldspaat en aan glimmer. Vooral in de hogere horizonten van deze gneizen komen zeer glimmer-arme banden voor. Het bovenste deel van de graniet-gneis formatie wordt gedeeltelijk gevormd door de biotiet-rijke mikrokliengneizen. Behalve door een vrij hoog biotietgehalte kenmerkt deze serie zich door het optreden van banden, welke zeer rijk zijn aan epidoot, hoornblende en in mindere mate aan calciet. In alle drie gesteentegroepen treden in geringere hoeveelheid dunne inschakelingen op van donkerder amphibolieten en van bijzonder biotiet-rijke gesteentetypen. Plaatselijk, ten zuiden van Vatnhauge en verder westwaarts, komt boven de biotiet-rijke mikrokliengneizen nog een horizont van glimmer-arme mikroliengneis voor.

De gesteenten van de graniet-gneis formatie zijn gemetamorfoseerd in de epidootamphiboliet facies. Als oorsprongsmateriaal voor de kwarts- en veldspaat-rijke gesteenten van deze formatie worden zandstenen of arkosen aangenomen. Op grond van de gelijkenis met gesteenten in zuidelijker en in noordelijker gelegen gebieden wordt een eocambrische ouderdom en een correlatie met sparagmietische gesteenten mogelijk geacht.

In de gesteenten van de graniet-gneis formatie heeft metasomatische vorming van veldspaat plaats gehad. Een metasomatische oorsprong voor de oudere, voornaamste, plagioklaasgeneratie is, hoewel waarschijnlijk, niet aan te tonen. Kaliveldspaat is, althans ten dele, tén gevolge van toevoer ontstaan, gelijk blijkt uit: het voorkomen van mikroklien-arme reliktische massa's te midden van mikroklien-rijke gesteenten, het optreden van mikroklienaders en de vervanging van plagioklaas door mikroklien. Op geringe schaal is de kaliveldspaat vervangen door een jongere plagioklaasgeneratie.

De grafietschist formatie. — Deze formatie is als een dunne, ten oosten van het Saltdal plaatselijk ontbrekende, mantel op de graniet-gneis formatie aanwezig. De meest kenmerkende gesteenten zijn grafietschisten. Onder deze grafietschisten komt een enkele meters dikke laag van kwartsietische glimmerschisten voor; er boven is meestal een tientallen meters dikke afwisseling van kwartsieten, glimmerschisten en glimmergneizen aanwezig. Waarschijnlijk is de grafietschist formatie gemetamorfoseerd in de epidootamphiboliet facies. Ook in deze, van oorsprong kleiige, kleiig-zandige en zandige gesteenten komt mikroklien voor, waarvan de vorming aan metasomatische processen wordt toegeschreven. Op grond van gelijkenis met gesteenten in zuidelijker en in noordelijker gebieden, wordt voor de grafietschist formatie een eocambrische tot ordovicische ouderdom mogelijk geacht.

De kalkglimmerschist formatie. — Deze formatie beslaat het grootste gedeelte van het onderzochte gebied. Het onderste deel, dat rust op de grafietschist formatie, of waar deze ontbreekt op de graniet-gneis formatie, bestaat uit een afwisseling van kalken en kwartsieten. Hierop volgt een serie, welke voornamelijk uit granaat-glimmerschisten en -gneizen bestaat, met inschakelingen van amphibolieten, kwartsieten en kalken. Het hoogste deel der formatie wordt gevormd door een dik pakket van kalkige glimmerschisten en -gneizen. Deze kalkige gesteenten gaan in de allerhoogste horizonten over in meer kwartsietische gesteentetypen. In het noord-westen van het onderzochte gebied is de opeenvolging in de kalkglimmerschist formatie gedeeltelijk afwijkend: De stratigrafisch diepst gelegen gesteenten zijn hier granaat-glimmerschisten; hierop volgen biotiet-rijke mikrokliengneizen, welke bedekt worden door de kalkglimmerschisten en -gneizen. In de hoogste horizonten van deze laatstgenoemde gesteenten komen, behalve kwartsieten, ook conglomeraten voor met rolstenen van kwartsiet. De gesteenten van de kalkglimmerschist formatie zijn afkomstig van kleiige, kleiig-zandige, zandige en kalkige sedimenten, en basische vulkanieten (ten dele tuffogeen). De gesteenten van de kalkglimmerschist formatie zijn voor een deel in de epidootamphiboliet facies, voor een deel in de amphiboliet facies gemetamorfoseerd. Metasomatische vorming van kaliveldspaat heeft in de diepere delen van de formatie plaats gehad. De ontstaanswijze van de mikroklien in de biotiet-rijke mikrokliengneizen uit het noord-westelijk deel van het gebied is onzeker. Het zelfde geldt voor het overgrote deel van de plagioklaas; voor een metasomatische ontstaanswijze van dit mineraal werden geen aanwijzingen gevonden. Voor de gesteenten van de kalkglimmerschist formatie wordt een cambrische tot silurische ouderdom mogelijk geacht.

In de kalkglimmerschist formatie hebben, op een relatief laat tijdstip in de metamorfe evolutie, granietische en trondhjemietische intrusies plaats gehad, getuige het voorkomen van kleine lensvormige lichamen, welke soms omgeven zijn door een smalle contact-metamorfe zone.

De amphiboliet-staurolietgneis formatie. – Deze formatie is dermate door tektonische bewegingen beïnvloed, dat een stratigrafische opeenvolging zeer moeilijk is op te stellen. Tot het onderste deel der formatie wordt een afwisseling van grafietschisten, schisteuze amphibolieten, granaat-glimmerschisten en -gneizen, hoornblendegarvenschisten en dolomieten gerekend. Dit gesteentepakket is in het noord-oosten van het terrein aanwezig doch vermindert in zuid-westelijke richting snel in dikte, om ter hoogte van het Saltdal uit te wiggen. Op dit pakket volgt een, eveneens uitwiggende, kalkhorizont en vervolgens een afwisseling van voornamelijk stauroliet-rijke schisten en -gneizen en massieve, ongerichte amphibolieten. De gesteenten van de amphiboliet-staurolietgneis formatie zijn afkomstig van kleiige, kleiig-zandige en zandige sedimenten met inschakelingen van basische tuffen (en mogelijk lava's) en in de hogere delen met, waarschijnlijk, intrusies van basische stollingsgesteenten. Plaatselijk, vooral ten westen van het Saltdal, komen in de onderste delen van de formatie lenzen van ultrabasische gesteenten voor. De gesteenten der amphiboliet-staurolietgneis formatie zijn gemetamorfoseerd onder de P-T verhoudingen van het hoger metamorfe deel van de amphibolietfacies. Metasomatische plagioklaasvorming kon in deze formatie slechts in enkele randzones van amphibolietlichamen worden aangetoond.

De ouderdom van de formatie is onzeker. Er is enige overeenkomst met onder-ordovicische gesteentesuccessies in noorderlijker gelegen gebieden.

Zoals uit het voorgaande blijkt, treedt in het onderzochte terrein een sprongsgewijze toename van de metamorfosegraad op van dieper naar hoger gelegen eenheden. Deze sprongen treden op in zones, die zich kenmerken door een sterke tektonische beïnvloeding, gelijk blijkt uit het uitwiggen van dikke gesteente-serien. Op grond van deze verschijnselen worden overschuivingsvlakken aangenomen onder de kalkglimmerschist formatie en onder de amphiboliet-staurolietgneis formatie. De metasomatische vorming van mikroklien heeft na de overschuivingen voortgeduurd, hetgeen blijkt uit het ongestoord doorlopen van de mikroklinisatieverschijnselen aan weerszijden van het overschuivingsvlak onder de kalkglimmerschist formatie. Behalve door deze overschuivingsstrukturen is het onderzochte gebied gekenmerkt door het optreden van een plooiing met een amplitude van meerdere kilometers, welke, daar ook de overschuivingsvlakken meegeplooid zijn, duidelijk jonger is dan de dekbladbouw. Onderscheiden werden: In het noord-westen een, zeer steil naar het ENE duikende, antikline (Kvassteinanticline), bestaande uit gesteenten der kalkglimmerschist formatie. Deze antikline wordt aan haar overkipte zuidflank begrensd door een zone van sterk tektonisch beïnvloede gesteenten van de amphiboliet-staurolietgneis formatie, waarvoor een synklinale bouw wordt aangenomen. Zuidelijk hiervan volgt een wijde, noordwaarts duikende antikline, gevormd door de gesteenten van de graniet-gneis formatie. Ten oosten van het Saltdal treft men in de kalkglimmerschist formatie een overkipte synkline aan met een steile noordwaartse asduiking.

De steil-assige structuur van de jongere plooiing, de plasticiteit welke de gesteenten tijdens deze plooiing hebben bezeten, en de sterke veldspatisatie, maken het aannemelijk, dat het onderzochte gebied diepere delen van het Kaledonische gebergte omvat.

De voornaamste resultaten van het onderzoek van het gebied ten zuiden van Russånes kunnen worden samengevat in de volgende rekonstruktie van de geologische geschiedenis:
Aan de rand van de Kaledonische geosynklinaal werden, op een archaisch grondgebergte en zijn eocambrische bedekking (de graniet-gneis formatie), cambrische tot ordovicische sedimenten van de grafietschist formatie afgezet. In de zelfde periode – en mogelijk ook later (tot in het siluur) – kwamen, in diepere delen van de geosynklinaal, de gesteenten van de kalkglimmerschist formatie tot afzetting. Verder westelijk werden mogelijk, tijdens het ordovicium, de gesteenten van de amphiboliet-staurolietgneis formatie afgezet. Tijdens de Kaledonische orogenese werd het in de geosynklinaal afgezette materiaal in, zoals algemeen wordt aangenomen, zuid-oostelijke richting gestuwd, waarbij de regionale metamorfose voor een belangrijk deel zijn beslag kreeg. Na de overschuivingen trad een jongere plooiing op, terwijl rekristallisatie en metasomatische vorming van veldspaat (voornamelijk mikroklien) plaats vond. Doordat de rekristallisatie eindigde na de voornaamste bewegingen, werden kataklastische verschijnselen voor het overgrote deel uitgewist.

Injectie van basisch en ultrabasisch magma vond prae- en/of synorogeen plaats. In een laat stadium van de regionale metamorfose is op geringe schaal granietisch tot trondhjemietisch magma geintrudeerd.

INTRODUCTION

Geological investigations in the northern Scandinavian mountains by students of the University of Amsterdam under the leadership of Professor H. A. BROUWER started in 1936. The results so far obtained have been put down in a number of theses, of which this is the fourteenth.

The region investigated is situated between 66° 50′ and 66° 55′ N lat. and 15° 4′ and 15° 24′ E long. in the Norwegian province Nordland.

The fieldwork was carried out during the summer months of 1954, 1955 and 1956. As topographic maps, the "topografisk kart over Norge" sheet L 14, Junkerdalen and sheet K 14, Beiardalen, scale 1 : 100.000 were used.

At the end of my studies at the University of Amsterdam, I wish to express in the first place my sincere gratitude to Professor BROUWER. Both in the Geological Institute of Amsterdam and in the field, I had the privilege of profiting by his rich experience. During the preparation of this thesis his stimulating guidance formed an indispensable support.

To Dr C. G. EGELER I am indebted for his continual readiness to help with the preparation of the manuscript and for his valuable suggestions.

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CHAPTER I

LANDSCAPE

The region south of Russånes has a moderate relief with rounded land-forms. A great part of the region is situated between an altitude of 500 and 700 metres above sea-level (fig. 1). The valley of the northward streaming Saltelv has been deeply eroded into the landscape. The

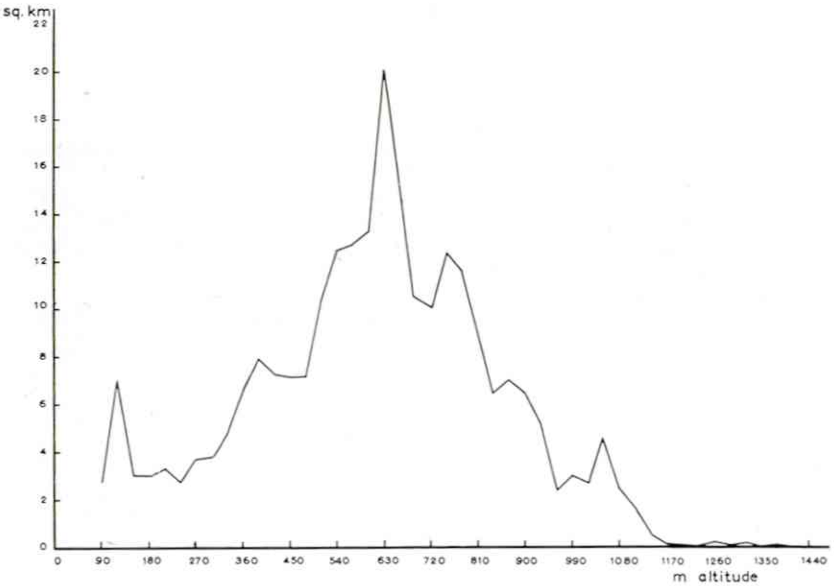


Fig. 1 - *Diagram, showing the distribution of the altitude in the region investigated.*

lowest point of the region, near Russånes, is found at less than 60 metres above sea-level. The highest point is at an altitude of more than 1000 metres. Immediately outside the investigated region a few peaks rise above the landscape, viz. Ølfjell (about 1700 metres) and Solvågtind (about 1500 metres).

The relief of the investigated region has largely been determined by glacial erosion. Large parts of the land surface are characterized by the occurrence of roches moutonnées. Further the landscape is strewn with numerous lakes and marshes, which evidences the incomplete drainage, typical of a glacial eroded topography.

On the northern Ølfjellsummit (1652 metres), an erratic boulder, consisting of coarse grained red granite was found, of a type which, as far as known, has not been found *in situ* in the vicinity. T. VOGT (1927, p. 28) assumes that the highest summits in the Sulitelma area were

Fig. 2 - *Esk, extending from the Ølfjellridge to the Northern Bjellåvatn; viewed from the South.*

nunataks. For the tops in the region south of Russånes this seems unlikely. In our opinion the sharp forms of the higher summits must be ascribed to the development of glacial cirques in their flanks. The highest parts of the region are still covered by perennial snow.

Especially near the Northern Bjellåvatn, large surfaces are covered by moraine deposits, the bulk of which consists of rocks of the granite-gneiss formation. East of the Northern Bjellåvatn a long ridge is found, which SUND (1954) considers to be an Esk (fig. 2). This ridge can be traced from the Ølfjellplateau as far as the Northern Bjellåvatn. On its north side, the Northern Bjellåvatn is dammed by a moraine-ridge. The shores of the lake show strandlines up to tens of metres above the present water-level. High above the bottom of the Harodal again well-marked strandlines are found. (fig. 3). T. SUND and S. NORDNES (1954) give further particulars about the glacial history of the area around the Northern Bjellåvatn.

The Saltdal locally shows a "U"-form; on the bottom of the valley "Rundhöcker" with glacial striae are found. Many tributary rivers empty, because of their hanging valleys, with waterfalls into the main

Fig. 3 - *Shore-lines, marked by snow, on the western slope of Harodalen, west of Steinfjell.*

valley. In the Saltdal at many places terraces are found, formed by thick deposits of gravel and sand, in which locally a few thin layers of clay are present. From similar deposits further north in the Saltdal, HOLMSEN (1932, p. 70) described the occurrence of marine mollusks. According to REKSTAD (1929) and HOLMSEN (1932) these sediments are post-glacial fjord deposits. The highest terrace found in the region south of Russånes is situated at a height of about 120 metres above the present sea-level.

The post-glacial fluviatile erosion influenced only to a small extent the relief of the investigated region. The river-system is very young; it is characterized by very flat watersheds and many small lakes and waterfalls in the course of the streamlets. Only in rocks offering less resistance to erosion, e.g. limestones and calciferous schists and gneisses, a more considerable fluviatile erosion has taken place. Examples are represented by the canyon of the Rusåga, sometimes attaining a depth of 150 metres, and by the subterranean courses of some streamlets in limestones. On the whole the rocks of the granite-gneiss formation have offered a stronger resistance against the erosion than the rocks of the other formations. In the last mentioned, especially the ultrabasic rocks and pure quartzites appear to be resistant to the erosion.

The river system has strongly adapted itself to the geologic structure; the streamlets often follow the strike of the layers or joint directions; many brooks east of the Hessihompvatn have their beds in a joint system, trending in a direction N 330 E (fig. 4).

Fig. 4 - *Stream bed, coinciding with a joint (N33OE), about perpendicular to the strike of the bedrock.*

Aside from local small occurrences, fluviatile and lacustrine deposits are especially found in the Harodal, in the extreme western part of the region. The strongly meandering Harodalselv cuts its bed in these deposits, probably originating from a large ice-dammed lake.

CHAPTER II

ROCK FORMATIONS

The following formations can be distinguished in the investigated region:

A *granite-gneiss formation,* consisting of light mica-poor and dark biotite-rich microclinegneisses and microcline-rich granitic rocks. This formation is exposed in the south and south-west, forming the northernmost extension of the Nasa massive which continues far to the south.

A *graphiteschist formation,* which in addition to graphiteschists, also contains quartzites, (garnet)-micaschists and–gneisses. This formation overlies the granite-gneiss formation as a relatively thin, here and there totally or partly missing mantle.

A *calciferous micaschist formation,* composed of mostly plagioclase-bearing (and partly calciferous) micaschists and micagneisses, quartzites, limestones and amphibolites. Lenticular bodies of granitic and trondhjemitic rocks occur as intrusives in some horizons.

The rocks of this formation cover a great part of the region investigated; firstly they form a wide zone, concordant in great lines, around the granite-gneiss complex with bordering graphiteschist formation, secondly they crop out in a vast area, east of Saltdal. Furthermore, the rocks forming a great anticline in the north and north-west of this region, belong to this series. In addition to the rock-types already mentioned, a thick biotite-rich microclinegneiss horizon occurs here.

An *amphibolite-staurolitegneiss formation,* consisting of amphibolites, graphiteschists, staurolite- kyanite- and garnet-bearing plagioclase-rich micaschists and -gneisses, quartz-rich micaschists, quartzites and limestones. Furthermore some small metamorphic ultrabasic lenses are found. The formation is exposed in the north-east, proceeds to the south-west over the Saltdal beyond Hessihompvatn and pinches out further west.

CHAPTER III

DESCRIPTIONS

THE GRANITE-GNEISS FORMATION

The rocks of the granite-gneiss formation are found over a vast surface in the south and south-west of the region investigated. They are for the greater part well exposed; in two areas only they disappear entirely under a cover of moraine deposits, viz. east of the Northern Bjellåvatn and in a smaller area east of the Ølfjellridge. Furthermore, in the Saltdal they are covered by fluviatile and probably partly marine sediments of post-glacial age.

The boundary between the granite-gneiss formation and the remaining units can easily be recognized; in the field it is very easy to distinguish the mostly light-coloured, often rather massive rocks of the first formation from the darker and considerably more schistose rocks of the others.

In so far as banding and schistosity are observable in this formation, these always appear to dip under the bordering schist-succession. The composition of the rocks is rather uniform; they are mainly fine-grained. Macroscopically, one recognizes quartz and feldspar as the main constituents and a varying amount of dark brown to black biotite, a light olive-green mica, pink garnet and magnetite.

In the extreme south of the region investigated, on the northern spur of the Ølfjellridge, the rocks have, on account of their directionless texture, the aspect of a medium-grained granite. These granitic rocks are characterized by their usually pink colour. Biotite is the principal dark constituent, muscovite is seldom found.

East of the westernmost moraine cover, the granite encloses an amphibolite band of an average thickness of 70 centimetres, the strike of which is approximately east-west. Over a short distance north and south of the mentioned band several other, thinner amphibolite bands are found. During a survey south of the region investigated, amphibolitic and biotite-rich bands were also found close under the northern summit

(1585 m) of the Ølfjellmassive. Here they are sometimes several metres thick. Certain biotite-rich masses are found about 1,5 kilometre south of the border of this region; their form is reminiscent of that of xenolites (see fig. 5). Apart from the one as shown in figure 5, similar structures of smaller sizes were found over a limited surface. Also pockets of hornblende crystals, sometimes measuring several decimetres in diameter, appear here.

Fig. 5 - *Relict mass of a relatively biotite-rich and microcline-poor composition, in mica-poor microclinegneiss; north-eastern side of the Ølfjell-ridge.*

In the stratigraphically higher parts of the granite-gneiss formation a gradual increase in the schistosity is coupled to a decrease in grain-size. Further the varying content of dark elements causes banding; often muscovite and sometimes garnet are found instead of biotite. Some bands have a light reddish colour caused by the impregnation with limonite. Still higher horizons, just underneath the biotite-rich microclinegneisses are very massive, snow-white and sugary in appearance, due to the almost complete absence of dark constituents.

It is not possible to indicate an exact boundary between the directionless and directed rocks of the granite-gneiss formation, because the change takes place gradually in a zone, several hundreds of metres wide.

The upper part of the granite-gneiss formation is partly formed by biotite-rich microclinegneisses. These rocks are distinguished, macroscopically, from the mica-poor microclinegneisses especially by their much darker colour. In addition to a varying quantity of quartz and feldspar, they contain a relatively high amount of biotite and further sometimes considerable amounts of Ca-rich minerals such as epidote and hornblende. These rocks show a well-marked banding, caused by a strong variation in their content of dark minerals. Occasionally coarsely crystalline bands occur, with beautiful "garben" of hornblende, while bands containing calcite are found as well. The biotite-rich gneisses are coarser grained than those poor in mica.

In the eastern wall of the Saltdal, the thickness of the biotite-rich microclinegneiss horizon, does not exceed 60 metres. West of the Saltdal the content of dark mica and Ca-rich minerals decreases gradually, which makes the difference with the underlying rocks less apparent. The peculiar form of the outcrop of the biotite-rich gneisses can be explained by the fact, that south of Tretnes the schistosity planes of this horizon, which show slight undulations, tend to run parallel to the topographic surface. In the region around Tretnes and Langånes, however, the biotite-rich gneiss cover has disappeared by erosion, as a result of which the mica-poor gneiss series is exposed.

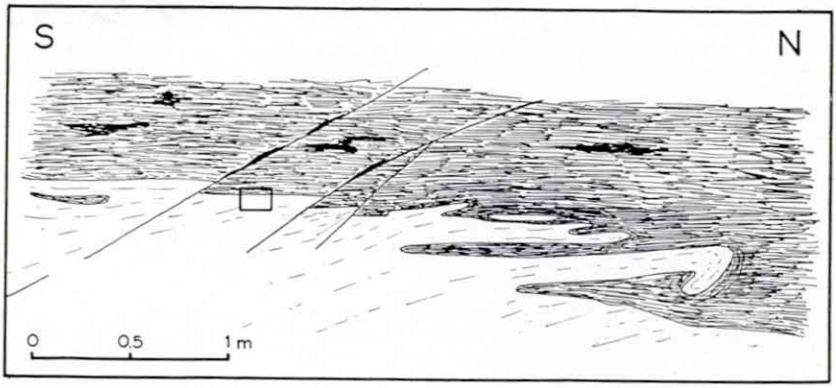


Fig. 6 - *The contact of the mica-poor (below) and the biotite-rich microclinegneisses of the granite-gneiss formation, as exposed along the railroad, about 800 metres N of the Stampelv. Interfolding has taken place; part of the underlying mica-poor rock appears to be torn loose and is now enclosed by the biotite-rich gneisses. Some small upthrusts are observable, with local concentrations of quartz (black) along the thrust planes (The outlined area is shown in fig. 7).*

The contact of both gneiss horizons, especially well-marked in the eastern part of the complex, can be observed very well at the railway intersection, approximately 800 metres north of the Stampelv (see fig. 6 and p. 108). In this exposure proofs of exceptionally strong differential movements are present. The rocks have yielded extremely plastically to the deformation. Locally, truncation of the schistosity in the underlying, light coloured, microclinegneisses at the contact is visible (fig. 7).

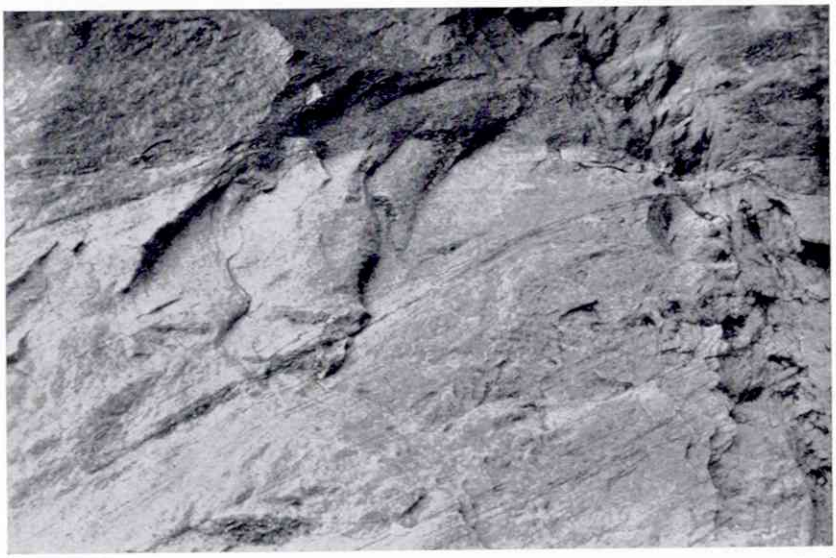


Fig. 7 - *Detail of fig. 6. The light coloured mica-poor gneisses are seen to pinch out at the contact.*

Further north along the railway, the upper part of the biotite-rich gneiss series is very well exposed. Here one finds, at irregular distances, bands of varying thickness, composed of a very dark coloured rock, often almost entirely consisting of biotite. These bands–the thickness of which varies from some centimetres to several metres–show folding and well developed boudinage structures (fig. 8 and 9). Quartz veins are numerous.

South of the Hessihompvatn, a second horizon consisting of mica-poor gneisses, overlies the biotite-rich microclinegneisses (upper series, p. 38). To the east, this horizon shows a rapid decrease in thickness; south of Vatnhauge it disappears entirely. The boundary between the two gneiss horizons is formed by a dark band, varying in thickness and attaining at most 20 metres. This band consists for a great part of biotite and it is similar to the biotite-rich bands along the railroad, described above. To the west, this band pinches out rather suddenly south of the Hessihompvatn; the boundary between the biotite-rich gneisses and the mica-poor gneisses covering them is then hard to follow. This dark band shows strong minor folding of a similar type as exposed in the bands along the railroad. In one place (viz. 660 metres west of Langånes) in this biotite-rich band, an amphibolite lens was found, a few metres in length. Furthermore this band contains several lenses of light

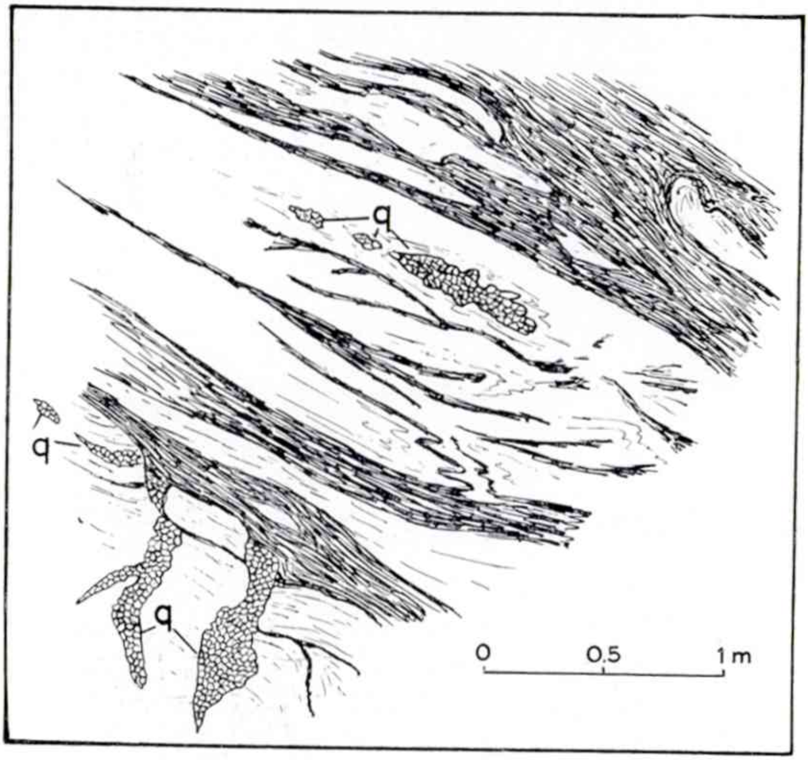


Fig. 8 - *Microcline-gneisses with extremely biotite-rich bands, showing folding and quartz-impregnation (q). In the highest levels of the granite-gneiss formation, along the railroad, E of the bridge near Langånes.*

gneisses (fig. 10), several tens of metres long and several metres thick as a maximum and sometimes marked by minor folding.

Through the whole of the granite-gneiss formation pegmatite pockets occur, varying in size from some centimetres to several metres. Their

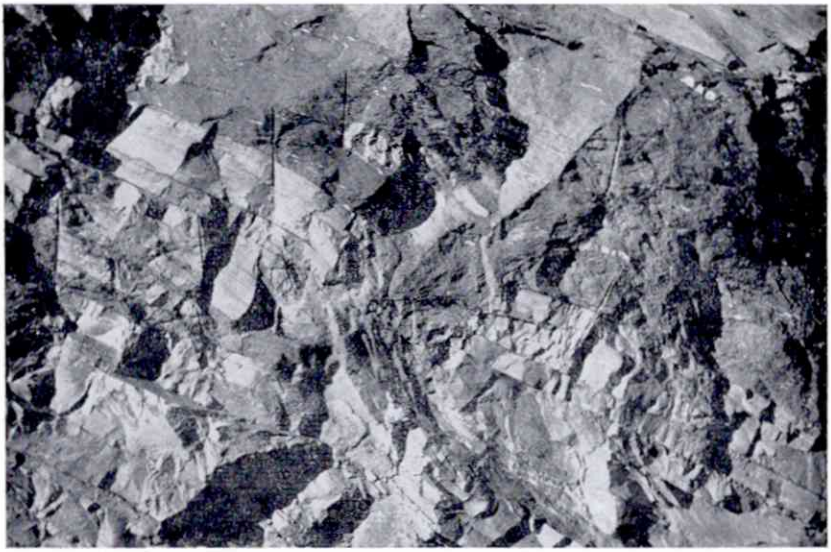


Fig. 9 - *Boudinage in biotite-rich microcline-gneiss. The darker bands are extremely rich in biotite. Along the railroad, E of the bridge near Langånes.*

number seems to increase in the higher levels: in the biotite-rich gneisses many, often very coarsely crystalline, concentrations are found of quartz, feldspar, amphibole, light mica, chlorite, calcite, epidote and ore minerals. Narrow quartz veins are occasionally present, as well

Fig. 10 - *Light-coloured lenses of microcline-gneiss, in the extremely biotite-rich band in the higher part of the granite-gneiss formation; ca. 1800 metres SE of Hessihompvatn.*

as veins and irregular patches, measuring up to several metres in diameter, of coarse-grained granitic material.

Joints have frequently been observed in the rocks of the granite-gneiss formation. In addition to a joint-system in a direction parallel to the banding, there are two joint-systems, approximately perpendicular to each other. The one, striking between north-west and north, shows the best development. The dip of the two last systems varies between 65 and 90 degrees.

Petrography

Microclinegranite.

3 :	Microclinegranite	plateau Ølfjellryggen 1020 m.
4 :	id.	S-branch of Stampelva, 840 m.
24 :	id.	at 615 m along telegraphline
25 :	id.	at 570 m about 1200 m S of Stampelva.

Fig. 11 - *Microclinegranite, consisting of microcline (diagrammatical crosshatched, mi), albite-oligoclase (showing twinning and cleavage, pl) and quartz (white, q). Furthermore a few small flakes of muscovite are shown (m). Ølfjellridge.*

These medium-grained (grain-size about 1.5 mm,), qua composition granitic rocks (fig. 11), contain as main constituents: quartz, plagioclase and microcline, which last constituent often appears in smaller quantities than the plagioclase. These minerals show a xenoblastic development. The microcline often shows a well developed cross-hatched structure. The mineral forms clear crystals; showing no alteration. Occasionally, this feldspar shows perthitic intergrowths. The plagioclase varies from albite to albite-oligoclase (5-8 % An.). It is mostly polysynthetically twinned according to the albite-law; sometimes, however, twins occur in accordance with the pericline- or karlsbad-law. This mineral too is remarkably fresh and shows no alteration. As the figure 12 shows, the

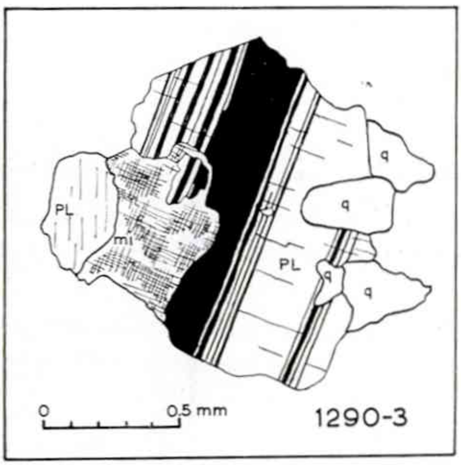


Fig. 12 - *Replacement of albite-oligoclase by microcline (mi); q: quartz. Microclinegranite, Ølfjell-ridge.*

Fig. 13 - *Myrmekite (my), formed between, and at the expense of microcline crystals (mi). In microclinegranite, Ølfjell-ridge.*

microcline has originated, at least partly, at the expense of the plagioclase. In its turn, however, it appears that the microcline is, here and there, replaced by a younger plagioclase generation, whereby myrmekitic textures have developed. These myrmekite textures often appear as small grains between two microcline crystals (fig. 13). No undulose extinction was observed within the quartz. This mineral is often enclosed, by potash-feldspar as well as by plagioclase. As dark minerals occur: green-brown biotite, and in smaller quantities muscovite, both directionless, unbent and remarkably "fresh". In addition one finds a relatively large quantity of titanite; further accessories are: apatite, zircon, orthite and ore-minerals.

The amphibolite bands and their contacts (p. 24), appearing in the microclinegranite are represented by:

2 :	Pyroxene-bearing microcline-amphibolite	at 960 m west of the Ølfjell-ryggen
29 :	Epidote-micagneiss	id.

The pyroxene-bearing microcline-amphibolite (2) is a representative sample of the amphibolite bands found in the granite. The rock contains a large quantity of microcline and to a lesser degree an oligoclase (23 % An.). Both feldspars are partly untwinned; the plagioclase is sometimes strongly sericitized and appears to be replaced by the microcline

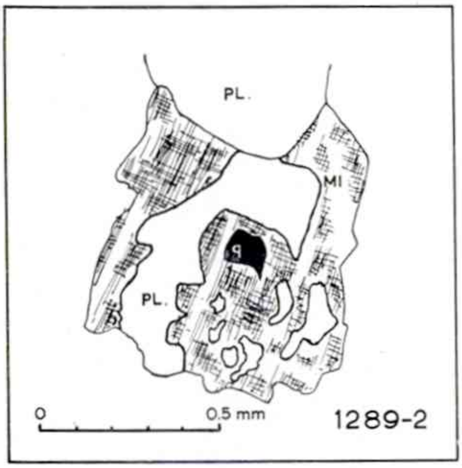


Fig. 14 - *Replacement of oligoclase (pl) by microcline (mi). The remnants of the plagioclase show optic continuity; q: quartz. Pyroxene-bearing amphibolite, W of Ølfjell-ridge.*

(see fig. 14). Green hornblende is the principal dark constituent, the crystals sometimes contain relics of a light green coloured, monoclinic pyroxene in their cores. Further smaller quantities of epidote and biotite were found and, accessorily, some grains of apatite and titanite.

The epidote-micagneiss (29), collected at about 30 centimetres from the contact of the pyroxene-bearing microcline amphibolite, is distinguished from all surrounding rocks by the absence of microcline. The plagioclase of this rock is an albite-oligoclase. Biotite, epidote and some grains of orthite occur as dark constituents. Apatite and ore-minerals are accessories. Both rocks do not show any cataclastic features, although they show strong small scale folding; the quartz shows no undulose extinction, the mica-scales are unbent.

Microclinegneisses, poor in mica.

In view of their geological occurrence the mica-poor microclinegneisses of the granite-gneiss formation may be divided into two groups, viz. a *lower series,* found under the biotite-rich gneiss horizon and an *upper series,* situated above the biotite-rich gneiss horizon.

Lower series.

28 :	Microclinegneiss	at 960 m, W of Ølfjell-ryggen.
5 :	Garnet-bearing microclinegneiss	N of Ølfjell, along the telegraphline, at 770 m.
23 :	Microclinegneiss	at 600 m, along Stampelva.
22 :	Garnet-bearing microclinegneiss	at 550 m, along Stampelva.
26 :	Garnet-bearing microclinegneiss	about 100 m S of the telegraphline, at 450 m.
19 :	Microclinegneiss	along the railroad, S of Stampelva.
11 :	Amphibole-bearing microclinegneiss	along the railroad SW of Kristendalnes.
20 :	Microclinegneiss	along the railroad, about 200 m N of the telegraphline.
21 :	Cataclastic, garnet-bearing microclinegneiss	along railroad, about 50 m S of Stampelva.
101 :	Microclinegneiss	at 145 m, about 200 m N of Kristendalnes.
12 :	Garnet-bearing microclinegneiss	railroad, S of Tretnes.
18 :	Garnet-bearing microclinegneiss	Tretnes.
211 :	Retrograde garnet-bearing microclinegneiss	about 1 km SE of Vatnhauge.
32 :	Microclinegneiss	about 200 m S of Markskjeelv.

In the above enumeration the rocks have been arranged as far as possible in sequence of increasing distance from the exposed granite;

all these samples examined are medium grained. They show an increasing foliation of the mica with increasing distance from the granite. As has been observed above (p. 25), the boundary between the directionless granite and the directed gneiss is not sharp. Some of the rock-samples (e.g. 28), classified here under the microclinegneisses poor in mica, can hardly be distinguished from those described under the section microclinegranite (p. 30). Main constituents are: quartz, in nearly all samples the most frequent mineral, microcline in slightly smaller quantities, and albite-oligoclase, mostly present in still smaller amounts than microcline.

Quartz mostly appears as large, only slightly undulose, grains without a crystal-form. The microcline forms large xenoblastic, usually beautifully twinned crystals, besides cross-hatching, sometimes showing round inclusions of quartz with optic continuity. Occasionally potash-feldspar occurs as filling of veins (11). Often the mineral is slightly kaolinized. Frequently perthitic intergrowths were observed. The albite-oligoclase (max. 9 % An) does not show a typical crystal form either. The mineral is seldom altered. In these rocks again the microcline seems younger than the greater part of the plagioclase, which is replaced by the potash-feldspar. On the other hand, part of the albite-oligoclase again proves to be younger than the microcline. In that case myrmekite textures have been formed. Besides these main constituents one finds biotite, muscovite and garnet in smaller and varying quantities. The mica often forms larger plates (measuring up to some millimetres in diameter), never bent and with a remarkably "fresh" appearance. The rock samples, which contain garnet, completely lack biotite or contain only small quantities of this mica, whereas at the same time an increase of the amount of muscovite can be observed. The garnet, found in the mica-poor microclinegneisses, reacts positively to pyrochemical reactions on manganese; an X-ray powder-diagram made of this mineral, reveals lines characteristic of spessartite.

Finally, there may be the following accessories: titanite (often in rather large quantities), rutile, orthite, zircon, tourmaline, apatite, fluorite, pyrite, hematite, magnetite and ilmenite. Limonite impregnations are rather common.

From the central part of the granite-gneiss complex outwards a decrease in grain size and a decrease in the quantity of myrmekite may be observed as wel as an increase in schistosity. No further regular changes have been observed during this examination. In so far as the data reveal, the garnet-bearing gneisses are irregularly distributed over the whole formation.

The amphibole-bearing microclinegneiss (11) collected at the railroad, SW of Kristendalnes, originates from a coarser grained band, measuring some metres in thickness. This rock contains black hornblende crystals, usually concentrated in eyes. In addition to hornblende, a small quantity of calcite is present. The garnet-bearing microclinegneiss (21), sampled along the railroad, several hundreds of metres northward, shows cataclastic zones, some millimetres in width. These are relatively young because of the fact that all minerals are broken and show undulose extinction. The position of the cataclastic zones as regards the schistosity is oblique and they appear to be related to an increase in the number of joints observed in the field. The width of the crushed zone in its entirety is estimated at 30 metres; it strikes about N 330 E, i.e. approximately in the direction of the principal joint-system.

Both the garnet and the biotite in the retrograde garnet-bearing microclinegneiss (211) have been partly altered into chorite. The feldspar in this specimen is rather strongly kaolinized and sericitized.

259 : Microclinegranite at 400 m, about 800 m S of Stampelva.

Locally coarsely grained granitic patches, having a maximal diameter of some metres, were found in the microclinegneiss.

The main constituents of these granitic rocks are microcline, albite-oligoclase and quartz. The albite-oligoclase is again replaced by the potash-feldspar (fig. 15), while a younger plagioclase generation characterized by myrmekitic intergrowths, is distinguished. The microcline shows perthitic intergrowths; also peculiar intergrowths of the potash-feldspar with quartz occur (fig. 16).

141 : Garnet-skarn at 770 m, W of Kristendalnes.

The garnet-skarn (141) has been collected from a pocket in the microclinegneiss, measuring some decimetres in diameter and, consisting almost entirely of quartz and idioblastic garnet. The rock further contains a small quantity of microcline and directionless biotite.

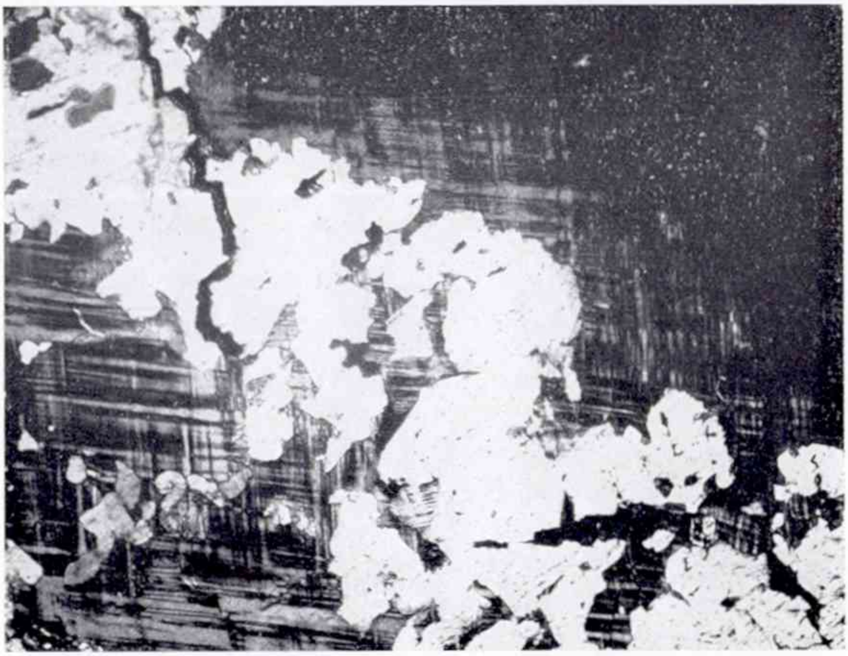


Fig. 15 - *Replacement of albite-oligoclase by microcline. Microcline-granite. At 400 metres, about 800 metres S of Stampelv.* (22 ×)

Fig. 16 - *Intergrowth of microcline (vaguely cross-hatched) and quartz. Microcline-granite. At 400 metres, about 800 metres S of Stampelv.* (93 ×)

Occasionally dark coloured, biotite-rich rocks were found in the lower series (see p. 25). The specimens 257 and 262 represent the centre of the dark relict body, shown in fig. 5, and the surrounding rock, respectively.

257 : Biotitegneiss	at 960 m, N of the northern Ølfjelltop.
262 : Hornblende-bearing microclinegneiss	id.

The first rock type is characterized by a large amount of biotite and by a low microcline content. The texture of this rock is rather coarsely granular, showing a foliation, parallel to that of the surrounding gneisses. In addition to microcline there is a large quantity of coarse grained albite-oligoclase (12 % An.); quartz is usually found as round inclusions in the plagioclase and as small vermicules in myrmekite textures.

The gneiss, no. 262, belongs to the normal type of mica-poor microclinegneisses, containing microcline as main constituent. The quartz, which occurs in a larger quantity than in the previous specimen, does not show undulose extinction. Biotite appears in a smaller quantity. Occasionally the potash-feldspar gives the impression of being formed at the expense of the biotite. Myrmekite intergrowths are abundant. A single dark-green hornblende crystal is present in the slide examined.

A comparison of the two specimens shows, that the first rock is less intensely microclinized, whereas the biotite content is much higher; it is possible that at least part of the potash needed for microclinisation originates from biotite. A decrease of the amount of dark constituents in case of proceeding kalimetasomatism has been described i.a. by Lapadu-Hargues (1945) and Strand (1949, p. 37).

258 : Albitized biotite-microclinegneiss	at 1585 m, N of the northern Ølfjell-summit.

The albitized biotite-microclinegneiss (258) originates from the dark band which is exposed just below the northern summit of the Ølfjell. Macroscopically, the rock shows the characteristics of an augen-gneiss, because of the occurrence of feldspar 'eyes'—measuring sometimes centimetres in diameter—in a very dark matrix, for the greater part consisting of biotite.

Microscopically, these 'eyes' appear to consist of microcline and albite-oligoclase aggregates. Part of the microcline crystals show a fine perthitic intergrowth. Furthermore, this mineral is sometimes crushed, while along the cracks thus formed an intensive albitization has taken place, together with formation of myrmekite textures.

Upper series.

216 :	Garnet-bearing microclinegneiss	along brook, at 570 m, W of Langånesbridge.
215 :	Microclinegneiss	about 1 km SE of Vatnhauge, 3 m above no. 214.
214 :	id.	about 1 km SE of Vatnhauge.
144 :	id.	W of Langånes, at 570 m.
93 :	id.	id.

The microclinegneisses of the upper series, which are distinguished macroscopically from the microclinegneisses of the lower series only by a stronger minor folding, show microscopically some distinct differences.

Firstly, the anorthite content of the plagioclase shows a greater variation; in three of the specimens examined (215, 214 and 144) an anorthite content of about 12 % was found, in one specimen (216) 20-27 % was measured, and in another (93) about 50 %. Secondly, the microcline and the plagioclase sometimes show, (216, 93) in addition to replacement-structures similar to those, observed elsewhere, rather intricate intergrowths of an antiperthitic character.

The microclinegneiss 93 deserves a further description. This strongly folded rock contains as main constituents microcline, a relatively calcic plagioclase (about 50 % An.) and quartz, while biotite, muscovite and tourmaline are found in smaller quantities. Furthermore this rock contains–finely divided–black opaque ore-mineral (especially enclosed by the feldspars), and a few grains of apatite, titanite and orthite. Microcline occurs as clear crystals with cross-hatched structure, in which sometimes inclusions, showing optic continuity, of slightly altered plagioclase are found. This fact and the occurrence of microcline in veinlets in the plagioclase crystals, proves again that the microcline is younger than part of the Na-Ca-feldspar. Part of the myrmekite structures, found here again, in conformity with those described elsewhere, are considered as generated in a younger plagioclase generation, formed at the expense of the microcline (see further p. 42). The rock shows an intensively small-scale folding, however, cataclasis was not observed: the quartz does not appear to be undulose, while the mica-plates are again unbent and have a "fresh" appearance.

Biotite-rich microclinegneisses.

140 :	Hornblende-epidote-biotite-microcline-gneiss	at 810 m, along the telegraph-line.
97 :	Diopside-hornblende-epidote-microclinegneiss	eastern wall of Saltdal, at 165 m, about 2 km S of Kristen-dalnes.
16 :	Contact biotite-microclinegneiss and and mica-poor microclinegneiss	about 900 m N of Stampelv.
17 :	Epidote-biotite-hornblende-microcline-gneiss	about 950 m N of Stampelv, along railroad.
15 :	Calciferous epidote-biotite-microcline-gneiss	along railroad, 1 km N of Stampelv.
14 :	Biotite-microclinegneiss	along railroad, about 1100 m S of Tretnes.
13 :	Biotite-microclinegneiss	400 m W of Tretneselv.
27 :	Calciferous biotite-microclinegneiss	along railroad, straight above Langånesbridge.

In comparison with the mica-poor gneisses, the biotite-rich ones show a much greater variation in mineralogical composition. Apart from a single exception, they are much darker and, without exception, well directed. The content of biotite and calcite or Ca-rich minerals is higher and the ratio quartz/feldspar, as well as the composition of the plagioclase, varies more. The quantity of quartz present can diminsh strongly; in the specimen 140 the mineral is only scantily represented. In the specimen 17 quartz is not found. All samples examined contain a large quantity of microcline, always showing fine cross-hatched structure. Here again this mineral seems to have been formed at the expense of the plagioclase. Occasionally perthitic intergrowths were observed. Myrmekite textures appear to a lesser extent in these rocks than in the light coloured gneisses; sometimes they are completely missing. The plagioclase is sometimes slightly more calcic than that in the mica-poor microclinegneisses. The anorthite content may increase up to 17 %. Sometimes a slight inverse zoning is observed; in the epidote-biotite-hornblende-microclinegneiss no. 17, the plagioclase shows a core with 8 % and a rim with 15 % anorthite. Of the dark constituents, biotite is always present in great quantity. The greater part of the samples also frequently shows considerable quantities of calcite and/or epidote. Green hornblende is found only in a few representatives of the group (17, 140 and 97). This mineral shows a poikiloblastic development, and besides quartz it also encloses epidote. The amphibole, in its turn, is sometimes enclosed by the plagioclase. No. 97 contains, in addition to hornblende, also a light green monoclinic pyroxene, converted at the rims into amphibole. Finally some of these samples contain a small amount of muscovite, while, together with the biotite, there occurs sometimes some chlorite. Accessorily, all specimens contain a minor quantity of titanite and furthermore, incidentally, apatite, zircon and orthite. The last mentioned mineral occasionally forms brown cores in the yellow pleochroic epidote. Magnetite, ilmenite, and pyrite can be mentioned as ore-minerals. The pyrite crystals are often surrounded by a rim of limonite.

The dark bands found in the upper horizons of the biotite-rich microclinegneisses (p. 27), are represented by the following rock samples:

8 :	Biotitegneiss	along the railroad near Langånes.
9 :	Epidote-biotitegneiss	id.
10 :	Calciferous biotitegneiss	id.
212 :	Muscovite-rich biotitegneiss	about 1 km SE of Vatnhauge.
213 :	Calciferous hornblende-biotitegneiss	id.

These dark-coloured rock types differ from the surrounding gneisses not only because of a considerably larger content of biotite, but also because of the, frequently complete, lack of potash-feldspar, i.c. microcline. Only the specimen 212 contains a slight quantity of this mineral. The plagioclase, which is, together with quartz and biotite, the principal constituent of this rock, is slightly more calcic than that in the biotiterich gneiss dealt with above. Whereas there the anorthite content of the plagioclase averages 12 %, this percentage varies from 10 to 23 % in the rocks described here. A few samples bear a slight quantity of chlorite, while sometimes a minor amount of muscovite is present. No. 212 forms an exception to this rule, having a high muscovite content. The calciferous hornblende-biotitegneiss (no. 213) contains a quantity of actinolitic hornblende, characterized by a light bluish green colour and an extinction angle $^{n}\gamma/c = 18°$. Some samples are rich in epidote (10 and 9), while calcite also may occur in larger quantities. (nos. 10 and 213). Accessories are: orthite, zircon, titanite, apatite, pyrite, magnetite, and/or ilmenite.

142 : Muscovite-bearing microclinegneiss — about 800 m N of Tretneselv, at 690 m.

Light coloured gneiss lenses, found locally in the dark bands, are represented by the muscovite-microclinegneiss no. 142; they show a great resemblance, as regards composition and texture, to the mica-poor microclinegneisses described above. Microcline forms the main constituent. Like in the mica-poor microclinegneisses, the anorthite content of the plagioclase is low again (5 %); biotite is absent.

Amphibolite-lens in the dark band south of Vatnhauge (p. 28):

143 : Garnetamphibolite — at 690 m, 1600 m S of Vatnhauge.

By far the greater part of this garnetiferous amphibolite consists of a fine grained, parallelly directed, dark green hornblende. Sodic plagioclase (7 % An.) is present in small quantities only; it has slightly been converted into sericite. Garnet appears as individuals measuring up to some millimetres in diameter. The crystals are poor in inclusions. In comparison with the amphibolites found elsewhere in the investigated region, the anorthite content of the plagioclase is remarkably low.

General considerations on the granite-gneiss formation

In our opinion the quartzo-feldspathic rocks of the granite-gneiss formation are most probably of sedimentary origin. This is suggested by:

1. The marked banding, occurring especially in the higher horizons of the formation, caused by a variation in the content of dark constituents (p. 25);
2. The high content in Ca-minerals such as epidote, hornblende and calcite in particular bands, found in the biotite-rich microcline horizon (p. 26);
3. The fact that the quartz- and feldspar-rich rocks of the granite-gneiss formation sometimes alternate with very thin amphibolite layers (p. 24).

The unequal distribution of the potash-feldspar and the quartz, often observed microscopically, appears to be in harmony with a sedimentary origin.

When assuming a sedimentary origin for the rocks of the granite-gneiss formation, the initial material may either have been of a quartzitic or of an arkosic character. Because of their relatively low content in quartz, part of the gneisses not only fall outside the normal composition of quartzites, but also outside that of arkoses, of which the composition was established by TALLMAN (1949, p. 587) at 27 % feldspar and 58 % quartz on an average. Also the ratio potash-feldspar / Ca-Na-feldspar is usually too low for arkoses; according to several authors (e.g. BARTH, 1938, p. 54) the principal feldspar represented in arkosic rocks is potash-feldspar. The plagioclase-richness of the rocks of the granite-gneiss formation may probably be due to metasomatic processes, but this could not be proved (p. 114).

The general replacement of plagioclase by microcline points to a metasomatic origin of the latter mineral. The occurrence of relict bodies (fig. 5), in which the replacement of the plagioclase by the potash-feldspar is less advanced, and the occurrence of microcline in veins, also suggest a potash metasomatism.

After the microclinization the formation of a younger plagioclase, attended by myrmekite, took place, though on a much smaller scale. This myrmekite often occurs between microcline crystals and is partly clearly independent of the older plagioclase. Whether all the myrmekite textures occurring in the rocks of the granite-gneiss formation have been formed at the expense of the microcline, is, however, uncertain. H. HOLTEDAHL (1950, p. 49) assumes that the myrmekite textures described by him from the rocks in the Opdal area—which rocks are comparabe to those of the granite-gneiss formation (p. 104)—were partly formed at the expense of the plagioclase and partly at the expense of the potash-feldspar.

In older literature (HOLMSEN, 1932, p. 44) the rocks of the granite-gneiss formation are described as "finkornig, tildels skifrig, på enkelte steder aplitisk granitt"; the texture and composition of the gneisses are indeed often reminiscent of those of aplites. On account of more recent investigations in the Swedish part of the Nasa massive, to which the rocks of the granite-gneiss formation in the region south of Russånes belong, Swedish geologists (e.g. DU RIETZ, 1949, p. 244) consider comparable rocks as, partly metamorphic arkoses of Sparagmitian age. As will appear from other considerations, a similar age interpretation is acceptable for the rocks under consideration. DU RIETZ (1949) found only a slight quantity of albite in the arkoses in the Swedish Nasafjell, which show a lower grade of metamorphism. During a discussion in connection with a lecture by DU RIETZ (1949), BACKLUND (1948, p. 502) suggested that the rocks of the Nasafjell might be feldspathized quartzites. From the foregoing it may appear that this suggestion has only partly been corroborated by the present investigations. Although it seems true indeed that feldspathized sediments are dealt with here, no proof has been found for an initially quartzitic composition.

The rocks of the granite-gneiss formation show resemblance to those described from the North-western Gneiss Area of Southern Norway as "flagstones" of Eocambrian age (e.g. O. HOLTEDAHL, 1952; H. HOLTEDAHL, 1950; ROSENQVIST, 1942). These "flagstones" grade downward into "basal gneisses"; in this case also feldspathization has taken place (p. 116).

The amphibolites occurring in the granite-gneiss formation are considered to represent intercalations of volcanic (at least partly tuffogeneous) origin, as suggested by the alternation of well-defined, very thin amphibolite bands (often no more than a few millimetres thick) with quartzo-feldspathic ones.

The extremely biotite-rich rocks, represented locally within the formation, may probably be considered as metasomatically altered amphibolites. Hornblende-rich portions in the biotite-rich bands on the northern Ølfjell summit (p. 24) and the amphibolite lens in the biotite-rich band south of Hessihompvatn (p. 28), seem to suggest such an origin. A comparable alteration has been described by HÄRME and LAITALA (1955, p. 95) in Southern Finland. Here a reaction rim, rich in biotite, has been formed around a hornblende-gabbroid relict in migmatite. DU RIETZ (1949, p. 93 f.f.) describes the biotitization of amphibolites in connection with the granitization of the Västervikks-quartzites in Jämtland (Sweden).

The mineral-paragenesis in the rocks of the granite-gneiss formation is in equilibrium under the P-T relations of the epidote-amphibolite facies, in the sense as defined by ROSENQVIST (1952, p. 30, 38). Here epidote and plagioclase represents the critical mineral association. The occurrence of spessartite gives no indication concerning the degree in which these rocks have bee metamorphosed (HARKER, 1932, p. 217).

As has been observed above, retrogressive metamorphism has hardly taken place within the rocks of the granite-gneiss formation. Moreover, traces of cataclasis are extremely scarce: Except within narrow cataclastic zones, related to younger joints, the quartz is never undulose and the feldspar is never bent or broken, this indicates completion of the recrystallization after the conclusion of the movements. As will be discussed later (p. 115), this recrystallization is presumably related to a post-kinematic metasomatic phase. STRAND (1952-a, p. 119) also fixed the migmatization in the Surnadalsdistrict in Southern Norway after the tectonic phase. For the North-western Gneiss Area of Southern Norway, a relatively late metasomatism has been postulated by ROSENQVIST (1942, p. 190) and H. HOLTEDAHL (1950, p. 48).

The graphiteschist formation comprises the rocks overlying the granite-gneiss formation and underlying the lowermost limestone horizon of the calciferous micaschist formation.

The most conspicuous rocks of the graphiteschist formation are represented by a series of, usually black coloured graphiteschists. When wheathered, these rocks show characteristic rusty brown and yellow colours. West of the Saltdal this series appears to have a thickness varying from 20 to 50 metres. Locally thin, discontinuous bands and lenses of quartz are found in the graphiteschists. These quartz aggregates often show a grey to reddish-brown colour due to inclusions of graphite and ore-minerals respectively.

Nearly everywhere, hard quartzitic micaschists, measuring a few metres in thickness, were found under the graphiteschists, the micaschists in their turn resting directly upon the granite-gneiss formation.

West of the Saltdal a series of monotonous, fine grained, light grey coloured micaschists and thinly layered, usually white quartzites occur between the graphiteschists and the calciferous micaschist formation. Besides quartz, biotite,and muscovite, occasionally feldspar and garnet can be macroscopically distinguished in the micaschists. The thickness of this micaschist-quartzite succession varies from 80 to almost 300 metres, a variation which is apparently due to the frequently intensive folding. The amplitude of this usually isoclinal folding varies from a few millimetres to tens of metres; a fine example is found south of Vatnhauge.

Whereas in the west the rocks described above have a general E - W to NE - SW strike, this strike changes suddenly to approximately N - S on the east side of the Saltdal. In the Saltdal the graphiteschist formation is partly located in the steep eastern valley-wall, but is further poorly exposed. Here too the series of monotonous micaschists and quartzites is represented, although in considerably smaller and strongly varying thickness. The graphiteschist series is strongly reduced and locally completely missing. Approximately 1 kilometre north of Langånes, there, where the strike changes from E - W to N - S, the boundary of the granite-gneiss formation is well exposed. The graphiteschist formation appears to the completely missing here. In the biotite-rich gneisses of the granite-gneiss formation, a horizon—measuring a few metres in thickness—with a great number of lenses of limestone, and bands of a very biotite-rich material, is found (fig. 17). On top of this

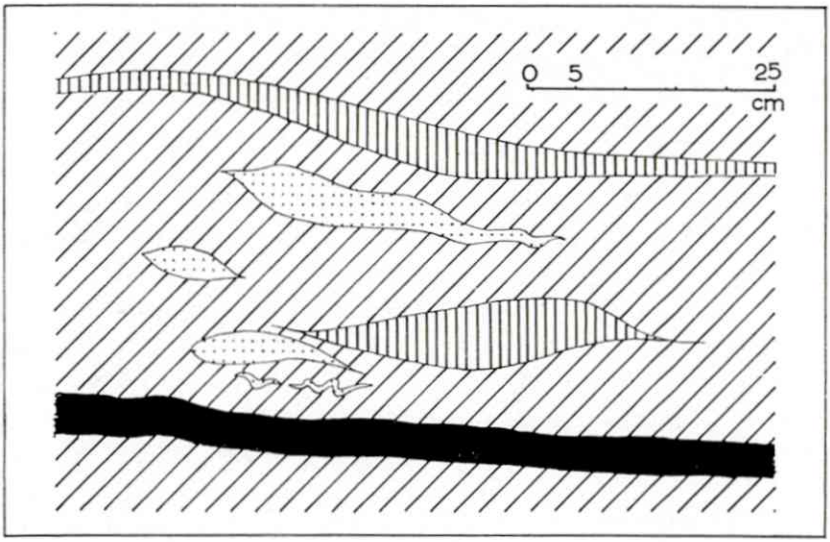


Fig. 17 - *Lenses of limestones (vertically hatched), and a layer, extremely rich in biotite (black) in a matrix consisting of microclinegneiss (obliquely hatched). Some lenticular quartz aggregates are shown (dotted). About 1 kilometre N of Langånes, 150 metres E of main road.*

horizon, biotite-rich gneisses some tens of metres in thickness, are represented, and overlain by the calciferous micaschist formation. The possibility may be considered, that a zone of tectonic mixing in dealt with here.

Near the Kjegåelv graphiteschists, about 10 metres in thickness, are exposed. Further south only finely grained micaschists are locally present between the microclinegneiss formation and the calciferous micaschist formation. Due to the poor exposure, the pinching out of the graphiteschist formation could be indicated on the geological map diagrammatically only.

Petrography

In the following petrological description the rocks of the graphite-schist formation are divided into:

Graphiteschists

Micaschists and -gneisses

Graphiteschists.

83 :	Plagioclase-bearing graphiteschist	about 800 m, south of Hessihomp-vatn.
145 :	id.	on path to Bjellåvatn, south of top 797.
126 :	id.	near Kjegåelv, at 240 m.
102 :	id.	along Kjegåelv, at 240 m.

The majority of the graphiteschists investigated have as a main constituent non-undulose quartz. The sample 102, which is relatively quartz-poor, forms an exception. Further all samples contain great quantities of colourless and/or dark mica. In addition to graphite–usually concentrated in bands–plagioclase is further the only mineral, present in considerable quantities. This feldspar has a remarkably high anorthite-content, varying from 40-60 %. Zoisite is sometimes represented in large quantities (no. 126) and is sometimes entirely missing (83 and 102). Among the characteristic features of this mineral the small, positive axial angle and the grey–or rarely anomalous–interference-colours may be mentioned. The zoisite shows no characteristic crystal shape. In the sample 26 it is intensely intergrown with the plagioclase, which latter mineral seems to form at the expense of the zoisite. The samples 102 and 126, both originating from the east side of the Saltdal, contain prehnite, partly as lamellae in the mica scales. Sometimes prehnite aggregates occur independently of the mica. Accessories are: tourmaline and titanite (often in considerable quantities) and further rutile, apatite, black opaque ore and limonite. All specimens show an intensive small scale folding, which is well marked by the graphite-rich bands. It appears that after this folding both micas have crystallized, which is evidenced by the occurrence of folded graphite bands in porphyroblasts of these minerals (see e.g. fig. 18). Finally, it is worth mentioning that the feldspar-porphyroblastesis seems to be restricted to the graphite-rich parts of these rocks.

Micaschists and -gneisses.

Micaschists, under the graphiteschists:

7 : Microcline-bearing micaschist — along railroad, about 30 m south of the southernmost tunnel.

This microcline-bearing micaschist is a strongly schistose, medium grained rock, which contains as main constituents about equal quantities of quartz, muscovite and biotite. Furthermore well-twinned microcline

Fig. 18 - *Folded trends of graphite inclusions in biotite porphyroblasts. Parallel to its cleavage the biotite crystal contains lamellae of prehnite (p). A muscovite flake (m) is partly enclosed. Plagioclase-bearing graphiteschist, along Kjegåelv, at an altitude of 240 metres.*

occurs in smaller quantities. It seems that this mineral is, at least partly, formed at the expense of the biotite. It is noticeable, further, that the accessories titanite and orthite are prominent here. These minerals occur in thin bands, the light brown coloured orthite causing pleochroic haloes in the surrounding biotite. Hereby it is noteworthy, that instead of the normal brown colour the biotite in the orthite-rich bands displays a greenish grey colour, which phenomenon may be attributed to the radio-activity of the orthite.

Micaschists and -gneisses, above the graphiteschists:

187 :	Micaceous microclinegneiss	W of Langånes, at 660 m.
31 :	Microcline-bearing micaschist	along railroad, south of the southernmost tunnel.
130 :	Garnet-mica-microclinegneiss	E valley wall, near Langånes-bridge at 150 km.
98 :	Biotite-microclinegneiss	at path near Kristendalnes, at 220 m.
119 :	Micaschist	at 290 m, in E valley wall, near Bergholnes.
120 :	Garnet-micaschist	at 250 m, in E valley wall, near the Bergholnes bridge.

The micaschists and -gneisses occurring over the graphiteschists contain quartz and mica. In the majority of the samples (except no. 120) microcline is found. Plagioclase is present in varying quantities; the anorthite-content varies from 14 to 50 %. Garnet occurs in a few samples. The biotite-microclinegneiss no 98, is strongly veined with calcite, a phenomenon, probably connected with the proximity of the limestones of the calciferous micaschist formation.

General considerations on the graphiteschist formation

This formation consists of rocks of sedimentary origin. Partly they are made up of pelitic rocks containing much organic material, partly also of pelites free of organic constituents and usually closely alternating with more psammitic rocktypes. The strongly varying thickness of the succession and the fact, that east of Saltdal, this formation is only locally represented, renders it very probable that it has been affected by strong differential movements. The rapid lateral changes are probably not of sedimentary, but of tectonic origin. Microscopically, strong tectonic influencing is not noticeable: again the quartz is not undulose and also the other minerals usually do not show any cataclastic phenomena. The fact that the microfolds of the graphite are enclosed by feldspar- and biotite porphyroblasts (see fig. 18) evidences that these last two minerals crystallized after the beginning of the movements. On account of the absence of characteristic mineral associations, the rocks of the graphiteschist formation cannot exactly be classified in a metamorphic facies. It seems likely, however, that the formation was metamorphosed in the epidote-amphibolite facies, as suggested both by tectonical (p. 107) and stratigraphical (p. 105) considerations. In all probability, these rocks have again been affected by metasomatic processes. As in the granite-gneiss formation, although to a smaller extent, replacement of microcline by myrmekitic plagioclase was observed. Microclinization of plagioclase, rather generally occurring in the granite-gneiss formation, was never observed in these rocks. Noteworthy is the high anorthite content (up to 60 %) of the plagioclase in the graphiteschists.

The rocks of the calciferous micaschist formation cover a large part of the investigated region. The formation is composed of limestones, quartzites, caleiferous and garnet-bearing micaschists and -gneisses and amphibolites. Furthermore granitic and trondhjemitic rocks occur as small, lens-shaped intrusions in this formation.

The lower boundary of the lowest limestone horizon, which can be traced over the entire region with sufficient accuracy, has been chosen as the interformational boundary between the calciferous micaschist formation and the underlying graphiteschist formation. The upper boundary of the calciferous micaschist formation lies above a calciferous micagneiss, found everywhere in contact with the amphibolite-staurolitegneiss formation.

In the western part of the investigated region the calciferous micaschist formation is very well exposed, as its outcrop is above the tree-line. In the Saltdal, however, and also east of the Saltdal, the rocks of this series are frequently covered with a close overgrowth. The eastern part of the formation is locally poorly exposed, due to the occurrence of swamps.

The best exposure of this formation is represented by the railway intersection north of Langånes (see fig. 19). Here were found, successively, from south to north:

1. A succession of limestones and white quartzites, about 100 metres in thickness. There are all transitions between pure, coarsely crystalline marble–in bands attaining a few metres in thickness–and calciferous quartzitic micaschists. The quartzites often show well-directed muscovite scales. Both the limestones and the quartzites are intersected by quartz-feldspar veins in which the quartz dominates.
2. Following the limestone-quartzite horizon, a succession, some 40 metres in thickness, of alternatively dark garnet micagneisses and strongly schistose amphibolites. Furthermore, some thin limestone

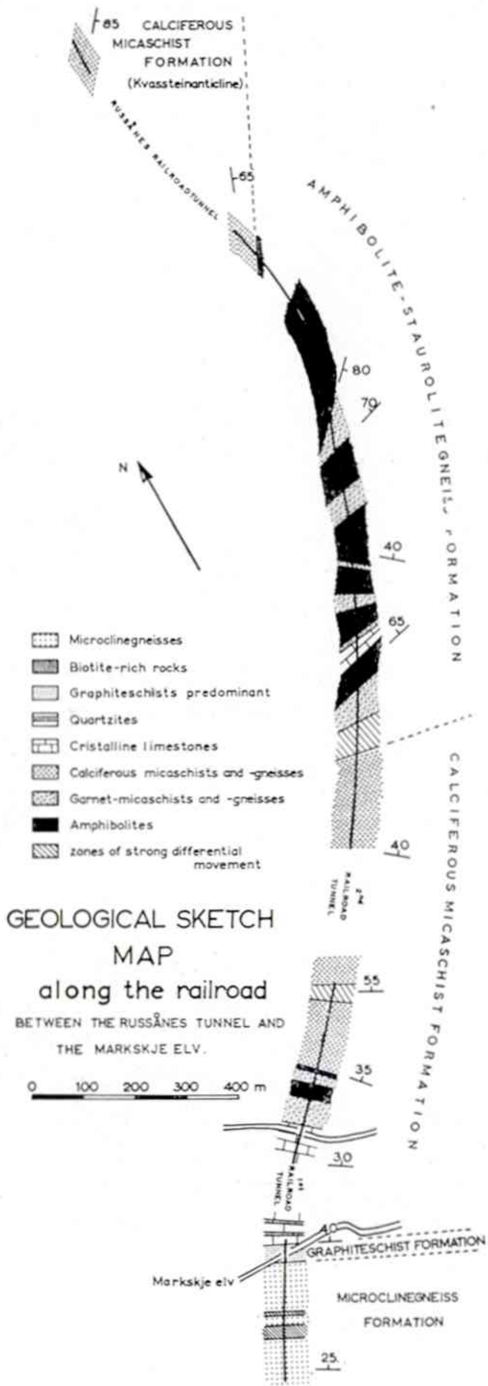

85
CALCIFEROUS MICASCHIST FORMATION
(Kvassteinanticline)
RUSSÅNES RAILROADTUNNEL
65
AMPHIBOLITE-STAUROLITEGNEISS FORMATION
80
70
N
40
65
Microclinegneisses
Biotite-rich rocks
Graphiteschists predominant
Quartzites
Cristalline limestones
Calciferous micaschists and -gneisses
Garnet-micaschists and -gneisses
Amphibolites
zones of strong differential movement
40
CALCIFEROUS MICASCHIST FORMATION
2nd RAILROAD TUNNEL
GEOLOGICAL SKETCH MAP
along the railroad
BETWEEN THE RUSSÅNES TUNNEL AND THE MARKSKJE ELV.
0 100 200 300 400 m
55
35
30
1st RAILROAD TUNNEL
40
GRAPHITESCHIST FORMATION
Markskje elv
MICROCLINEGNEISS FORMATION
25

Fig. 19.

intercalations and a single lightly coloured gneiss layer, measuring about 3 metres in thickness, are present. The drawing-out of the bands and boudinage-structures form conspicuous features.

3. A succession, approximately 400 metres in thickness, for the greater part consisting of calciferous micagneisses, representing the uppermost horizon. Some bands (a few millimetres in thickness) and "eyes" of quartz and feldspar occur in these lightly greyish-violet, finely grained rocks. Locally a small quantity of garnet is present. At about 125 metres from the base, the succession is interrupted by

Fig. 20. *Zone of strong differential movement, consisting of calciferous micaschists (and -gneisses) and light-coloured layers of quartzo-feldspathic rocks. Along railroad, ca. 500 metres N of the Markskjeelv.*

a zone, consisting of light coloured quartz-feldspar rocks, garnetiferous micaschists and strongly laminated limestones. As appears from fig. 20, the rocks of this zone are characterized by strong differential movements.

In this exposure the rocks of the calciferous micaschist formation have an E-W strike and a northward dip, varying between 30 and 55 degrees. Both westward as far as Steinfjell and on the east side of the Saltdal the strike trends about parallel to the outcrop of the granite-gneiss formation. In the south-easternmost part of the investigated region these rocks form a syncline, overturned to the west; here the strike changes to NNE-SSW.

The succession described above can be roughly traced to the west as far as Hessihompvatn. However, in this direction, amphibolite intercalations are found, though in subordinate quantity, to disappear east of Hessihompvatn. West of Hessihompvatn the importance of the calciferous micaschists and -gneisses decreases strongly. On the Steinfjell these rocks, elsewhere forming the uppermost part of the calciferous micaschist formation, appear to be missing.

East of the Saltdal this formation appears to have a greater thickness than in the west. On the lower succession of limestones and quartzites, which is still rather constant in thickness, follows a succession of garnet-micaschists and -gneisses, in which strongly schistose amphibolite intercalations, up to a few metres in thickness, are found. This series is overlain by a horizon, especially thick in the south-eastern part, of more or less pure marble (thickness about 150 metres). Near Langånes this horizon, which is for the greater part badly exposed, appears to diminish rapidly.

The synclinal structure and the steep, northward axial plunge in this area is, in the south, well illustrated by the shape of the outcrop of the limestone horizon SW of the Kjegåvatn. In the direction of the Kjegåvatn the thickness of this horizon diminishes rapidly. In both limbs of the syncline the limestones dip eastward, i.e. 25 degrees in the normal and about 75 degrees in the inverted limb.

On top of the limestone horizon, in the core of the syncline, intensely folded calciferous gneisses are found, closely resembling those occurring in the west. Further northward these gneisses may be traced to the extreme north-east of the investigated region. The great thickness of the rather steeply dipping calciferous gneisses may be attributed to tectonic causes.

In the north-west of the investigated region the calciferous micaschist formation partly shows a different development. Here it consists, from bottom to top, of garnet-micaschists, biotite-rich microclinegneisses, limestones and calciferous gneisses and -schists. Quartzites and monomict quartzite-conglomerates with a usually calciferous matrix are present in minor quantities. Amphibolites are rare in this succession; they were only observed associated with the garnet-micaschists. While mainly well exposed in the north-eastern part of the region, in the basin of the Rusåga, the rocks of the formation are covered by a dense vegetation. The succession forms a large anticline, overturned towards the south. The axis of this anticline trends approximately WSW - ENE, and plunges to the north-east at a large angle, approximately 50° in the west and increasing in eastern direction up to 90°.

The succession of the layers in this anticline is as follows:

1. The core is made up of a monotonous succession of garnet-micaschists, measuring at least 500 metres in thickness. Occasionally light-coloured quartzitic bands and thin concordant, finely grained, schistose amphibolites were observed. At higher levels the grain size of these schists appears to increase; whereas on the lowest levels the garnet-crystals seldom exceed a size of 1 millimetre in diameter, in

Fig. 21 - *Ridge, consisting of vertical, massive quartzites, in the southern limb of the Kvassteinanticline, viewed from top 639, in the direction of the strike.*

the highest horizons they often measure up to 1 centimetre. Further the amount of garnet also increases in upward direction. A massive, light-coloured quartzite horizon is clearly marked in the topography, due to its erosion resistance (fig. 21). The thickness of this horizon in the normal limb is about 40 metres, and in the inverted one about 90 metres; in either limb it appears to be constant. The structure of the Kvassteinanticline is well marked by this quartzite; in the normal limb it forms a ridge north of Kvassteinvatn; north-east of "top 639" (outside the investigated area) it turns, rather suddenly, to the inverted limb north of Kvassteinhauge and Steinfjell. Whereas this quartzite is commonly rather pure, some parts are relatively rich in muscovite and somewhat schistose. Boudinage is especially observed in the thinner northern limb.

2. The garnet-micaschists are overlain by a thick succession, for the greater part consisting of biotite-rich microclinegneisses. These rocks are massive in appearance; still the mica is mostly well directed. Macroscopically, garnet and epidote can be distinguished in addition to quartz, feldspar and mica. The thickness of this gneiss-horizon varies strongly; in the inverted limb of the anticline (exposed in the investigated region) this variation is estimated at from 600 to over 1500 metres. The composition of this succession is again very uniform: only a few lenses of mostly pure marble, and a quartzite-layer (see fig. 22), measuring a few metres in thickness, and showing

Fig. 22 - *Boudinage in a quartzite layer in the biotite-rich microclinegneisses, about 800 metres S of Kvassteinhauge. The greatest thickness of the boudins is about 4 metres.*

boudinage structures, occur. The largest of these limestone lenses, which is exposed east of Kvassteinhauge, is at the maximum 180 metres thick; the margins are very schistose. Also at the boundary of the garnet-micaschists and the microcline-gneisses a limestone horizon is found, measuring a few metres in thickness in the inverted limb. In the normal limb this limestone, as well as the garnet-mica-schist directly underlying the microclinegneisses, are only exposed in the form of lenses. In connection with their slight thickness, these limestones are not indicated on the geological map. The lowermost microcline-gneisses are often very rich in quartz, occurring both in thin veins and in lenses.

A third, very remarkable occurrence of limestone is exposed north-east of Vatnhauge. From the Ruså̊ga a limestone horizon can be followed in a south-westward direction. At first this limestone is bordered on both sides by microclinegneisses; north of Vatnhauge, however, it forms the boundary between the microclinegneisses and the overlying calciferous micaschists. There is a distinct decrease in the schistosity of the limestone horizon in a south-westward direction.

Fig. 23 - *Characteristic wheathering of calciferous micaschists, on the NW-slope of Steinfjell, at an altitude of 815 metres.*

3. In the southern limb of the anticline, as well as in the north (outside the investigated area, the microclinegneisses are overlain by a thick series of calciferous micaschists, which contains the last mentioned limestone horizon at its base. This limestone horizon varies in thickness from approximately 60 to over 200 metres. The calciferous schists and gneisses attain a thickness of several hundreds of metres. They are finely grained and of a violet-grey colour, while differential wheathering has given the erosion surface a characteristic appearance (see fig. 23). The rocks show a great resemblance to the calciferous schists and -gneisses, elsewhere in the calciferous micaschist formation, already described. Especially in the easternmost parts of the anticline, oval spots of iron-rich carbonate, measuring a few millimetres, are of frequent occurrence in the calciferous schists and gneisses. The higher parts of this calciferous series are richer in quartz; often the last 20 metres consist of an impure, grey-coloured quartzite. In addition to quartzites, intercalations of a conglomerate, consisting of exclusively quartz pebbles, were sometimes observed, showing lateral transition into the quartzites. The pebbles are usually embedded in a calciferous matrix; locally, however, the matrix consists of a rather pure quartzite. These pebbles—which are relatively constant in size—have a flattened, ellipsoidal shape; the longer axis, which often exceeds 40 centimetres, invariably lies in the direction of dip. The medium axis, usually not exceeding 10 centimetres, is in the strike direction; the shorter axis, perpendicular to the bedding-plane, measures up to about 5 centimetres in length. According to KVALE (1954, p. 62) the main linear structures (including elongated pebbles) in the Scandinavian Caledonides trend parallel to the direction of movement.

Apart from the above mentioned small-scale folding in the garnet-micaschists and in the horizon forming the boundary of garnet-micaschist- and microclinegneiss series of the Kvasstein-anticline folding was only rarely observed in these rocks. Near Kvassteinhauge a folding with an amplitude of tens of metres is found, giving rise to an appreciable increase in thickness (see fig. 24 and 25). This duplication of erosion resistant quartzite has caused the topographical culmination of Kvassteinhauge.

Especially in the calciferous micaschists in the Kvasstein anticline a joint system with a strike direction approximating N330 E is clearly distinguishable. This direction coincides with that found most frequently in the granite-gneiss formation. As has been stated earlier (p. 22), the course of the brooks is frequently determined by this principal joint direction (see fig. 4).

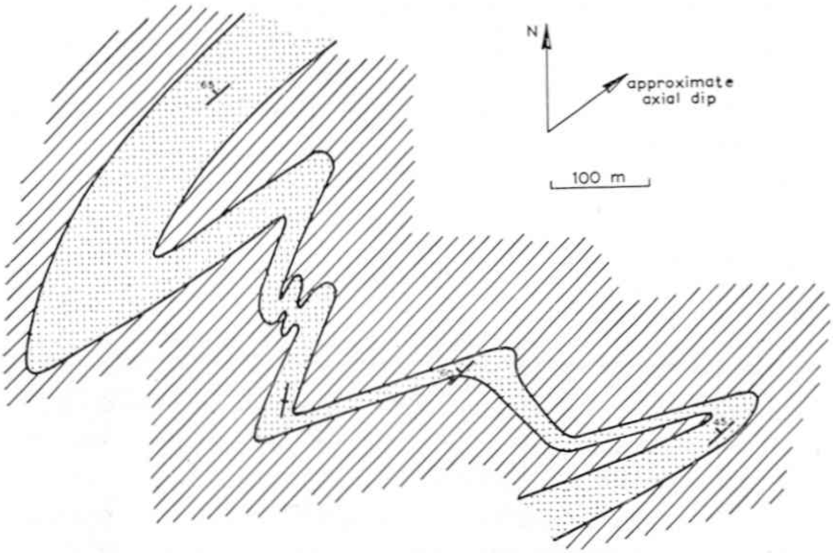


Fig. 24 - *Folding of quartzites (dotted) in garnet-micaschists. Kvassteinhauge.*

Distributed throughout the calciferous micaschist formation many pegmatitic pockets occur, mainly consisting of quartz and feldspar. West of Kjegåvatn a system of quartz dikes (measuring up to 1 metre in thickness) was observed with a strike N70E. Further the occurrence of quartz-feldspar material in the hinges of the folds is worth mentioning, a phenomenon which can be observed both in microfolds and in folds with an amplitude of tens of metres. Fig. 26 shows a representative example. Finally, lenticular, leucocratic bodies are of frequent occurrence in certain horizons of the calciferous micaschist formation, east of the Saltdal. Part of these rocks show a texture and composition resembling those of the mica-poor microclinegneisses of the granite-gneiss formation. Partly, however, they have a granitic or trondhjemitic

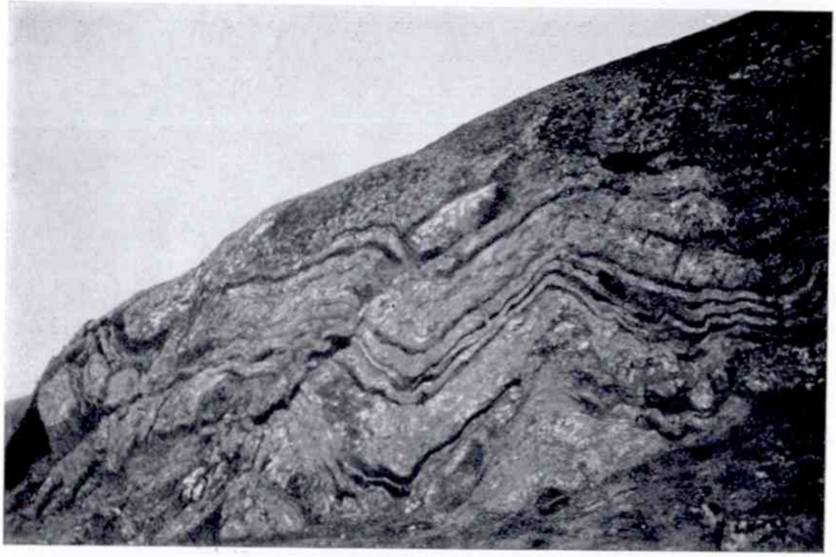


Fig. 25 - *Folding in the quartzites of fig. 24.*

texture and composition. The granitic and trondhjemitic lenses are concordant with respect to the surrounding rocks; their length varies from a few decimetres to some hundreds of metres. The larger ones can reach a thickness of about 30 metres. The boundary with the neighbouring rock is always sharp. Occasionally a narrow pyroxene- and amphibole-rich zone (approximately 0.5 metre wide) was observed in the micagneisses around a trondhjemitic body, e.g. east of Kristendalnes at a height of 400 metres. In addition to quartz and feldspar, muscovite

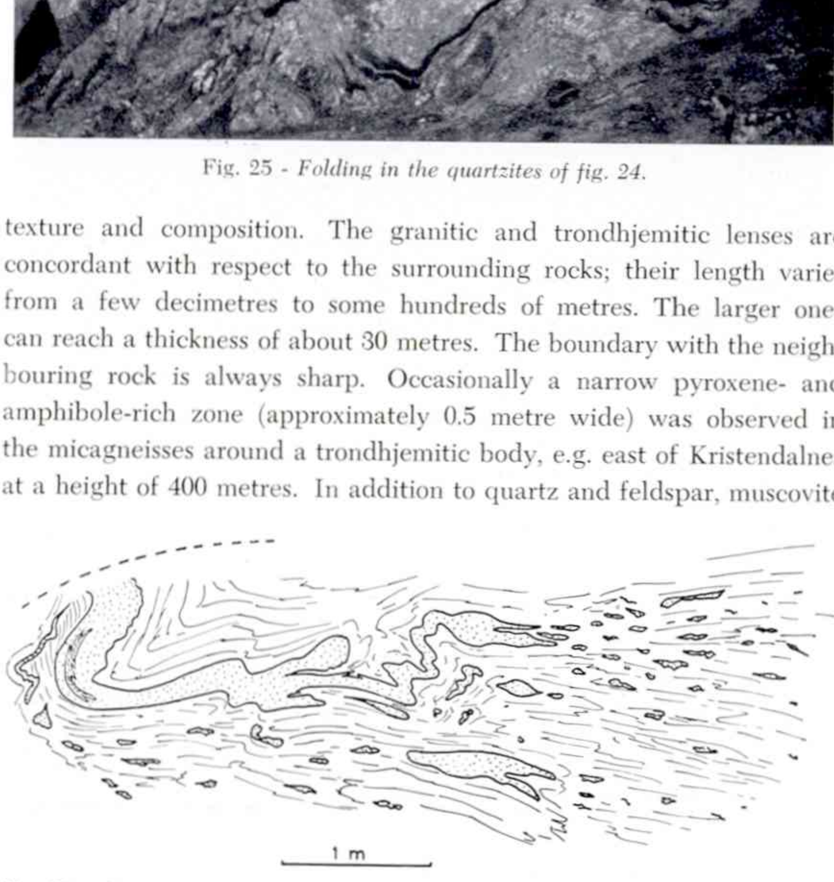


Fig. 26 - *Concentration of quartzo-feldspathic material (dotted) in the hinge of a fold in garnet-micaschists and -gneisses. Along the W-shore of Kjegåvatn (dashed line).*

and biotite can be observed in these granitic and trondhjemitic rocks. These last minerals are sometimes directed more or less parallel to the schistosity in the surrounding rocks, occasionally giving rise to a distinctly gneissose appearance. The leucocratic rocks seem to be restricted to the horizons immediately over and under the limestones, exposed e.g. near Kjegåvatn. Only the larger occurrences could be indicated on the geological map.

Petrography

In the description of the rocks of the calciferous micaschist formation the following groups have been distinguished:

Quartzites
Limestones
(Garnet)-micaschists and -gneisses
Calciferous micaschists and -gneisses
Microlinegneisses
Amphibolites

Furthermore the granitic and trondhjemitic rocks found as minor intrusive bodies within the formation are described under a separate heading, together with their contact rocks.

Quartzites

Quartzites of the Kvassteinanticline.

146 :	Calciferous scapolite-epidote-quartzite	E-Hessihomp.
80 :	Calciferous quartzite	id.

These rocks originate from the topmost quartzitic horizon of the calciferous micaschists. Quartz is the main constituent. Andesine, with appr. 35 % An. is present in smaller quantities. A yellow, iron-rich epidote and calcite are important constituents. Further a large quantity of scapolite was found in the sample 146.

89 :	Quartzite (pebble in quartzite-conglomerate)	1 kilometre E of Hessihompvatn.

A quartzite pebble, originating from the conglomerate exposed between Hessihompvatn and Vatnhauge, contains some directed muscovite crystals and a very small quantity of calcite. Further the occurrence of rounded tourmaline, rutile, zircon, titanite, magnetite and epidote (?) may be mentioned, which minerals tend to be concentrated in bands.

Quartzites in the remaining parts of the calciferous micaschist formation.

34 : Microcline-bearing quartzite along the railroad, about 80 m northward in the southernmost tunnel.

This impure microcline-bearing quartzite is a representative example of the quartzite bands in the lowest marble-quartzite horizon of the calciferous micaschist formation.

In addition to the main constituent—non-undulose quartz—smaller quantities of microcline, biotite, and muscovite are present. The quartz occurs in small equidimensional crystals of a rather regular grainsize (on an average 0.2 mm). The microcline forms irregular crystals between the quartz grains. The mineral shows for the greater part a cross-hatched structure; occasionally, however, it is untwinned. A rather strong alteration into kaoline and sericite is observed. Plagioclase is scantily represented. The mineral shows a relief equal to, or slightly lower than that of the canadabalsam. In addition to the micas there are smaller quantities of chlorite and epidote. Some calcite is found as a vein-filling mineral.

Limestones

Limestones of the Kvasstein-anticline.

The limestone horizon between the microclinegneisses and the calciferous micaschists and -gneisses (p. 58):

75 : Impure marble at 750 m, NE of Hessihompvatn.

The impure marble, no. 75, contains a considerable quantity of biotite, and a smaller amount of muscovite. Whereas the colourless mica is equally distributed throughout the rock, the quantity of biotite appears to increase with increasing proximity to the microclinegneiss contact. In addition to some quartz crystals a small quantity of zoned plagioclase was found. It is remarkable that this plagioclase is considerably more calcic than that in the bordering calciferous micaschists (p. 70); in the former an anorthite percentage of over 50 was measured, while the latter contain a percentage up to 25 %.

The limestone horizon east of Kvassteinhauge (p. 57):

77 : Graphite-bearing phlogopite-tremolite-marble	at 600 m, E of Kvassteinhauge.

The marble 77 contains, in addition to phlogopite and tremolite, a large quantity of graphite, distributed throughout the rock. Furthermore some plagioclase porphyroblasts were found, rich in inclusions of finely divided graphite. The tremolite shows alteration into fine-scaled talc.

Limestones in the remaining parts of the calciferous micaschist formation.

Marbles from the lowermost marble-quartzite horizon (p. 51):

33 : Marble (containing feldspar-rich band)	on railroad, south of the southernmost tunnel.
35 : Impure marble	on railroad, north side southernmost tunnel.

The marbles 33 and 35 originate from the massive marble layers which alternate with the quartzites mentioned on p. 62.

In addition to their main constituent, calcite, they contain a large quantity of quartz. This mineral is either distributed throughout the rock or forms discordant veinlets, a few millimetres in thickness. The quartz crystals are not undulose. As a third constituent of these marbles plagioclase is present in about the same quantity as the quartz. The mineral is mainly formed at the boundary of calcite and quartz. This plagioclase shows a remarkable habitus. Its anorthite content varies very strongly, viz. from rather pure albite to labradorite. Occasionally the plagioclase individuals show an inverse zoning; usually however, calcic patches are found within more sodic crystals. These calcic areas often appear to have as their core a mica- or a calcite-aggregate. The fact, that the inclusions often show an optic continuity suggests that the plagioclase is formed at their expense. Finally crystals with irregularly shaped lamellae are observed to concur with the schistosity. One of the samples (35) further contains an amount of microcline, formed at the expense of the plagioclase. In addition to muscovite and biotite, smaller quantities of titanite, apatite, pyrite, ilmenite and leucoxene are found.

Limestones from the uppermost limestone horizon (p. 54):

105 :	Actinolite-bearing marble	along Kjegåelv at 420 m.
104 :	Forsterite-diopside-actinolite-zoisite-marble	along Kjegåelv at 420 m.
122 :	Diopside-actinolite-zoisite-marble	E of Kristendalnes, at 570 m.

The marbles of the uppermost horizon contain a number of lime-silicate-minerals, viz.: actinolite, zoisite, and sometimes diopside. Further forsterite, potash-feldspar, and a smaller quantity of plagioclase have been formed. The actinolite, occurring in all these samples, appears to be a very light green variety; the extinction angle $^{n}\gamma/c$ varies from 18 to 20 degrees. Sometimes (105), the amphibolite is rather intensely altered into fine-scaled talc. All the samples contain a small quantity of light brown to colourless pleochroic mica, which is considered to be phlogopite. Whereas the sample 105 does not contain other constituents except for a few grains of quartz and magnetite, the other samples are rather rich in diopside. This mineral has an extinction angle $^{n}\gamma/c$ of about 40 degrees. A few rounded crystals without any cleavage were determined as forsterite. Zoisite occurs in the form of large porphyroblasts with a small, positive axial angle and grey, or occasionally anomalously blue, interference colours. This mineral appears to be strongly replaced by microcline. The plagioclase is inversely zoned. Whereas the sodic cores of the plagioclase crystals are sometimes partly replaced by microcline, more calcic rims appear partly to have remained in tact. Slide no. 122 contains some quartz aggregates; no. 104 some light-brown tourmaline.

Intercalations of clastic rocks in the uppermost horizon:

112 :	Gneissose band in marble	between Kjegåvatn and top 717.
114 :	Calciferous tremolitegneiss	400 m N of top 717.

Both samples contain in addition to calcite a large quantity of quartz, tremolitic amphibole, and light brown mica. In smaller quantities inversely zoned oligoclase to oligoclase-andesine is present, having an anorthite content varying from 20 to 30 %. One of the samples (114) further contains a considerable quantity of, sometimes perthitic, microcline. Sample 114 originated from a zone of strong differential movement, as indicated by finely granular zones of undulose quartz and feldspar, and impregnation with limonite.

Amphibole-rich rocks, occurring at the contact of limestone and gneiss:

113 :	Actinolite rock	about 800 m SW of Kjegåvatn.
115 :	Actinolite rock	200 m W of top 717.

The actinolite rocks 113 and 115 originate from narrow bands—entirely made up of an amphibole of the tremolite-actinolite series—which were often observed at the limestone-gneiss boundary. The formation of actinolite is attributed to a reaction between limestone and gneiss, causing a remarkable monomineralic product. The amphibole is slightly pleochroic from colourless to very light-green and has an extinction angle $^{n}\gamma/c$ of appr. 20 degrees.

(Garnet-) micaschists and gneisses

(Garnet-) micaschists (and -gneisses) of the Kvassteinanticline.

(Garnet-) micaschists from the core of the Kvassteinanticline (p. 55):

175 :	Garnet-micaschist	800 m NE of Kvassteinhauge.
165 :	Micaschist	600 m E of top 639.
67 :	Garnet-micaschist	at 600 m E of top 639.
166 :	Garnet-micaschist	200 m E of top 639.
167 :	Fine-grained garnet-micaschist to -gneiss	200 m E of top 639.
73 :	Garnet-micaschist	on top 639.
170 :	Graphite-bearing staurolite-kyanite-garnet-micaschist	N of Steinfjell, at 660 m.
74 :	Staurolite-garnet-micaschist	at 630 m, along Hessihompelv.
172 :	Garnet-micaschist (small-scale folded)	at 605 m, along Hessihompelv.
169 :	Staurolite-garnet-micaschist	at 650 m, N of Steinfjell.
168 :	Micaschist (small scale folded)	at 580 m, 1 km S of Kvasstein-vatn.
66 :	Biotiteschist	E of top 639, at 570 m.
71 :	Garnet micaschist (small scale folded)	at 540 m, N of Kvassteinvatn.
78 :	Garnet micaschist	500 m E of Kvassteinvatn.
79 :	Actinolite-clinozoisite-biotitegneiss	at 540 m, N of Kvassteinvatn.
176 :	Actinolite-clinozoisite-biotiteschist	at 660 m, on the NE summit of Kvassteinhauge.

The micaschists of the Kvassteinanticline possess a relatively uniform mineral composition. Nearly always quartz is the main constituent, with varying quantities of biotite and muscovite. Garnet is present in all of the 16 investigated micaschist samples. The low feldspar content of these rocks, as compared with that of similar rocks from the other parts of the calciferous micaschist formation, is remarkable. Potash-feldspar is present in very small quantities in two rocksamples from the contact with the microclinegneiss (66 and 71). The mineral forms sometimes strongly kaolinized aggregates. Plagioclase also occurs in small quantities only, except in sample 167, which is relatively plagioclase-rich. Some samples contain kyanite and/or staurolite (170, 169, and 74). Sometimes prehnite was observed in the form of lamellae in biotite (66). Titanite orthite, zircon, rutile, apatite and tourmaline may be present as accessories. The ore-minerals limonite and magnetite are found occasionally.

The anorthite content of the inversely zoned plagioclase usually varies between 15 – 30 %. In the staurolite- and kyanite-bearing samples, however, the anorthite percentage increases up to 40. In the highest horizons of the garnet micaschists, at the contact with a thin limestone horizon (p. 57), higher percentages of anorthite were also measured, i.e. 50 % in 66. Whereas the muscovite, especially in the higher parts of this succession, often show a very intensive folding, biotite appears to have been formed later. This is proved by the slighter

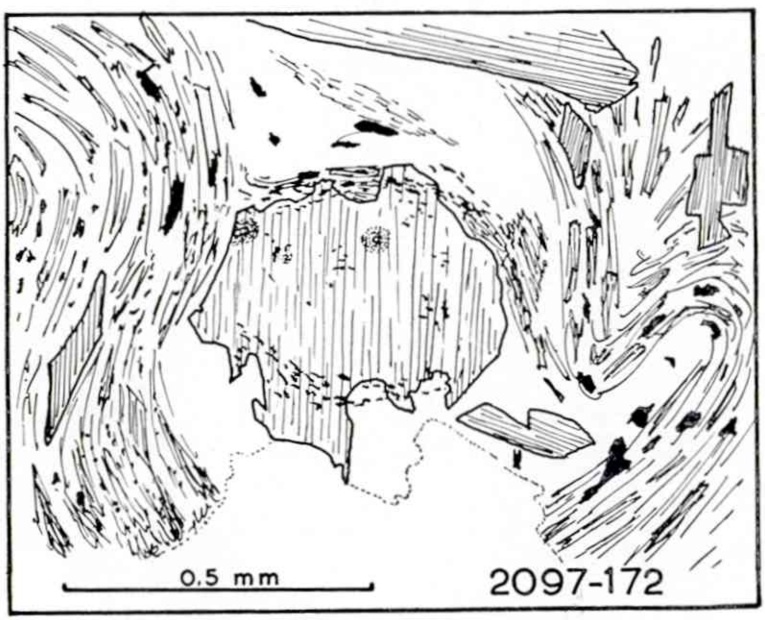


Fig. 27 - *Undirected porphyroblasts of biotite in a folded garnet-micaschist. Along the Hessihompelv, at an altitude of 605 metres.*

direction of the—frequently porphyroblastic—crystals and the absence of bent individuals (see fig. 27). In these rocks the garnet occurs in two forms: in the first place as large poikiloblasts, especially in the small-scale folded rocks often containing S-shaped trends of inclusions and showing chlorization at the rims; in the second place as small individuals, tending towards idioblastic development and containing a lot of dust-inclusions (fig. 28). Furthermore the frequent occurrence of tourmaline in these rocks is conspicuous.

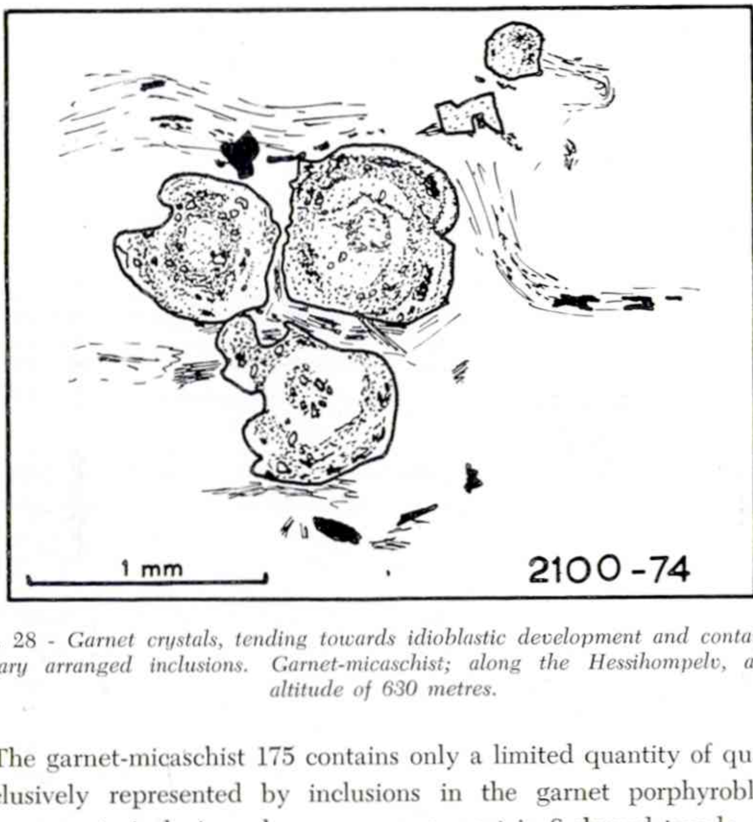


Fig. 28 - *Garnet crystals, tending towards idioblastic development and containing zonary arranged inclusions. Garnet-micaschist; along the Hessihompelv, at an altitude of 630 metres.*

The garnet-micaschist 175 contains only a limited quantity of quartz, exclusively represented by inclusions in the garnet porphyroblasts. These quartz inclusions show an arrangement in S-shaped trends. The occurrence of biotite in this rock is limited to the pressure shadows of the garnet individuals.

The actinolite-biotitegneisses (79 and 176) originate from the immediate vicinity of the boundary garnet-micaschist—microclinegneiss. The influence of the adjacent limestone is clearly noticeable: the plagioclase from these specimens has an anorthite content up to 50 %, while in addition the lime-silicates actinolite and clinozoisite were formed. Both minerals occur included in biotite-porphyroblasts, the clinozoisite surrounded by pleochroic haloes.

Garnet-micagneisses from the microclinegneiss series of the Kvassteinanticline (p. 56):

70 : Garnet-micagneiss	along Hessihompelv, E of Kvassteinvatn.
72 : Tourmaline-rich garnet-biotitegneiss	800 m ENE of Kvassteinvatn.
76 : Garnet-hornblende-biotitegneiss	at 750 m, NE of Hessihompvatn.

The retrogradely altered garnet-micagneiss no. 70 originates from a zone in the microclinegneiss series showing intensive quartz impregnation (approximately 20 metres from the contact with the underlying garnet-micaschist series). The most characteristic feature is represented by protracted and retrogradely altered garnet (fig. 29). The rock contains lenticular quartz concentrations. Neither these, nor the rest of the rock show the slightest trace of cataclasis.

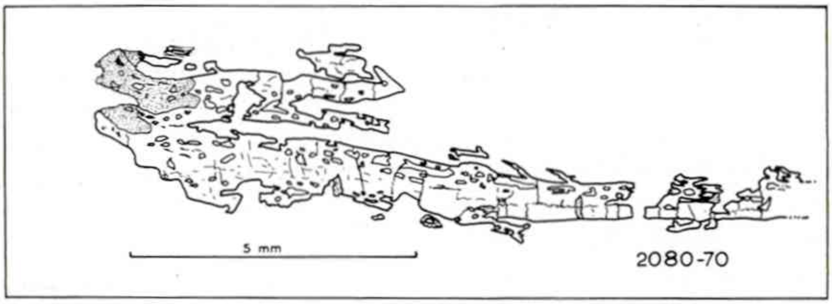


Fig. 29 - *Garnet crystal, strongly drawn out. The garnet is slightly altered into chlorite. In garnet-micagneiss, along the Hessihompelv, E of Kvassteinvatn.*

A band of a very hard, black rock type (sample 72), a few centimetres in thickness, was found north of Kvassteinvatn, at the contact of a limestone lens (p. 57) and the microclinegneiss. Microscopically, this fine-grained tourmaline-rich biotitegneiss appears to consist, for a very large part, of strongly zoned plagioclase, with an anorthite content which can exceed 40 % in the calcic rims. In the feldspar mass large quantities of well directed inclusions occur, principally consisting of clinozoisite, biotite, ore minerals and tourmaline. These inclusions are arranged in trends, showing a slight folding. Furthermore, large garnet- and undirected biotiteporphyroblasts are found, obviously formed in a late period, which also applies to the feldspar. There is only a minor quantity of quartz. Furthermore a large quantity of green hornblende and a few large zoisite crystals have been formed at the side of the limestone contact.

The garnet-hornblende-biotitegneiss 76 originates from the contact of the microclinegneiss series and the overlying calciferous micaschist series. It is distinguished by a high content of green hornblende. The anorthite content of the plagioclase amounts about 20 %, i.e. within the range of the values measured in the microclinegneisses. Furthermore there are no differences worth mentioning between this specimen and the other samples.

(Garnet-) micaschists and -gneisses in the remaining parts of the calciferous micaschist formation.

99 :	Garnet-micaschist	path to Sletfjell, at 300 m.
131 :	Garnet-micaschist (with feldspar 'eyes')	700 m SE of Langånesbridge, at 300 m.
63 :	Micagneiss	S of 2nd tunnel, along railroad.
192 :	Garnet-micagneiss	along Markskje-elv, at 340 m.
217 :	Garnet-biotitegneiss	along Markskje-elv at 600 m.

These medium grained, strongly schistose rocks are very dark grey coloured. Main constituents are: quartz, plagioclase and biotite. Furthermore varying quantities of muscovite and garnet are found. In one of the investigated samples (131) the feldspar is concentrated in 'eyes'; in other samples this mineral is scattered throughout the rock. Quartz, the main rockforming mineral, shows no undulose extinction but for a few exceptions (192 and 217). The plagioclase is strongly zoned: in several slides the basic rims were found to contain up to 45 % anorthite, the more sodic cores contain at the minimum 25 % anorthite. The feldspar in no. 131, however, forms an exception: it is hardly zoned, its anorthite content amounts to 16 %. Potash-feldspar was not observed. The biotite, which is present in considerable quantities, is well directed. Even in small-scale folded rock samples the biotite plates are not or hardly bent. Sometimes (192), the biotite contains folded trends of ore inclusions. Garnet is present in all specimens, except in no. 63. The habitus of this mineral varies considerably: sometimes it is in skeleton-like individuals without a distinctive crystal form and with biotite and quartz inclusions, then again it is in the form of idioblastic crystals devoid of inclusions. In no. 217 the cores of the garnet crystals contain abundant small titanite inclusions.

Accessories are: titanite, orthite, apatite, and tourmaline. Furthermore magnetite, pyrite, and limonite are present.

Calciferous micaschists and -gneisses.

Calciferous micaschists and -gneisses of the Kvassteinanticline.

48 :	Calciferous epidote-micagneiss	along railroad, S of Russånes-tunnel.
50 :	Calciferous hornblende-epidote-biotite-schist	station Rusåga.
49 :	Calciferous hornblende-epidote-biotite-gneiss	along the Rusåga, 400 m from confluence with Saltelv.

The calciferous micaschists and -gneisses are not only characterized by their calcite content, but also by the presence of epidote and the absence of garnet. Their content in plagioclase varies greatly: sometimes (e.g. in no. 49) it equals that of quartz. The anorthite content of the plagioclase is remarkably constant: percentages from 23 to 25 were measured. Biotite is always present in large quantities, in well-directed, dark brown plates. The epidote shows the yellow to colourless pleochroism, typical of the iron-rich variety. Some specimens (50 and 49) further contain a quantity of green hornblende. Some chlorite has been formed at the expense of the amphibole. Accessories are: tourmaline, rutile and apatite.

Calciferous micaschists and -gneisses in the remaining parts of the calciferous micaschist formation.

106 :	Calciferous biotiteschist	along Kjegåelv, at 460 m.
38 :	Calciferous biotitegneiss	along railroad, 60 m N of 2nd tunnel.
37 :	Calciferous garnet-micagneiss (retrogradely altered)	N of 2nd tunnel, along railroad.
36 :	Calciferous scapolite-garnet-biotite-gneiss	120 m N of southernmost tunnel, along railroad.
158 :	Calciferous garnet-biotitegneiss	appr. 350 m SE of Rundvatn.
91 :	Calciferous micaschist	W of Langånes, at 800 m.
237 :	Calciferous hornblende-biotitegneiss	W-Lakeshore, E of Bleiknesfjell.

As regards their main constituents, the calciferous schists and -gneisses appear to be of a fairly constant composition. They contain about equal quantities of quartz and well-directed, darkbrown biotite. An inversely zoned plagioclase, rather constant of composition, occurs to a slightly smaller extent. The anorthite content averages approximately 30 %. In a few strongly zoned examples values up to 17 % for the sodic cores, and up to 50 % for the rims of the crystals were measured. The size of the quartz grains in these specimens usually varies between 0.2 and 0.3 millimetre. Poikiloblastically developed garnet is present in many of the calciferous gneisses examined. Sometimes (e.g. in 37) this mineral is strongly altered into chlorite. Amphibole occurs in two specimens, in the one case (36) represented by a light green to colourless member of the actinolite-tremolite series and in the other (237) by a green hornblende. In one of the samples (36) a rather large quantity of scapolite was found, in a highly birefringent Ca-rich variety. The occurrence of this mineral and of tourmaline points to a metasomatic influencing of this rock. Calcite is present in all specimens in varying quantities. Accessories are: tourmaline, zircon, titanite, rutile, apatite and clinozoisite sometimes with brown orthite in the core. Finally magnetite, ilmenite, pyrite, and limonite may be mentioned.

Microclinegneisses.

65 :	Biotite-epidote-microclinegneiss	at 570 m, E of top 639.
6 :	Garnet-biotite-clinozoisite-microcline-gneiss	1 km NE of Hessihompvatn.
69 :	Biotite-epidote-microclinegneiss	at 480 m, along Hessihompelv.

The main constituents of the microclinegneisses are quartz, feldspars, biotite, and members of the epidote-zoisite group. These minerals occur in about equal quantities. In addition to being present in the form of non-undulose crystals scattered throughout the rock, quartz occurs, in smaller quantities, in the form of inclusions in both feldspars, partly as vermicules in the plagioclase. Sometimes the microcline shows porphyroblastic development. The plagioclase is zoned; the anorthite content ranges from 20 – 27 %. There are fine examples of replacement of this mineral by potash-feldspar (see fig. 30). Myrmekite textures are also of frequent occurrence. A second plagioclase generation is found to replace the microcline; at least part of the myrmekite textures are re-

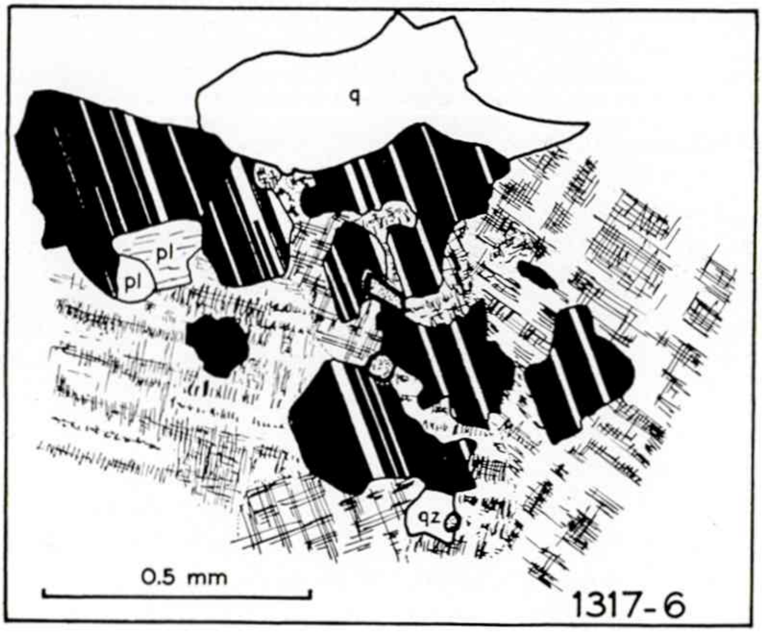


Fig. 30 - *Replacement of polysynthetically twinned oligoclase by microcline (cross-hatched). pl, oligoclase; q, quartz. Rutile is indicated as some dotted grains. In garnet-biotite-clinozoisite-microclinegneiss. About 1 kilometre NE of Hessihompvatn.*

lated to this replacement. Biotite is present as well directed, unaltered scales. Epidote or clinozoisite are represented as numerous small inclusions in all the main rockforming minerals. In one case, no. 6, there is an amount of garnet present. Only rarely muscovite is represented, and then in extremely small quantities only.

Amphibolites.

100 : Zoisite-amphibolite	path to Sletfjell, at 390 m.
103 : Quartz-rich amphibolite	at 300 m, along Kjegåelv.
107 : Amphibolite	near mouth of brook in Kjegåvatn.
116 : Quartz-rich garnet-amphibolite	at 510 m, 200 m N of top 582.
123 : Amphibolite	at 575 m, SW of top 717.
125 : Quartz-rich garnet-amphibolite	at 420 m, E of the Kristendalnes-bridge.
178 : Garnet-amphibolite	0.5 km NE of top 797, 100 m S of the Kjegåelv at 360 m.
121 : Amphibolite (strongly chloritized)	at 450 m, E of Kristendalnes.
154 : Amphibolite (crushed)	80 m S of Kjegåelv, at 360 m.
173 : Fine-grained amphibolite	at 610 m, along Hessihompelv.

174 : Garnet-amphibolite at 575 m, appr. 900 m E of Kvassteinvatn.

The texture of the amphibolites of the calciferous micaschist formation varies greatly. On the one hand highly schistose, fine-grained types are represented containing a dark green hornblende, on the other hand, occasionally, coarse grained, undirected types occur, with light-green hornblende crystals, sometimes a few centimetres in length. Furthermore garnet, quartz and plagioclase are present in varying quantities. Only occasionally (121 and 100) a few grains of untwinned potash-feldspar occur. The quartz content of the majority of these samples is conspicuous. The origin of this mineral is often uncertain; sometimes, however, it obviously bears relation to a veining by quartzo-feldspathic material (125). The anorthite content of the plagioclase varies greatly; in different samples values ranging from 10 to 70 % were observed. No regularity was found in the distribution of the anorthite content of the plagioclase; now calcic, and then again sodic plagioclase is found in schistose, as well as in undirected types. Inversely zoned crystals are common. In the zoisite-amphibolite no. 100 zoisite remnants in oligoclase (15 % An.) showing optic continuity suggest replacement by the latter. The occasionnally occurring garnet shows a poikiloblastic development; only quartz and hornblende are observed as inclusions. Occasionally small quantities of biotite and chlorite are present. Titanite is nearly always the principal accessory constituent; now and then a few grains of rutile, zircon, apatite, and of members of the epidote-clinozoisite series are found; ore occurs in small quantities in the form of magnetite, hematite and limonite.

The green hornblende in the coarse grained amphibolite 154 (average grain size 5 millimetres) contains greyish brown cores. It seems probable that these cores are relics of magmatic origin. In this specimen a rather advanced alteration of hornblende into chlorite and of plagioclase into sericite has taken place.

As regards composition, the amphibolite no. 121 differs considerably from the varieties described above. Instead of green hornblende it contains a very light green actinolite, intensely altered into chlorite. In addition to albite-oligoclase (10 % An.), this rock contains a small quantity of potash-feldspar and rather much muscovite. No quartz is present.

Granitic and trondhjemitic rocks, intrusive in the calciferous micaschist formation.

108 :	Trondhjemite	near Kjegåvatn.
118 :	Trondhjemite	at 440 m, E of Kristendalnes.
238 :	Granite	appr. 1100 m, E of Bleiknesfjell.

The quartzo-feldspathic rocks, which occur as intrusives in the calciferous micaschist formation, have been included under the heading of the same name, though they are obviously younger. The main constituents in these directionless rocks, quartz and feldspar, occur in about equal quantities. In the sample 238, where microcline is the principal feldspar, this mineral is developed as large, sometimes perthitically intergrown, crystals, which are again characterized by fine cross-hatched structures. The composition of the plagioclase in the various rocks varies from 12 tot 25 % An. In the trondhjemite no. 108 the zoned structure of the plagioclase is very conspicuous. In the central parts of the plagioclase crystals a normal zoning appears to have been developed, i.e. a more calcic core is surrounded by a more sodic zone. However, the zoning of the peripheral parts of the crystals is inverse, the more sodic zone just mentioned being surrounded by an outer rim of a more calcic composition. In these rocks the microcline is again younger than part of the plagioclase, which is clearly in course of replacement. In its turn the microcline is partly replaced by a younger generation of plagioclase, characterized by myrmekite textures. Both biotite and muscovite are represented, however, in strongly varying proportions. Sometimes the biotite shows some chloritization. Accessorily titanite and apatite may occur. Sometimes cataclastic phenomena were observed (118 and 238). The quartz in these specimens is undulose, the feldspar is sometimes bent and broken.

Contact rocks of the trondhjemites:

109 :	Pyroxene-amphibole rock	West shore of Kjegåvatn.
117 :	Pyroxene-amphibole rock	at 400 m, E of Kristendalnes.

An interesting feature is represented by narrow pyroxene- and amphibole-bearing zones (measuring approximately 0.5 m in width), which were sometimes found around the trondhjemitic bodies. The two samples investigated show a strong resemblance. In addition to

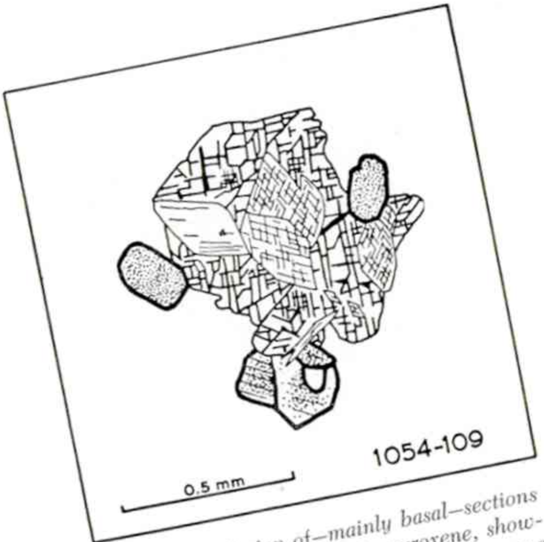


Fig. 31 - *Inclusion of—mainly basal—sections of amphibole in monoclinic pyroxene, showing diallage-cleavage. Furthermore some clinozoisite crystals (dotted) are indicated. Pyroxene-amphibole rock,* Kjegåvatn.

quartz, microcline and an inversely zoned oligoclase to andesine, a large quantity of monoclinic pyroxene with diallage cleavage ($^{n}\gamma/c = 47°$), and green actinolitic hornblende ($^{n}\gamma/c$ = appr. 20°) occurs. Both latter minerals tend towards idioblastic development. While occasionally the pyroxene is replaced by the amphibole, idioblastic amphibole individuals are very often enclosed by pyroxene crystals (fig. 31), suggesting that they were formed simultaneously. The microcline seems again to be younger than the sometimes sericitized plagioclase and sometimes it occurs as rims around the latter mineral. Minerals of the epidote-zoisite group are present in both rocks, sometimes represented by zoisite (117) and sometimes by clinozoisite (109). Furthermore a smaller quantity of biotite occurs, while tourmaline in well-developed crystals points to pneumatolytic influencing. Whereas sample no. 109 shows a decussate, hornfelsic, texture, the other (117) is directed.

General considerations on the calciferous micaschist formation.

The rocks of the calciferous micaschist formation are metamorphic derivates of pelitic, semipelitic, psammitic and calciferous sediments with intercalations of basic igneous rocks. The latter, now converted into amphibolites, are considered to be of volcanic—at least partly tuffaceous—nature, in view of the often very slight thickness of the individual layers, which frequently alternate with layers of micaschists and gneisses. It is considered improbable that the investigated amphibolites originate from marly sediments, as the mica and quartz content is very low, and as no gradual transitions into the micaschists and -gneisses were found. In the calciferous micaschist formation a small number of granitic and trondhjemitic bodies is present. The intrusive character is indicated by the presence of a thermally metamorphic zone around some of these bodies. The fact that the contact phenomena have not been obliterated by the regional metamorphism, points to intrusion in a relatively late stage with respect to the metamorphism.

In the various parts of the calciferous micaschist formation different metamorphic facies are represented. In view of the occurrence of oligoclase and more calcic members of the plagioclase series and the almost complete absence of epidote minerals, the rocks of the calciferous micaschist formation, occurring south and east of the outcrop of the amphibolite-staurolitegneiss formation, are reckoned to belong to the amphibolite facies, as defined by ROSENQVIST (1952, p. 30, 38). According to TURNER and VERHOOGEN (1951, p. 451 and 454) the assemblage diopside-forsterite-calcite, present in the limestones of this part of the calciferous micaschist formation, as well as the plagioclase-almandine-hornblende-biotite-quartz assemblage, present in the amphibolites, are stable in the staurolite-kyanite subfacies of the amphibolite facies. The absence, however, of staurolite and kyanite in the pelitic and semipelitic rocks of this part of the formation, points to a degree of metamorphism, representing the lower part of this sub-facies.

The rocks of the calciferous micaschist formation, exposed in the north-west of the region, in the Kvasstein anticline, have partly also been metamorphosed in the amphibolite facies; the lowest part of the succession exposed here (p. 55), i.e. the garnet-micaschist series, is distinguished by a relatively calcic plagioclase, by the absence of epidote minerals and by the occasional occurrence of kyanite and staurolite. In the higher part of the succession (p. 56 ff.), i.a. in the microcline-gneiss series and in the overlying calciferous micaschist series, however, there appears to be equilibrium between the epidote-clinozoisite minerals, present in great quantities, and the members of the plagioclase series. ROSENQVIST (1952) considers this equilibrium as characteristic for his epidote-amphibolite facies. It thus appears, that in the calciferous micaschist formation in the north-west of the region a normal succession of the metamorphic facies is represented.

The assemblage diopside-hornblende-plagioclase-microcline-quartz found in the contact rocks around trondhjemite intrusions (p. 74), is according to TURNER and VERHOOGEN (1951, p. 448) stable in the anthophyllite-cordierite subfacies of the amphibolite facies, corresponding with a thermal metamorphism at moderate temperatures.

Nearly all the rocks of the calciferous micaschist formation are rich in feldspar. Except in the garnet micaschists exposed in the core of the Kvasstein anticline, inversely zoned plagioclase has been formed in all the horizons in large quantities. The biotite-rich microclinegneisses, also occurring in the Kvasstein anticline, contain, in addition to plagioclase, a varying quantity of potash-feldspar. The replacement relations between the two feldspars occurring in these microclinegneisses, largely resemble those observed in the rocks of the granitegneiss formation (p. 31, et al.); part of the plagioclase has again been replaced by microcline (fig. 30), wheras a younger plagioclase generation showing myrmekite textures has been formed at the expense of the potash-feldspar.

On account of the occurrence of quartzitic and calciferous intercalations, the microclinegneisses of the Kvasstein anticline are considered to be of sedimentary–perhaps tuffogeneous–origin. It is worth mentioning that HOLMSEN (1932) indicated these rocks on the map 1 : 250,000, sheet Rana, as "Schistose granite". The fact that, elsewhere in the calciferous micaschist formation, the microcline appears to be restricted to the lowest parts of the formation, underlain by microcline-bearing rocks of the graphiteschist formation or by microcline-rich rocks of the granite-gneiss formation, is considered to indicate a metasomatic origin. It should be noted here, that the potash-metasomatism seems to be strongest, where the rocks of the graphiteschist formation are entirely or partly lacking, i.e. east of the Saltdal.

Also on a smaller scale introduction of material has taken place. Here the occurrence may be mentioned of relatively calcic plagioclase and of green hornblende in initially Ca-poor rocks at the contact with limestones (p. 66). Furthermore the local occurrence of tourmaline and scapolite points to introduction of B and Cl, respectively.

The occurrence of garnets with poikiloblastic cores with S-shaped trends of inclusions points to a syn-kinematic growth stage, whereas the less poikiloblastically developed rim zones and smaller massive garnet individuals (fig. 28) were probably formed during post-kinematic metamorphism. Biotite porphyroblastesis (p. 66) has also probably taken place after the conclusion of the movements.

THE AMPHIBOLITE-STAUROLITEGNEISS FORMATION

The rocks of the amphibolite-staurolitegneiss formation are exposed over a large area in the north-eastern part of the region investigated. Further they form, west of the Saltdal, a relatively narrow zone between the rocks of the calciferous micaschist formation; they pinch out near Hessihompvatn.

The interformational boundary between the calciferous micaschist formation and the amphibolite-staurolitegneiss formation is taken at the upper side of the calciferous micaschist series (p. 51). This series is in contact with different rock-types, all belonging to the amphibolite-staurolitegneiss formation.

The amphibolite-staurolitegneiss formation consists of an alternation of highly metamorphic schists and -gneisses, quartzites, limestones and amphibolites. Locally metamorphic ultrabasic rocks crop out. West of the Saltdal the rocks of this formation are well exposed, due to their position above the tree line. In the—topographically lower—north-eastern part of the investigated region, the formation is poorly exposed.

The amphibolite-staurolitegneiss formation is mainly characterized by:

1. The considerable variations in a lateral sense.
2. The high content of basic igneous rocks.
3. The highly glossy appearance of the schists and gneisses, caused by a high muscovite content, and the well developed porphyroblasts of garnet, staurolite and kyanite (fig. 32).

The lower horizons of the amphibolite-staurolitegneiss formation consist, in the north-eastern part of the area, of an alternation of graphite-schists, "hornblende-garben-schiefer", quartzites, garnet-micaschists, dolomites and schistose amphibolites. The graphiteschists are well-layered, and for the greater part very quartz-rich rocks. They are especially distinguishable in the field from the graphiteschists of the graphiteschist formation by their hardness, due to this high quartz content. Especially in the higher horizons intercalations of fine grained, darkgreen, schistose amphibolites, measuring up to tens of metres in

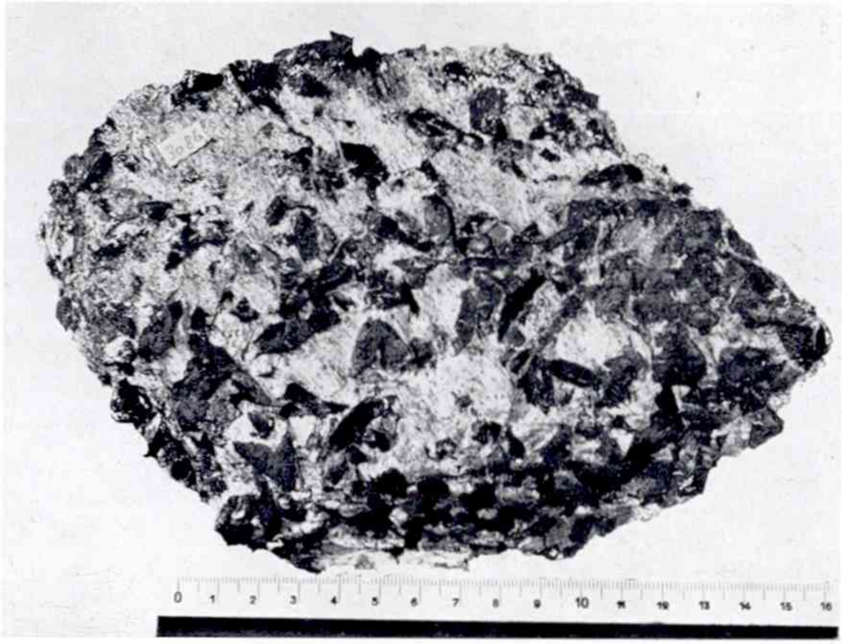


Fig. 32 - *Rock specimen, showing porphyroblastic development of staurolite in staurolitegneiss, eastern valley-slope, E of Russånes.*

thickness, are found between the graphiteschists. Furthermore garnet-micaschists are present, differing from the garnet-bearing schists and gneisses of the calciferous micaschist formation by the larger size of the garnet crystals, which measure up to three centimetres in diameter. In addition smaller quantities of, sometimes pure white, quartzites and light coloured "hornblende-garben-schiefer" are present, while an extremely fine grained, light greyish dolomite layer, measuring about 4 metres in thickness, was found in the central part of this graphiteschist series. These steeply dipping rocks have a N-S strike. In SSW direction they can be traced as far as a few hundreds of metres north of Sletfjell. Here these horizons, together with the rocks of the calciferous micaschist formation, form an anticline, overturned to the west, and with a northward axial plunge of about 45 degrees. This structure is clearly shown in the field by a white quartzite horizon, about 20 metres in thickness. This quartzite can be followed from the Sletfjell as far as the eastern wall of the Saltdal; it was not found further west. A zone of strong differential movement, found along the railroad about

900 metres south of the northernmost tunnel (fig. 19), consists of a rapid alternation of graphiteschists, quartzitic rocks and schistose amphibolites. Apparently this zone, together with the overlying amphibolite horizon, may be correlated with the graphiteschist series, east of the Saltdal. The graphiteschists, already of minor importance at the railroad, were not found further west.

In the north-east of the region, the graphiteschist series is bounded in the west by a limestone horizon, measuring approximately 300 metres in thickness. Contrary to similar rocks in the calciferous micaschist formation, this limestone contains only few impurities; locally thin hornblende and/or biotite-rich bands are observed. In the western marginal zone of this limestone horizon, isoclinal folding is locally observed (fig. 33). Here the axes of the folds dip in northerly direction. The limestone horizon remains fairly constant in thickness to south of the Bleikneselv. Further southward its thickness decreases rapidly, and east of the bridge near Langånes it pinches out. East of the Saltdal, in the neighbourhood of the Bleikneselv, thin and strongly folded limestone horizons were found. At the railroad, north of the zone of differential movement, de-

Fig. 33 - *Sharp isoclinal folding in marble. About 400 metres S of the Bleikneselv, at an altitude of 300 metres.*

scribed above, a limestone horizon, about 30 metres in thickness, is exposed, which perhaps represents the continuance of the main limestones described above, here greatly reduced.

East of Sølvbergnupen, the limestone is bounded by a thick series, mainly consisting, of massive amphibolite, alternating with schists and gneisses, rich in staurolite. The thickness of a given amphibolite body often varies strongly. The contacts as far as could be ascertained, are always concordant. In the marginal zones of the amphibolites large quartz-feldspar aggregates, measuring up to a few centimetres, are often found. In addition, irregular green zones occur in the amphibolite, which consist for the greater part of chlorite. Locally these chlorite-rich zones contain very schistose, muscovite-rich rocks in the form of thin, sometimes discontinuous, bands. These dark coloured rocks contain tourmaline needles, up to a few millimetres in length.

The amphibolites alternate with, usually light coloured, schists and gneisses with a silky lustre. These rocks, often showing an intense small-scale folding, mostly contain garnet and/or staurolite. These minerals tend to be idioblastic, in which case the staurolite prisms attain a length up to five centimetres. Light bluish-grey, slender kyanite crystals (maximum length 5 centimetres) occur less frequently. Locally the gneisses and schists show transitions into quartzites. Occasionally a lateral variation was observed in the garnet and staurolite content. Locally pyrite- and magnetite-rich bands occur.

East of Sølvbergnupen, approximately 100 metres west of the limestone horizon, a lenticular body is exposed, consisting of massive, light green, ultrabasic rocks. Its largest thickness is 40 metres and its length approximately 250 metres. South-east of Russånes the base of the amphibolite-staurolitegneiss formation consists of limestones and garnet mica-schists. At that place the graphiteschists are missing. However, they reappear a few kilometres to the north, outside the investigated area. The sketch map fig. 34, gives an impression of the different rocks composing the amphibolite-staurolitegneiss formation in the north-east of the region investigated. In the northern part of this mapped area a general SSW-NNE strike was observed, south of Sølvbergnupen, the dip and strike vary greatly.

West of the Saltdal the rocks of the amphibolite-staurolitegneiss formation can be traced, as a zone a few hundreds of metres in thickness,

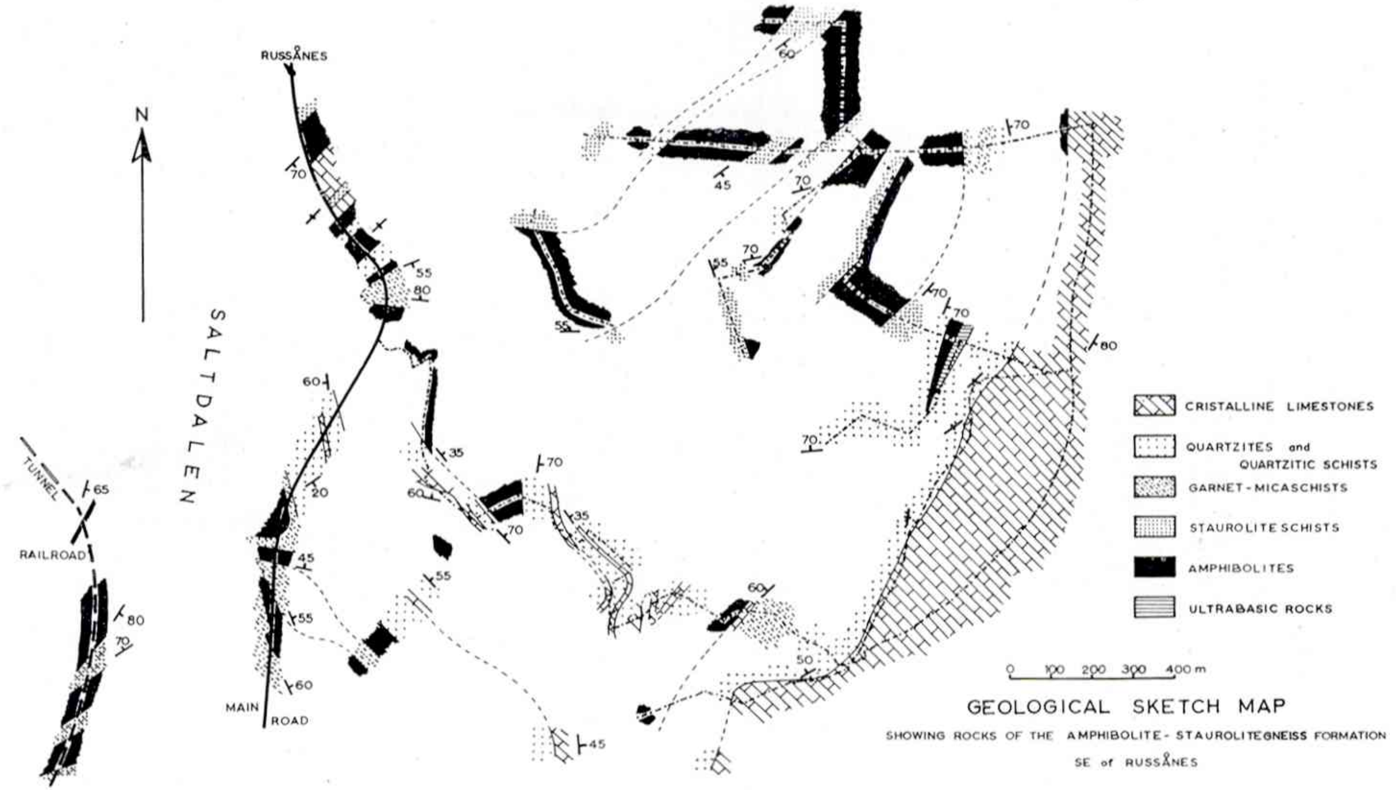

RUSSÅNES
N
SALTDALEN
TUNNEL
RAILROAD
MAIN
ROAD
CRISTALLINE LIMESTONES
QUARTZITES and
QUARTZITIC SCHISTS
GARNET - MICASCHISTS
STAUROLITE SCHISTS
AMPHIBOLITES
ULTRABASIC ROCKS
0 100 200 300 400 m
GEOLOGICAL SKETCH MAP
SHOWING ROCKS OF THE AMPHIBOLITE - STAUROLITEGNEISS FORMATION
SE of RUSSÅNES

Fig. 34

DIAGRAMMATIC SECTIONS through the AMPHIBOLITE-STAUROLITEGNEISS FORMATION between HESSIHOMPVATN and VATNHAUGE.

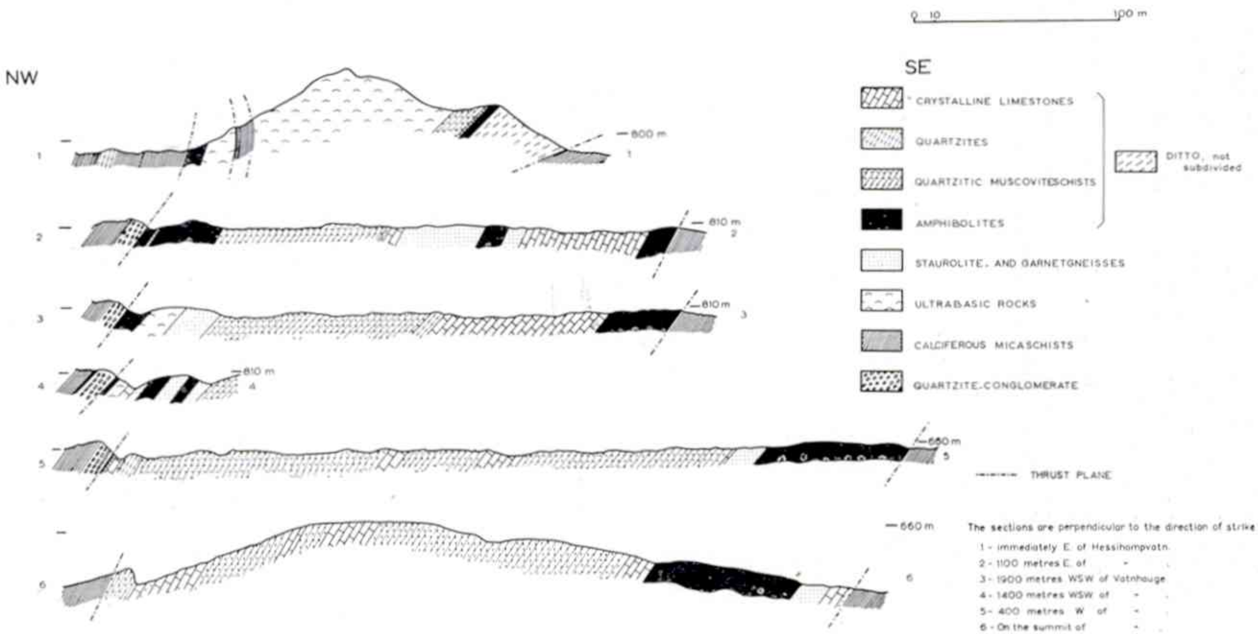


Fig. 35

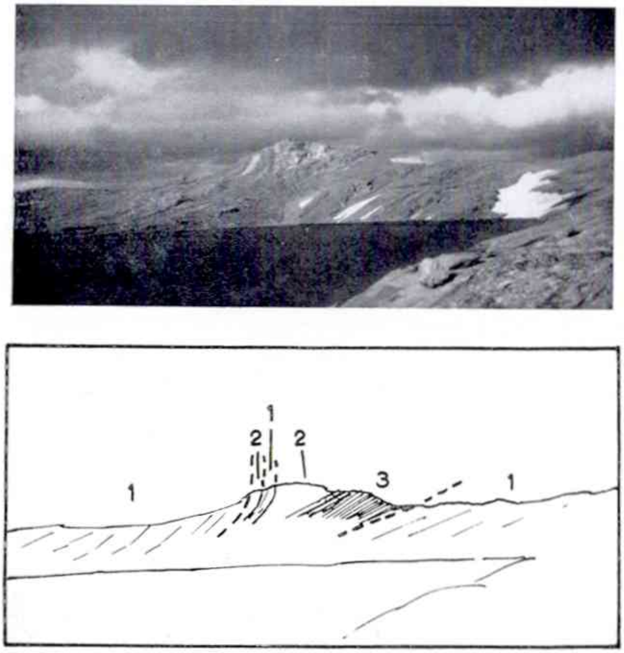


Fig. 36 - *Ultrabasics, E of Hessihompvatn, viewed from the west.*
1. *Calciferous micaschist formation.* 2. *Ultrabasic rocks.*
3. *Amphibolite-staurolitegneiss formation. Dashed lines: thrusts.*

from the railroad to Vatnhauge and Hessihompvatn. While at the railroad the amphibolites still form a great part of the formation (fig. 19), their importance diminishes towards the west. Fig. 35 shows a number of cross sections through this zone. The most conspicuous feature, shown by these sections, is the rapid variation, occurring in the direction of strike. This variation indicates, that the rocks of the amphibolite-staurolitegneiss formation form a zone of extremely strong differential movement. Lenticular bodies–one of which is shown in section 1 of fig. 35–consisting of metamorphic ultrabasic rocks are exposed between Vatnhauge and Hessihompvatn. These light bluish-green rocks usually have a massive habitus. In addition to the main constituent talc, large green actinolite needles, irregularly shaped rusty-brown aggregates of iron-carbonate and usually well developed octahedra of a mineral of the spinelgroup can be distinguished macroscopically. In the talc masses, especially in the lower parts, some zones occur, up to a few metres in width, which contain, in addition to actinolite and spinel, bluish-green serpentine. Occasionally irregular patches of amphibolitic material are found within these zones. Due to their erosion resistance, the ultrabasic rocks form topographic culminations (fig. 36) with characteristically rounded erosion forms. The largest of the ultrabasical lenses has a length of about 500 metres and a maximal thickness of over 100 metres. The talc-rich body, east of Hessihompvatn, is on its north side in contact with the calciferous micaschists of the calciferous micaschist formation. Between both, a grass-green rock, principally consisting of actinolite, forms a band, measuring a few metres in thickness. In the quartzitic calciferous micaschists, adjacent to this actinolite rock, hornblende poikiloblasts, measuring up to several centimetres in length, have been formed within a zone of a few decimetres in width. A thin layer of calciferous micaschists (about ten metres in thickness) is enclosed in the same talc-rich body (fig. 36).

West of Hessihompvatn ultrabasic lenses only rarely occur. Here the amphibolite-staurolitegneiss formation is only represented by a few small lenses of coarse grained and strongly folded garnet-micaschists and amphibolites.

Petrography

In the following petrographical description the rocks of the amphibolite-staurolitegneiss formation have been classified as follows:

Graphiteschists
Limestones
Quartzites and quartzitic 'garben-schiefer'
Muscoviteschists and -gneisses
Garnet-micaschists and -gneisses
Staurolite-, kyanite- and sillimaniteschists and -gneisses
Amphibolites
Metamorphic ultrabasic rocks.

Graphiteschists.

57 :	Feldspar-rich graphiteschist	600 m S of confluence of Bleikneselv and Saltelv.
132 :	Graphiteschist	at 490 m, E of Langånes.
56 :	Graphiteschist	summit Sletfjell.
157 :	Feldspar-rich graphiteschist	600 m SE of Rundvatn.
136 :	Graphiteschist	at 460 m, 700 m NW of Rundvatn.

231 : Feldspar-rich garnet-graphiteschist	at 450 m, on path to Evenesdal.
232 : Graphiteschist	at 460 m, on path to Evenesdal.
233 : Garnet-graphiteschist	at 460 m, on path to Evenesdal. 8 m E of 232.
235 : Feldspar-rich kyanite-graphiteschist	at 480 m, on path to Evenesdal.
236 : Kyanite-graphiteschist	100 m E of no. 234, on path to Evenesdal.
149 : Graphiteschist	on path to Evenesdal, at 480 m.

In the graphiteschists of the amphibolite-staurolitegneiss formation quartz is invariably the main constituent. All specimens contain, in addition to graphite, large quantities of biotite and/or muscovite. In some slides garnet, kyanite or a mineral of the epidote-zoisite group were further found. Plagioclase is present in varying quantities; in some specimens (157 and 235) this mineral is entirely missing. Accessories may be: rutile, leucoxene, tourmaline, orthite, zircon and apatite. Of the ore-minerals especially limonite occurs frequently. In some samples an intensive small-scale folding is displayed which is well marked by graphite, concentrated in bands. The principal rock-forming minerals have crystallised after the production of the small-scale folding. The muscovite flakes follow the microfolding, but are rarely bent. The biotite, however, is developed in undirected porphyroblasts. The quartz shows no undulose extinction. The anorthite content of the plagioclase varies greatly in the different samples (5 to 60 % An.). The most calcic plagioclase occurs in the kyanite-bearing samples. This feldspar is often concentrated into bands of a few centimetres in thickness, while sometimes it forms porphyroblasts, up to a few millimetres in size, enclosing graphite-rich bands. The garnet in the garnet-graphiteschist no. 231 contains S-shaped trends of inclusions in its core. The outer rim of these garnet-poikiloblasts shows an arrangement of inclusions coinciding with the schistosity of the rock (see fig. 37).

Limestones.

228 : Diopside-actinolite-scapolite-marble	on path to Evenesdal, at 400 m.
205 : Actinolite-marble	on top 372.
134 : Actinolite-marble	along Bleikneselv, at 330 m.
150 : Anthophyllite-marble	E of top Vatnhauge, at 630 m.

In addition to its main constituent, calcite, the diopside-actinolite-scapolite-marble (no. 228) contains fine grained diopside and smaller

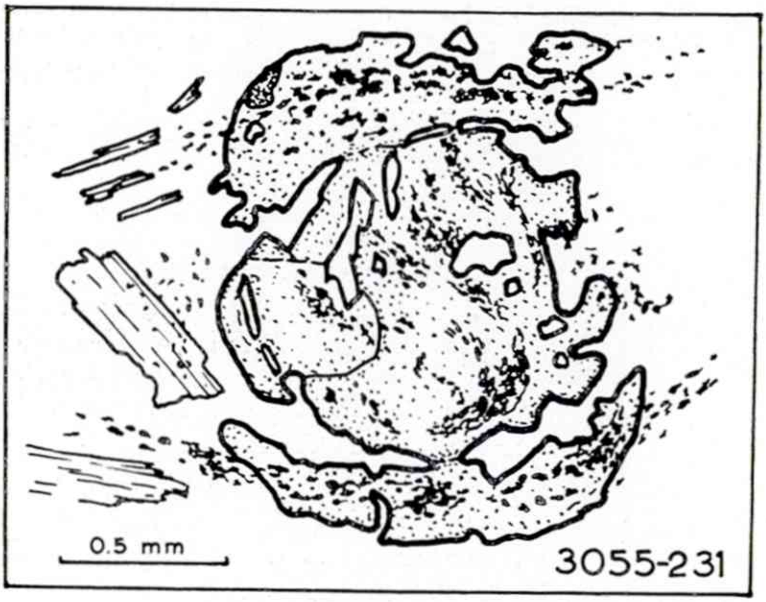


Fig. 37 - *Garnet crystal, with S-shaped trends of inclusions in its core. The arrangement of the inclusions in the outer zone coincides with the schistosity of the rock. In feldspar-rich garnet-graphiteschist, along path to Evenesdalen, at an altitude of 450 metres.*

quantities of actinolite and scapolite. A few albite aggregates occur. The diopside ($^{n}\gamma/c = 40°$) forms small rounded crystals (0.1 to 0.2 millimetres in diameter). The actinolite ($^{n}\gamma/c = \pm 18°$) is in light green crystals of about equal size. Whereas the scapolite crystals are irregularly shaped, the albite crystals, measuring up to 1 millimetre, are characterized by their rounded forms. It seems that both minerals are formed at the expense of the calcite.

Whereas quartz is entirely missing in the diopside-actinolite-scapolite-marble, this mineral is abundantly represented in the actinolite marbles (205 and 134). Both investigated specimens contain, in addition to calcite, a great quantity of coarse grained, poikiloblastically developed actinolite. The last mentioned mineral contains inclusions of quartz, calcite and titanite. The marble 134 contains a slight quantity of oligoclase (20 % An.). Further a considerable amount of pyrite is present, evidently late-formed, as proved by the inclusion of actinolite and feldspar.

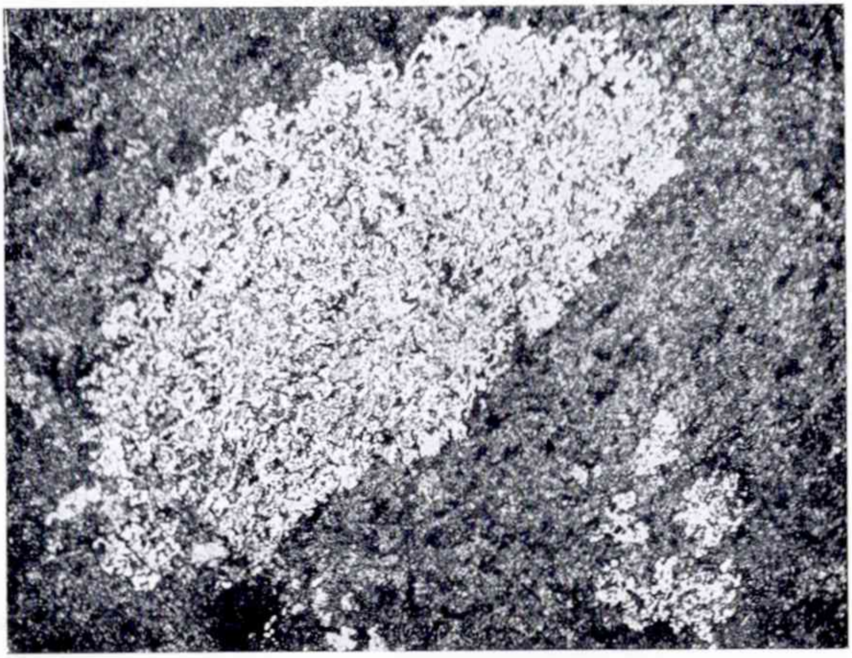


Fig. 38 - *Poikiloblasts of scapolite in lime-silicate rock, enclosing hornblende, clinozoisite, calcite, diopside and titanite. Along path to Evenesdalen, at an altitude of 400 metres. (17 ×)*

The anthophyllite marbles, of which the sample no. 150 is a representative example, occur as irregularly shaped light brown patches in the limestones exposed on Vatnhauge. In addition to the principal main constituent calcite, a great quantity of faintly coloured anthophyllite is present. This last mineral is in slender crystals, measuring up to one centimetre in length, with a distinct parting normal to the c-axis. Often the anthophyllite aggregates are radially arranged. They may be embedded in a fine-scaled talc mass. Replacement phenomena were, however, not observed between the amphibole and the talc.

227 : Lime-silicate rock	at path to Evenesdal, at 400 m.
138 : Gneissose bands in marble	300 m SW of Bleikneselv.

The lime-silicate rock (227) occurs as a rounded, hard and dark green nodule (approximately 10 centimetres in diameter) in a diopside-bearing marble (228). It consists of a fine-grained, undirected mass of about equidimensional green hornblende and clinozoisite crystals. In slightly smaller quantities calcite, diopside, and titanite are present. Finally poikiloblasts of scapolite, about 2 millimetres large are found, formed in a relatively late period, as proved by the inclusion of all other minerals (fig. 38).

Locally intercalations are found in the limestones, now represented by layers rich in quartz, plagioclase, biotite and hornblende.

Marbles in contact with amphibolite:

60 : Zoisite-scapolite-actinolite-marble	S of Russånestunnel along the railroad.
59 : id.	id.

The zoisite-scapolite-actinolite-marbles represent a limestone horizon at the contact with amphibolite. In addition to the main constituent calcite these rocks contain a great quantity of actinolitic amphibole, in small, slender needles. Furthermore the two investigated samples contain plagioclase; in one specimen (no. 60) an anorthite content of appr. 50 % was measured. Zoisite crystals are often included by the actinolite. Occasionally zoisite seems to be replaced by plagioclase, which is evidenced by the optic continuity of remnants of the former in the latter mineral. Further scapolite and a smaller quantity of light brown mica were observed. One of the samples contains some muscovite and titanite.

Quartzites and quartzitic "garben-schiefer":

2 : Quartzite	400 m W of Nordnesfjell.
4 : Quartzite	200 m S of top 444.
5 : Plagioclase-rich epidotequartzite	on top 444.
9 : Calciferous quartzite	along main road, appr. 50 m S of path to Bleiknesfjell.
184 : Calciferous hornblendequartzite	between Vatnhauge and Hessihompvatn.
251 : Quartzitic "hornblende-garben-schiefer"	at 420 m SW of Sølvbergnupen.

In all the investigated samples of quartzites and quartzitic "hornblende-garben-schiefer" quartz is the main constituent. Plagioclase is present in varying quantities; in one specimen (195) this mineral forms an important constituent. The anorthite content of the plagioclase varies greatly (from 10 to over 50 %); the highest anorthite-percentages were measured in the calcite-bearing samples. Sometimes (like in no.

199) the feldspar appears to be closely associated with calcite and to be formed at the expense of this mineral. Often the plagioclase crystals have an inversely zoned structure. All calciferous samples moreover contain a considerable quantity of amphibole, nearly always represented by green hornblende, except, however, the calciferous quartzite no. 199, which contains a light green member of the tremolite-actinolite series. The amphibole appears to be formed at the expense of the calcite (fig. 39). Whereas the hornblende-bearing quartzitic rocks sometimes have the appearance of "garben-schiefer", varieties are also found in which the amphibole displays a linear arrangement. In addition to a varying —but always small—quantity of mica and chlorite, some of the investigated samples contain epidote. Only in the epidotequartzite (195) this last mineral is present in larger quantities in an iron-rich variety. Sometimes the quartzitic "garbenschiefer" grade into feldspar-rich gneissose types (206).

Muscoviteschists and -gneisses:

92 :	Plagioclase-bearing muscoviteschist	Vatnhauge.
152 :	Muscovite-microclinegneiss	along railroad, appr. 80 m N of 2nd tunnel.
139 :	Calciferous muscovitegneiss	at 325 m, along path to Nordnesfjell.
151 :	Muscoviteschist	N of Sølvbergnupen, along path.

In addition to their main constituents quartz and mica, these rock contain a varying quantity of plagioclase. In two of the investiga samples (139 and 152) this mineral occurs in fairly large quantities. anorthite content in the various samples ranges from 15 to 45 % highest percentage was measured in the calciferous micagneiss this sample, the plagioclase forms large poikiloblasts with inclus calcite and muscovite. In some of the other samples the plagio changes into sericite. The gneiss no. 152 contains, in addition to high amount of plagioclase (15 % An.), a slighter quantity of well-twinned microcline, developed interstitially. Muscovite is always present in larger quantities than biotite. Some samples contain some tourmaline and calcite; the calciferous micagneiss 139 is rich in the last-mentioned mineral. The majority of the investigated samples show small-scale folding, often with bent mica flakes.

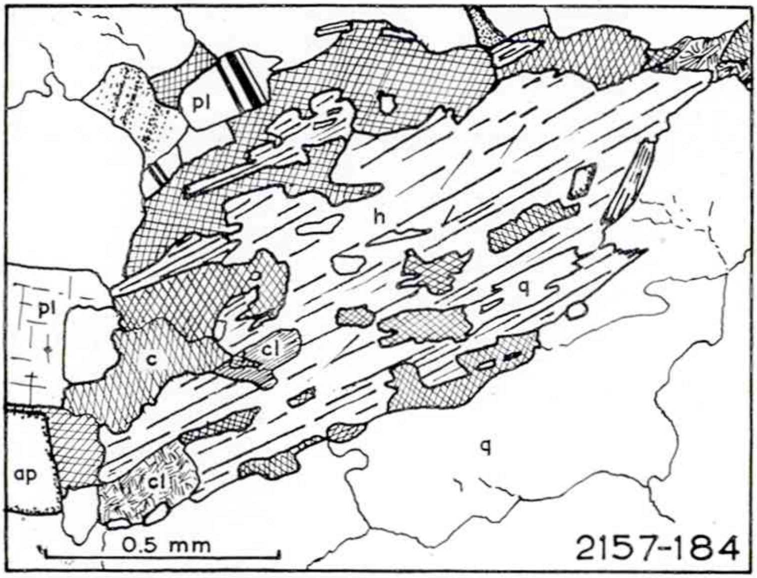


Fig. 39 - *Green hornblende (h), forming at the expense of calcite (c). Furthermore quartz (q), plagioclase (pl), apatite (ap) and chlorite (ch) are indicated. In calciferous hornblende quartzite, between Vatnhauge and Hessihompvatn.*

Garnet-micaschists and -gneisses:

153 :	Garnet-micaschist	E of Sølvbergnupen, at 400 m.
245 :	Garnet-mica-chloriteschist	S of Sølvbergnupen, at 440 m.
183 :	Garnet-micaschist	near the 2nd ultrabasic lens E of Hessihompvatn.
3 :	Garnet-biotitegneiss	S-side of Sølvbergnupen at 480 m.
:	Garnet-micagneiss	along main road, appr. 100 m N of Bleikneselv.

e garnet-micaschists (153, 245 and 183) contain as their main ents quartz and mica. In addition a varying quantity of garnet The quartz is undulose. Biotite is usually present as the princi- ica, generally in the form of well-directed crystals. In the sample this mineral, however, tends towards development as undirected porphyroblasts. The garnet-mica-chloriteschist 245 contains a great quantity of chlorite. This last mineral sometimes forms crystals with a direction transverse to the general schistosity. The garnet is in idioblastic individuals, usually with only a small number of inclusions. Sometimes, however, this mineral contains a large quantity of minute inclusions, causing a peculiar grey colour (245).

The garnetgneisses (243 and 96) contain a great quantity of plagioclase with an anorthite content of about 30 %. Further the mineral composition conforms with that of the garnetiferous schists. It is worth mentioning that the sample 243 has a fine grained, almost directionless texture. While some of the garnet individuals in this sample have been entirely altered into chlorite, others appear to be entirely fresh.

Staurolite-, kyanite- and sillimaniteschists and -gneisses:

260 :	Staurolite-garnet-micaschist	between Vatnhauge and Hessihompvatn.
185 :	id.	between Vatnhauge and Hessihompvatn.
51 :	id.	near the bridge of Russånes.
161 :	Staurolite-garnet-micagneiss	at 120 m, 100 m S of Bleikneselv.
52 :	id.	1100 m N of Sølvbergnupen.
242 :	Staurolite-muscovitegneiss	on top Sølvbergnupen.
207 :	Staurolite-kyanite-garnet-micagneiss	at 340 m, W of top 372.
61 :	id.	100 m N of Bleikneselv, a 120 m.
239 :	Staurolite-kyanite-muscovitegneiss	W of Sølvbergnupen, at
54 :	Sillimanite-staurolite-garnet-micagneiss	NW of Sølvbergnupen, 280 m.
42 :	id.	450 m S of the Russånestu at railroad.
204 :	Sillimanite-staurolite-kyanite-garnet-micagneiss	at path to Bleiknesfjell, ap 300 m E of top 372.
256 :	Kyanite-garnet-micagneiss	500 m E of Vatnhauge.

These highly metamorphic rocks are coarsely granular and, due their usually high muscovite content, they have a light colour and glossy appearance. The aluminous silicates garnet, staurolite kyanite, usually tend towards porphyroblastic development, freque forming idioblastic crystals, a few centimetres in size (fig. 32).

The investigated samples show as their main constituent: quartz biotite and muscovite. The gneissose types are distinguished by a high plagioclase content. Also the garnet and staurolite, occurring in all the samples, except one, are often present in considerable quantities. A few samples contain kyanite and/or sillimanite. Chlorite is always represented in some quantity, in fresh crystals. A high tourmaline content is a conspicuous feature of most these rocks. Quartz seldom shows

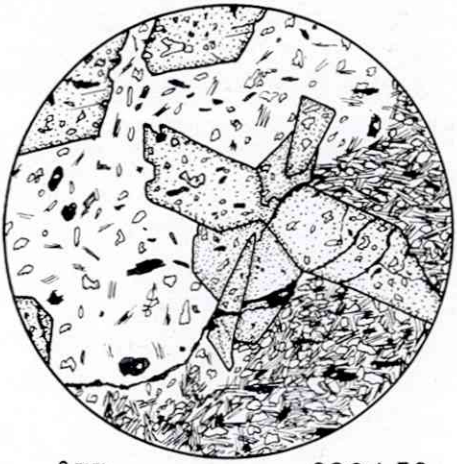


Fig. 40 - *Staurolite porphyroblasts, showing cruciform twinning. The staurolite is partly ...osed by an oligoclase poikiloblast, form... the expense of the fine-grained quartz- ... mass, remnants of which are en... staurolite-garnet-micagneiss, 1100 ...tres N of Sølvbergnupen.*

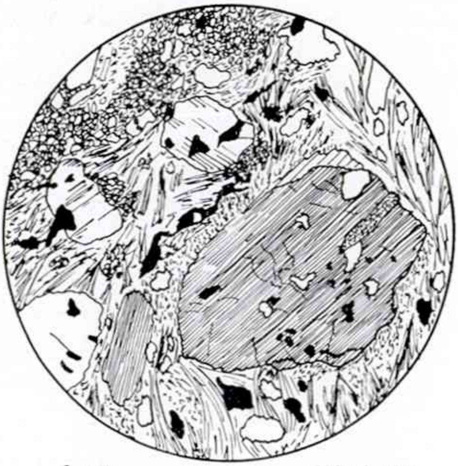


Fig. 41 - *Cataclastic amphibolite. The hornblende crystals are surrounded by fine-scaled chlorite; coarser-scaled chlorite is abundant, apparently formed independent of the hornblende. In the left upper part of the figure, a granulated zone of quartz and feldspar is shown, together with some larger plagioclase crystals. The larger white crystals are quartz. Quartz-amphibolite, along the railroad, about 200 metres of Russånes tunnel.*

...ulose extinction. The mineral is often enclosed by the garnet-, ...rolite- and feldspar crystals. Muscovite is nearly always the princi... mica, developed as larger plates, the diameter of which sometimes ...ains several millimetres. The muscovite has always participated in ... intense small scale folding in these rocks, the scales being bent. ...tite on the other hand is mostly unfolded and usually shows a more ...u less haphazard orientation. Occasionally inclusion of the muscovite ...d n biotite was observed (185). Consequently the biotite is, at least ...artly, younger than the colourless mica. The composition of the plagioclase varies considerably (from 25-50 % An.). The mineral distinguishes itself from the type commonly found within the investigated region, by the absence of zoned structures. The plagioclase porphyroblasts, sometimes measuring over one centimetre, were formed in a late period, as evidenced by the inclusion of staurolite (fig. 40). When the feldspar is poikiloblastically developed, the inclusions are often arranged in parallel trends, a direction which is generally far less obvious elsewhere in the rock. The garnet forms large, poikiloblastically, and sometimes idioblastically developed crystals. Often different phases of growth can be distinguished, sometimes by alternating concentric inclusion-rich and inclusion-poor zones (54), then again by the occurrence of a core with S-shaped trends of inclusions, and a rim, in which the inclusions show a linear arrangement. In a few cases the garnet is obviously older than the staurolite, as proved by the fact that it is enclosed by the latter (185). Staurolite usually occurs as idioblastic poikiloblasts. Sometimes well-developed cruciform twins occur (fig. 40). Sometimes folded trends of inclusions are found. The staurolite seems occasionally (54) to have been formed in the stress shadow of the garnet crystals. Kyanite forms elongated crystals, occasionally showing undulose extinction. The mineral is sometimes broken, with the separate parts displaced (256 and 207). Sillimanite is developed as small needles. Often these needles are grouped in irregular zones in feldspar porphyroblasts. Tourmaline is present in remarkably large quantities in nearly all the samples; sometimes it forms undirected idioblastic crystals, measuring up to 0.5 millimetre in length. The presence of this mineral indicates pneumatolytic influencing of these rocks. Chlorite sometimes evidently originates through a retrograde alteration of garnet and biotite; sometimes, however, this mineral is also present in the form of a few larger scales, the retrograde origin of which is uncertain. The relatively high magnetic content in some of the investigated samples may be mentioned.

Amphibolites.

Amphibolites from the graphiteschist-rich horizon (p. 79):

148 : Amphibolite	appr. 300 m NE of Nordnesfjell, 450 m.
229 : Amphibolite	at path to Evenesdal, about 15 m E of no. 228.
155 : Calciferous zoisite-amphibolite	on Sletfjell.
135 : Amphibolite	at 470 m, E of Langånes.
209 : Quartz-rich amphibolite	E of confluence of Markskjeelv and Saltelv, at 380 m.
133 : Amphibolite	at 135 m along Bleikneselv.
39 : Calciferous amphibolite	N of second tunnel, at railroad.

Macroscopically, these amphibolites are characterized by a very dark bluishgreen to almost black colour, a small grain size, and a well-developed schistosity. Microscopically, a dark-green hornblende is the main constituent (except in the sample 133). The length of the amphibole crystals seldom exceeds 2 millimetres. The quartz content of the amphibolites is usually very low. In a few samples this mineral occurs in larger quantities in veins and in the form of lenticular aggregates. The plagioclase has a composition varying from oligoclase to andesine (15 - 38 %). Often the crystals are inversely zoned. The feldspar is usually present in only minor quantities; the amphibolite no. 133, in which this mineral occurs in about the same quantity as hornblende, forms an exception. In a few samples small amounts of garnet, biotite, chlorite, epidote, and calcite were observed. In the calciferous zoisite-amphibolite (no. 155) zoisite crystals, measuring up to a few millimetres, are found, which appear to be replaced by andesine. Of the accessories rutile and titanite are represented in considerable quantities.

The texture of the amphibolite no. 135 differs from that of the other samples. This amphibolite is coarsely granular and poikiloblastically developed. The crystals show undulose extinction and are often bent.

Amphibolites alternating with staurolitegneisses (p. 82):

.46	Amphibolite	at 440 m, S of Sølvbergnupen.
44	Quartzamphibolite	at 480 m, on S-top of Sølvbergnupen.
197	Quartzamphibolite	at 220 m, along path to Bleiknesfjell.
60	Amphibolite	at 120 m, 400 m S of the Bleikneselv.
40	Amphibolite	300 m N of second tunnel, along railroad.
1	Amphibolite	550 m S of Russånes tunnel, along railroad.
43	Sillimanite-garnetamphibolite	425 m S of Russånes tunnel, along railroad.
47	Kyanite-quartzamphibolite	175 m S of Russånes tunnel, along railroad.
193	Garnetamphibolite	300 m S of top 444.
254	Amphibolite	600 m E of Vatnhauge.
186	Clinozoisiteamphibolite	800 m E of E-Hessihomp.
88	Zoisite-kyaniteamphibolite	400 m NE of the E-Hessihomp.
198	Chlorite-rich amphibolite	along main road, 300 m N of Bleikneselv.

46 : Quartzamphibolite (chloritized) — 200 m S of Russånes tunnel, along railroad.

45 : Amphibolite (cataclastic) — 220 m S of Russånes tunnel, along railroad.

The amphibolites from the higher parts of the amphibolite-staurolite-gneiss formation differ greatly from those from the graphiteschist-rich horizon: Firstly, the rocks of this group, with the exception of two of the investigated samples, are directionless, whereas those already described are highly schistose. Secondly, the massive amphibolites are, contrary to those of the first group, very coarse grained. Thirdly, only 5 out of 15 investigated samples of the massive amphibolites contain quartz, whereas this mineral is present in all the specimens of the first group, except for two. Fourthly, as compared with the schistose amphibolites, the massive amphibolites are more highly feldspathic.

Sometimes the main constituent, green hornblende ($^{n}\gamma/c = \pm 17^{\circ}$) is porphyroblastically developed; in that case this mineral contains inclusions of plagioclase and ore-minerals. In some amphibolites (41 and 160) a small quantity of a rather colourless member of the tremolite-actinolite series occurs. In addition to slender needles, distributed throughout the matrix, this mineral forms rims around and patches in the hornblende crystals. All the samples contain a large quantity of plagioclase with an anorthite content usually between 20 and 30 %. However, percentages as low as 13 and as high as 50 have been found. Often the feldspar is inversely zoned with a difference of about 10 % between the anorthite content of the core and that of the rim. The amphibolites 47 and 88 contain a rather large quantity of kyanite, while in the latter sample zoisite is also present. The kyanite forms undirected porphyroblasts. Both the zoisite and the kyanite are replaced by the plagioclase which is evidenced by the optic continuity of remnants of these two minerals in the feldspar crystals. Whereas the zoisite is often enclosed by the hornblende, thus being obviously older, it seems that the kyanite and hornblende has been formed simultaneously. In a few of the investigated samples small quantities of biotite, garnet and calcite occur. The sillimanite-garnet-amphibolite (43) is distinguished from the other amphibolites by its high content of biotite and garnet and the occurrence of sillimanite. This last mineral is developed in swarms of very small, irregularly arranged, needles, enclosed by the feldspar porphyroblasts. The garnet and biotite both show intensive alteration into chlorite.

Three of the investigated samples (46, 45 and 198) originate from chloritized zones in amphibolites (p. 82). Two of these show cataclastic phenomena. Besides the main constituents green hornblende and plagioclase (appr. 30 % An.), these cataclastic specimens contain large quantities of undulose quartz and chlorite. The latter mineral is only partly formed at the expense of the hornblende; in addition it is found independently, in sometimes bent scales, measuring up to 2 millimetres in diameter. Besides green hornblende a smaller quantity of amphibole of the tremolite-actinolite series is represented. This mineral forms rims around the hornblende crystals and is further found independently as fine needles. Its colour varies from light green to colourless. Here and there alteration into talc occurs. Both the amphibole and the plagioclase crystals are frequently bent; they show cracked, finely granular, border-zones (fig. 41). The sample 198 is distinguished by the fact that is does not contain quartz and by the absence of cataclastic phenomena. However, this rock too is characterized by a large quantity of coarse-scaled chlorite, while here again the hornblende crystals are surrounded by actinolitic rims.

Locally thin bands rich in muscovite- and tourmaline are found in the ...loritized zones of the amphibolites (p. 82). These bands are repre-...nted by the following samples:

44 :	Tourmaline-muscovite rock (rich in magnetite)	along railroad, 350 m S of the Russånes tunnel.
162 :	Tourmaline-staurolite-muscovite rock (rich in magnetite)	along railroad, 200 m S of the Russånes tunnel.
)1 :	Retrogade kyanite-garnet rock, (rich in magnetite)	SE of Russånes, at 410 m.

These rocks show a close resemblance to each other: usually they have a lustrous black colour and show a tabular schistosity. The schistosity planes sometimes show a lineation, caused by an intensive microfolding. Locally thin, more coarsely grained zones are found, showing no relation to the schistosity, in which individual crystals of staurolite may measure over a centimetre. Usually black tourmaline needles, a few millimetres in length, are visible on the schistosity planes. Microscopically, the examined samples show great differences. The tourmaline-muscovite rock no. 44 consists almost exclusively of muscovite and finely dispersed magnetite, the former mineral marking the isoclinal folding. Further a large quantity of idioblastic, undirected tourmaline occurs. The sample no. 162 contains, in addition to tourmaline, muscovite and magnetite, a great quantity of, sometimes idioblastic staurolite. Kyanite and plagioclase are found in smaller amounts. The last mentioned mineral forms inversely zoned crystals, up to 0.5 centimetre in size (16-26 % An.). Frequently quartz inclusions occur in the plagioclase. The sample 201 shows retrograde alteration: Kyanite and oligoclase are altered into sericite, garnet and biotite into chlorite. In the plagioclase porphyroblasts folded magnetite trends occur.

95 : Hornblendegneiss (fine-grained) E-wall of Saltdal, appr. 100 m N of Bleikneselv.

Occasionally a light coloured, hornblende-rich zone, a few decimetres in width, was found at the contact of the amphibolites and the mica-schists and -gneisses. No. 95 represents a representative sample from such a zone. The rock consists largely of a mosaic of only partly twinned, slightly zoned andesine, and non-undulose quartz crystals. Herein idioblastic garnet crystals, up to a few millimetres in size, and large green hornblende poikiloblasts are present. Furthermore a small quantity of epidote is found.

Epidote-rich bands in the amphibolites:

240 : Epidote rock W of Sølvbergnupen, at 400 m.
253 : Epidote-hornblende rock appr. 600 m E of Vatnhauge.

Some zones within the amphibolites contain very epidote-rich bands a few decimetres in width. The sample 240 appears to consist, nearly exclusively, of an iron-rich epidote; further, in very minor quantities quartz and mica are present, the latter forming felty aggregates of biotite and muscovite, interstitial between the equidimensional epidote crystals.

The epidote-hornblende rock (253) consists nearly exclusively of epidote and dark green hornblende. Remarkable is the absence of quartz and the scarcity of feldspar. The rock contains a small quantity of garnet, titanite and apatite.

Metamorphic ultrabasic rocks:

250 :	Carbonate-bearing anthophyllite rock	at 440 m, S of Sølvbergnupen.
249 :	Cataclastic tremolite rock	id.
247 :	id.	id.
55 :	id.	id.
248 :	id.	id.
190 :	Carbonate-bearing chlorite-actinolite rock	600 m S of Vatnhauge.
81 :	Carbonate-bearing tremolite-chlorite-talc-rock	E Hessihomp.
90 :	Carbonate-bearing anthophyllite-serpentinite	2nd ultrabasic lens, E-ward from Hessihompvatn.
87 :	Actinolite rock	N of E Hessihomp.

The first five samples enumerated above represent the lenticular body of ultrabasic rock, east of Sølvbergnupen (p. 82). The sample 190 originates from an isolated outcrop on the south side of the amphibolite-staurolitegneiss formation, South of Vatnhauge (not indicated on the eological map on account of its small size). The last three are re-esentative samples of the ultrabasic rocks between Hessihompvatn and .tnhauge.

Most of the ultrabasic rocks first mentioned, consist exclusively of remolite. Sometimes, a very light green member of the tremolite-ctinolite series is present in addition to the colourless tremolite. The nphibole is partly represented as a strongly cataclastic mass of bent nd broken crystals, with turbid, entirely pulverized zones (fig. 42). specially the sample 249 has, microscopically, a truly mylonitic char-icter. In addition, slender tremolite crystals (sometimes measuring several millimetres in length) are observed, obviously formed in a atively late period, as indicated by their growth through mylonitic zones. Iron-bearing carbonate is found in irregularly shaped aggregates. Further a small quantity of chlorite is present in a few samples (249 and 5).

The anthophyllite rock (250) consists almost exclusively of rhombic mphibole in the form of colourless anthophyllite, no monoclinic amphi-ole being present. Very often this anthophyllite is developed in rather arge crystals. No cataclastic phenomena were observed in this rock.

The chlorite-actinolite rock which was collected S of Vatnhauge (190) shows a great resemblance, in respect of its habitus, to the remolite-rich rocks described above. However, here a much larger

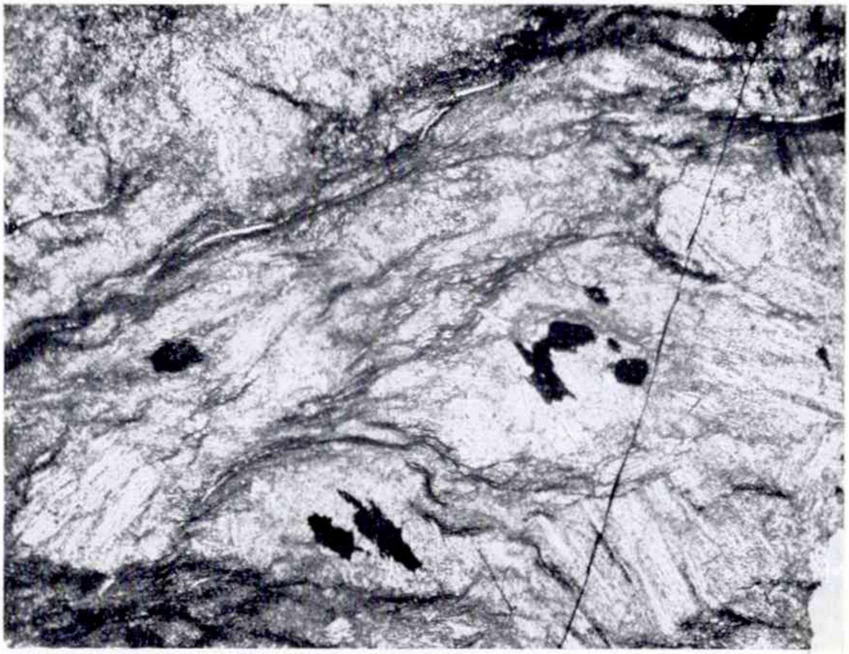


Fig. 42 - *Cataclastic tremolite rock. Mainly consisting of very fine-grained tremoli turbid zones of entirely pulverized material are visible. Some remnants of large tremolite crystals are shown, i.a. in the lower, left part of the photo. 21 ×. S Sølvbergnupen, at an altitude of 440 metres.*

quantity of chlorite is present. The amphibole is represented by li green actinolite. Iron-bearing carbonate is again present. This ro shows also cataclastic phenomena.

The sample no. 81 represents the type-rock forming the greater part of the ultrabasic lenses between Hessihompvatn and Vatnhauge. I consists principally of a fine-scaled talc mass, in which slender tremolit crystals, up to a few centimetres large, are distributed irregularly. Thes crystals show intensive alteration into talc. Large crystals of iron-bearing carbonate, often altered into limonite, occur. A light brown rhombic amphibole forms felty aggregates. The serpentinite 90 i only partly altered into talc. The main constituent of this sample is serpentine. It occurs in the form of fine scaled, sometimes radial, ag-gregates of a light green colour. Furthermore very fibrous, light brown crystals of a mineral of the anthophyllite-gehdrite series and large crystals of carbonate occur in this mass.

The actinolite-rock 87 consists entirely of a pale green actinolitic amphibole. On account of its directionless texture, it greatly resembles some of the ultrabasic rocks already described. The sample under consideration is, however, coarser grained and does not show cataclastic phenomena.

General considerations on the amphibolite-staurolitegneiss formation.

The rocks of the amphibolite-staurolitegneiss formation are the highly metamorphic derivates of pelitic sediments and, to a smaller extent, of semipelitic, psammitic and calciferous sediments. In addition, metamorphic basic rocks are prominent in this formation, while furthermore, in smaller quantities, metamorphic ultrabasic rocks are present.

The schistose amphibolites, which alternate in the lower parts of the amphibolite-staurolitegneiss formation with graphiteschists, are assumed to represent basic volcanics. The fact that, at least partly, these amphiolites have been tuffs, appears from their alternation in thin layers with ther rocks. The massive, coarse grained and directionless amphibolites occurring in the higher parts of the formation, probably represent inusions, possibly gabbros, as frequently observed elsewhere in the candinavian Caledonides (e.g. in the relatively adjacent Sulitelma ea, Vogt-1927—Kautsky-1953).

The metamorphic grade of the rocks of the amphibolite-staurolite-iss formation is considered to represent the transition between the taurolite-kyanite subfacies and the sillimanite-almandine subfacies Turner and Verhoogen, 1951, p. 452 ff.) of the amphibolite facies. The usion of staurolite, kyanite, garnet and sillimanite by plagioclase orphyroblasts (see e.g. fig. 40), proves that the formation of plagioclase ok place at a relatively late stage of the metamorphism. It may be oted that in the massive amphibolites, porphyroblastic plagioclase is of estricted occurrence. Only in the outer zones of some of the massive mphibolite bodies, "eyes" containing plagioclase porphyroblasts and uartz and obviously indicating metasomatic processes, were locally bserved (p. 82). The frequent occurrence of tourmaline in many rocks f the amphibolite-staurolitegneiss formation and the occurrence of scapolite in the marbles, evidence the introduction of material. The esence in chloritized zones in the massive amphibolites, of tourmaline-muscovite rocks rich in staurolite, kyanite, garnet and biotite (p. 98), is perhaps due to imbrication. Besides by the high degree of metamorphism the amphibolite-staurolitegneiss formation is distinguished by a strong tectonic influencing. In all parts of the formation a considerable variation in the rock succession is found in the direction of the strike; this is especially the case west of the Saltdal (fig. 35 and p. 85). But for one exception (i.e. the ultrabasic lens east of Sølvbergnupen), the ultrabasic rocks are located along the boundary between the amphibolite-staurolitegneiss formation and the underlying calciferous micaschist formation, which boundary represents a major thrust plane (p. 107).

CHAPTER IV

STRATIGRAPHY

The investigated region belongs to the zone of higher metamorphic rocks in the western part of the Scandinavian Caledonides. In these metamorphic rocks fossils are lacking, which makes accurate dating impossible. In this chapter an attempt at correlation on a lithological basis with other parts of the Scandinavian Caledonides will be made. Two areas appear to be suitable for this comparison, viz. the Trondheim area (i.a. Vogt, 1945) some hundreds of kilometres farther south, with the adjacent areas in Sweden (Kulling, 1933; Marklund, 1952 et al.), and further the Tysfjord and Sulitelma areas (Vogt, 1927; Foslie, 1941 and 1942; Kautsky, 1953 et al.), north and north-east of the investigated region, again at a considerable distance. The investigated area and ·; immediate surroundings are only incidentally described in the ex-lanation to the sheet Rana (1 : 250.000) of the geological outline map Holmsen, 1932) and in a few older publications.

he granite-gneiss formation and the graphiteschist formation may be mpared, as regards their geological position and the composition of he constituent rocks, with the North-western Gneiss Area in Southern Norway (i.a. O. Holtedahl, 1952; H. Holtedahl, 1950 and Rosen-ist, 1942) and with the Tysfjord area (Foslie, 1941, 1942; Kautsky, 953). In the North-western Gneiss Area of Southern Norway the flag-ones, considered to be Eocambrian sparagmites, pass downwards into asal gneisses; sometimes the boundary is sharp (Strand, 1949, p. 32), sometimes the transition is gradual (Gjelsvik, 1951, e.g. p. 36). The lagstones are covered by "Trondheimschists" which, according to i.a. Rosenqvist (1942, p. 142), belong to the Ordovician Bymark-group f the Trondheim area, but according to H. Holtedahl (1950, p. 53) possibly to the older Røros-group. According to O. Holtedahl (1953, p. 238) the graphiteschists of the graphiteschist formation, overlying the gra ite-gneiss formation in our region, and the "Dictyonema-schiefer" in the Trondheim area, belonging to the Røros-group, may be considered to be of the same age (basis Lower-Ordovician). It should be observed here, that lithologically the rocks of the graphiteschist formation and the "Trondheimschists" show little resemblance.

In the Tysfjord area the directionless Tysfjord granite grades, according to FOSLIE (1941, p. 41), outwards into aplitic and mica-rich rock types, which show a strong resemblance to the gneissose rocks of the granite-gneiss formation in the region investigated. According to FOSLIE (1941, p. 42), these aplitic and mica-rich rocks form the border zone of the Tysfjord granite—which he considers to be of Caledonian age. VOGT (1941, p. 211), and KAUTSKY (1953, p. 163, 176) on the other hand assume that the granite is Archaic and reactivated during the Caledonian orogeny. According to KAUTSKY (1953, p. 175 ff.), the rocks of the border zone of the Tysfjord granite are of sedimentary origin and represent Eocambrian and Cambrian rocks of the "Hyolithus-zone type", which may be correlated with the non-metamorphic rocks of the Hyolithus-zone at the Eastern Mountain border. The base of this Hyolithus-zone consists of sandstones and arkoses, probably of Eocambrian age, while the upper part of the series, where graphite-bearing rocks take an important place, is considered to be Cambrian. Conglomerates as found locally in the lower parts of the Hyolithus-zone by KULLING (1955, p. 146) and KAUTSKY (1953, p. 152), are lacking in our granite-gneiss and graphiteschist formations.

KULLING (1955) gives a detailed description of the fossiliferous rocks of the Cambro-silurian of the Eastern facies at the Caledonian mountain border in Västerbotten (Sweden), with which the Hyolithus-zone may be compared. According to this author the highest part of this Eastern Cambro-silurian may be reckoned to belong to the Ordovician.

The limestones, alternating with quartzites, at the base of the calciferous micaschist formation, may be connected directly—via Gradda—across the Swedish border—with the Pieske-limestones in Sweden. In the Sulitelma area VOGT (1927, p. 187) found fossils in the lowest part of the Furulund-schists—which are, stratigraphically, higher than the Pieske-limestones. These fossils indicate an uppermost Lower-Ordovician to Middle-Ordovician age for these schists.

The amphibolite intercalations, occurring in the calciferous micaschist formation, may perhaps be correlated with the Ordovician volcanism of the Bymark-group in the Trondheim-area (i.a. O. HOLTEDAHL, 1953, p. 222), and with the Ordovician volcanism distinguished in Sweden (Jämtland) i.a. by KULLING (1955, e.g. p. 263).

The quartzite conglomerate occurring locally in the upper part of the calciferous micaschist formation, may, in view of its position on top of a thick succession of calciferous micaschists, most likely be correlated with the "Gimja-conglomerate", which, in Swedish Jämtland, also rests upon calciferous micaschists of the Lövfjälls series, (KULLING, 1955). This Lövfjälls series and the overlying "Gimja-conglomerate" are assumed to be of Silurian age. A Silurian calciferous micaschist series, containing in its highest parts quartzite-conglomerates, has been described from Helgeland (N-Norway) by STRAND (1952-b, p. 132) as representing the youngest formation.

Little can be said about the stratigraphical position of the rocks of : amphibolite-staurolitegneiss formation. Lithologically, this forma- ı shows some resemblance to the highest tectonic unit distinguished the Sulitelma-Salojaure area by KAUTSKY (1953), i.e. the Gasak nappe. ike our amphibolite-staurolitegneiss formation this nappe is distinguished by the occurrence of gabbroid components among the amphibolites and of staurolite-rich rocks; moreover, at the base of the Gasak ppe, as is the case with the amphibolite-staurolitegneiss formation, hiteschists occur. KAUTSKY holds it to be possible that the rocks Gasak nappe are of Lower-Ordovician age.

ımarizing we thus consider, that in the marginal zone of the Cale- geosyncline, on an Archaic basement and its Eocambrian cover resented by the granite-gneiss formation, p. 41), Cambrian to Ordo- sediments of the graphiteschist formation have been deposited. the same period—and probably also later, i.e. until during the Si- ırian—the rocks of the calciferous micaschist formation were deposited deeper parts of the geosyncline. If the rocks of the amphibolite- urolitegneiss formation may be correlated with those of KAUTSKY's ak nappe and if the assumption that the latter are of Lower-Ordo- cian age is correct, the amphibolite-staurolitegneiss formation would of the same age as part of the calciferous micaschist formation, having inated from a part of the Caledonian geosyncline situated still ther west.

CHAPTER V

TECTONICS AND METAMORPHISM

Tectonics

The amphibolite-staurolitegneiss formation forms the highest tectonic unit in the investigated region. In the north-east, this formation forms the core of a syncline dipping northward, while west of the Saltdal rocks of the amphibolite-staurolitegneiss formation appear to form the core of a syncline, clenched between the Kvasstein anticline (p. 55) and the granite-gneiss massive with its surrounding rocks.

The contact between the amphibolite-staurolitegneiss formation and the underlying calciferous micaschist formation is formed by a thrust plane. The tectonic character of this contact follows from the occurrence of a higher metamorphic formation on a lower metamorphic one (p. 110, 112), and from the wedging out over short distances of thick horizons. This wedging out can be observed e.g. in the extreme north-east of the investigated region, where, at the base of the amphibolite-staurolitegneiss formation, a series, many hundreds of metres in thickness, principally consisting of graphiteschists, disappears over a relatively short distance. The wedging out is also observed west of the Saltdal, where different horizons of the amphibolite-staurolitegneiss formation are found in contact with the calciferous micaschist formation. There is a rapid variation in a lateral sense in this part of the amphibolite-staurolitegneiss formation, as is shown in fig. 35. The rapid variation observed in this zone, may also have been caused to some extent by the younger phase of folding (as mentioned on p. 108).

A second tectonic contact is assumed to be present below the calciferous micaschist formation. Here the graphiteschist formation varies strongly in thickness, whereas east of the Saltdal it is locally entirely lacking. The metamorphic facies to which the graphiteschist formation belongs could not be accurately determined, due to the absence of c[illegible] acteristic minerals (p. 49). Between the rocks of the granite-gneiss formation and those of the calciferous micaschist formation, however, a distinct difference in the grade of metamorphism was observed, the calciferous micaschist formation being the higher metamorphic unit. Stratigraphical considerations (p. 105)—i.e. the parallelisation of the graphiteschist formation with rocks of the Eastern Cambrosilurian (Hyolithus-zone type)—render a normal position of the graphiteschist formation on the granite-gneiss formation very probable, in which case the principal thrust plane lies below the calciferous micaschist formation. The structure of the granite-gneiss formation is unknown. Evidence of the presence of an Archaic basement, as well as traces of possible movements, must have been entirely obscured by the strong feldspathization and recrystallization, which have taken place in this formation.

Not only in the principal tectonic zones, but also within the formations, phenomena are often found which point to strong differential movements. A fine example may be observed, along the railroad, in the calciferous micaschist formation (fig. 20). Over a distance of some tens of metres an alternation of calciferous schists, garnet-micaschists and quartz-feldspar rocks is exposed, in which a strong lamination and boudinage was observed.

A second example, where thinner horizons have been strongly reduced, is found in the north-west of the investigated region, in the Kvassteinanticline. Between the garnet-micaschists in the core of this anticline and the overlying biotite-rich microclinegneisses, a limestone horizon is found, which in the northern limb of the anticline is locally drawn out into lenses. At the base of the microclinegneiss series the rocks sometimes contain numerous veins and lenses of quartz (fig. 43).

A third place where apparently intensive differential movements have taken place is found in the rocks of the granite-gneiss formation (fig. 44) along the railroad, about 800 metres north of the Stampelv, where the contact between the mica-poor and the overlying biotite-rich microclinegneisses is well exposed and where parts of the underlying rocks have been dragged off (fig. 6 and 7).

Apart from the phenomena mentioned above, the structure of the investigated region is characterized by a folding with an amplitude of

Fig. 43 - *Biotite-rich microclinegneiss of the Kvassteinanticline (with numerous lenses and veins of quartz), overlying limestone. N of Kvassteinvatn.*

Fig. 44 - *Intensive isoclinal folding in calciferous micaschists, marked by some light coloured quartzo-feldspathic bands. Along the railway, 600 metres N of the Markskjeelv.*

several kilometres. The fold axes of the syn- and anticlines thus formed, trend in the north-west in a WSW-ENE direction, and in the east in a N-S direction. The pitch of the axes is remarkably steep: the EN pitch of the axis of the Kvasstein-anticline varies between 50 and 90° (in the west and in the east respectively), whereas in the syncline east of the Saltdal a pitch of 45° towards the N was observed. In the north-west as well as in the east there appears to be an overturning of the folds towards the granite-gneiss formation. The fact, that the thrust planes have participated in the folding, evidences that this folding is younger than the overthrusting.

Besides this folding in large syn- and anticlines, an intensive small scale folding may be distinguished. This phenomenon is very conspicuous in the amphibolite-staurolitegneiss formation, and further in the rocks of the calciferous micaschist formation in the eastern limb of the syncline east of the Saltdal. Frequently the small scale folding is of an isoclinal type (fig. 44).

Metamorphism

s has been stated in the description of the various formations, the s in the investigated region are partly metamorphosed in the epidote-bolite facies and partly in the amphibolite facies (fig. 45). As ary between the two facies has been taken the one defined by ENQVIST (1952, p. 30): i.e. for the epidote-amphibolite facies chemical brium between epidote-clinozoisite and plagioclase, and for the olite facies instability of the first mentioned mineral in the e of plagioclase. The lowermost unit–the granite-gneiss forma- as been metamorphosed in the epidote-amphibolite facies. The of characteristic minerals renders an accurate facies-determi- r the graphiteschist formation impossible. As the graphite- ormation and the granite-gneiss formation appear to form a unit (p. 108), the former has been probably also metamorphosed pidote-amphibolite facies. The calciferous micaschist formation en metamorphosed partly in the epidote-amphibolite- and partly amphibolite facies. The part of the formation, exposed south and f the amphibolite-staurolitegneiss formation, appears to have been orphosed in the amphibolite facies. In the Kvasstein anticline, , normal succession of the facies is represented; whereas the he core of the anticline have been metamorphosed in the lite facies–represented by the staurolite-kyanite subfacies

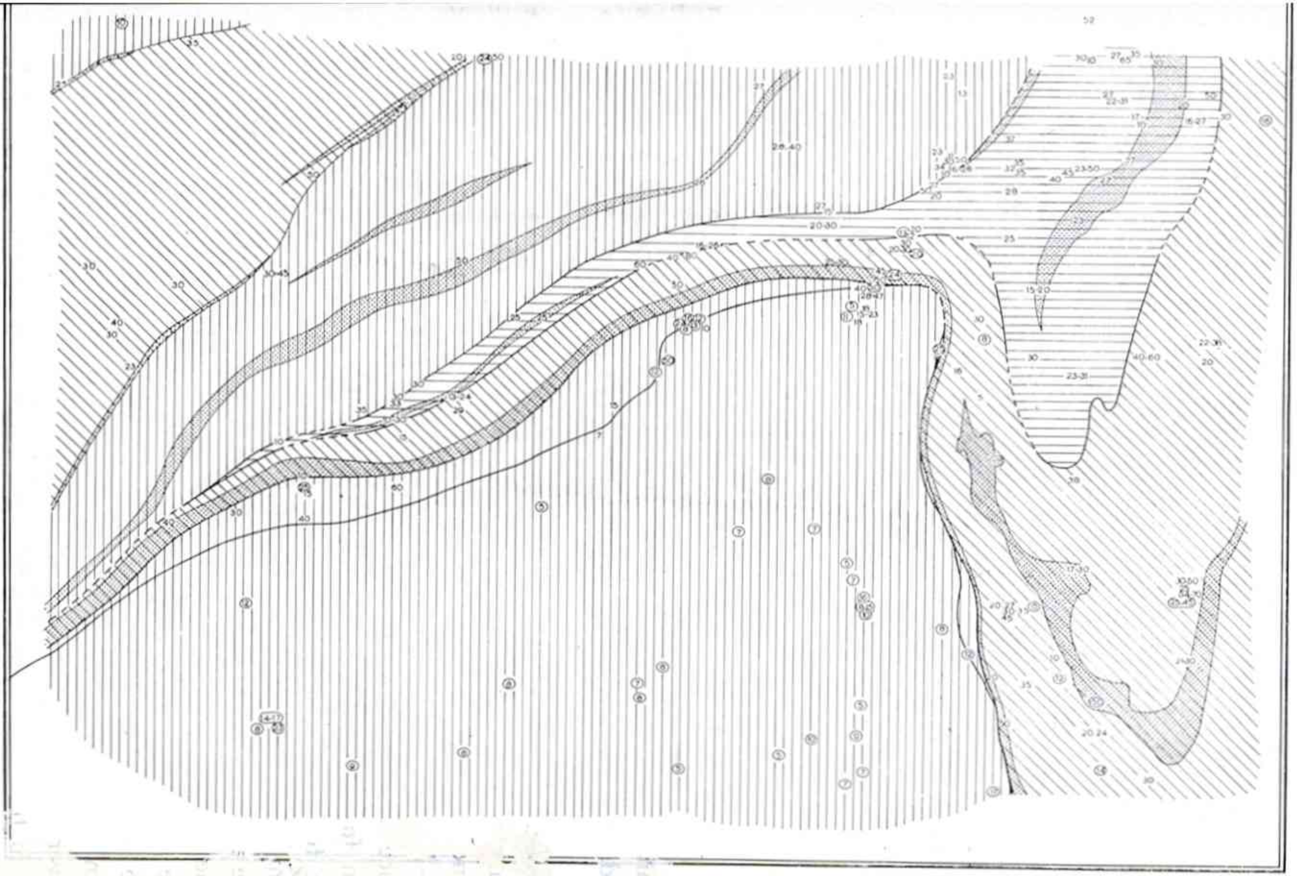


Fig. 45. Sketch map showing the composition of the plagioclase, the distribution of microcline and the metamorphic (sub)facies ... indicate limestones.

... An-content of the plagioclase ... facies

40-60 etc. An-content of core and rim of the reversely zoned plagioclase ... facies of the amphibolite facies

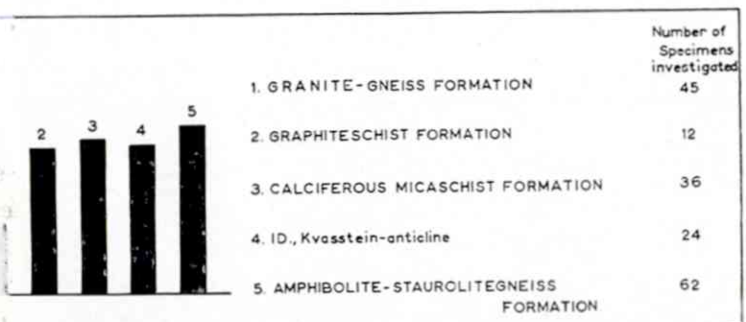
○ microcline ... kyanite subfacies to the sillimanite-

— Formation boundaries

(TURNER and VERHOOGEN, 1951, p. 452)—the stratigraphically higher parts belong to the epidote-amphibolite facies. The amphibolite-staurolite-gneiss formation appears to belong to a somewhat higher metamorphic part of the amphibolite facies (fig. 45), i.e. to the transition between the staurolite-kyanite and the sillimanite-almandine subfacies.

Consequently, the investigated region exhibits—with the exception of the Kvasstein anticline—an inversion of metamorphic (sub)facies; the facies boundaries coincide with tectonic contacts. Also for this reason (p. 107), the presence of two nappes on a basement is considered probable, assuming that in the undisturbed succession the metamorphism increased towards depth. On the one hand, the regional metamorphism appears to have been completed after the beginning of the orogenic movements, as evidenced by the inclusion of small scale folding by staurolite porphyroblasts. On the other hand, the regional metamorphism was concluded—at least for the greater part—before the main overthrust.

In all the formations plagioclase is present in considerable quantities; many rocks of pelitic and semipelitic origin may be reckoned among the gneisses on account of their high plagioclase content. The composition of the plagioclase shows considerable variation (fig. 45). From



Diagram, showing the average An-content of the plagioclase, occurring in ..s formations. The rocks of the calciferous micaschist formation, exposed ..vassteinanticline, are separated (4), because of the lower grade of metamor- ..f its higher, plagioclase-rich, horizons, compared with the remaining parts ..formation.

..umbers 1, 2 and 4 belong to the epidote-amphibolite facies,
..r 3 to the staurolite-kyanite subfacies of the amphibolite facies,
.. 5 to the transition of the last mentioned subfacies to the sillimanite-almandine ..

fig. 46, showing the "average" anorthite content of the plagioclase in the different formations, it appears that an increase in this anorthite content concurs with an increasing degree of metamorphism. In addition to a dependence on the degree of metamorphism, also a relation to the chemical composition of the rocks can be observed. The rocks of sedimentary origin containing Ca-rich minerals (calcite, epidote-clinozoisite, hornblende) contain, on an average, a more sodic plagioclase than those which are free of such minerals.

The fact that the plagioclase in many of the investigated rocks is inversely zoned, is remarkable. Whereas this inverse zoning is rather seldom found in the granite-gneiss formation and mainly limited to the higher, biotite-rich parts, it is of frequent occurrence in all the other formations, forming a characteristic feature. On the whole, the occurrence of zoned plagioclase in metamorphic rocks is a relatively rare phenomenon which indicates that a chemical equilibrium has not been attained (see e.g. HARKER, 1931, p. 83 and TURNER and VERHOOGEN, 1951, p. 376).

As a possible cause for the origin of zoned feldspar a variation in the pressure-temperature relation during its formation may be mentio while it seems, that in case of introduction also a variation in th c position of permeating solutions may play a part. WEBER (194 attributes the inverse zoning of the plagioclase of the Hochalm-A group (Tauern, Austria) to a rise of temperature, an explanation also seems acceptable for the present case.

On the whole, potash-feldspar occurs in our area to a less than plagioclase (fig. 45). Excepting the granite-gneiss compl microcline is an important constituent of most of the rocks, thi is only found in considerable quantities in the biotite-rich m gneiss horizon (p. 71) of the calciferous micaschist formatior smaller amounts in some rocks in the lower parts of this The potash-feldspar often appears to have been formed at th of the above mentioned plagioclase. In its turn the microclin placed, on a smaller scale, by plagioclase of a younger gene having about the same composition as that of the older gene (usually albite-oligoclase, p. 31 and 34) and invariably showing r kite textures. In our opinion, the high feldspar content in the

the investigated region must be partly attributed to introduction of material from elsewhere. It is uncertain how far this holds good for the plagioclase. The fact that there appears to be a relation between the degree of regional metamorphism and the anorthite content of the first and most important plagioclase generation, suggests the latter was formed during the regional metamorphism. It could not be ascertained here was how far the introduction of material played a part. As has been explained above, however (p. 42), the high plagioclase content in the rocks of the granite-gneiss formation—which are considered to be of sedimentary origin—suggests in our opinion, that here at any ate, metasomatism has contributed to the formation of plagioclase. hermore plagioclase of undoubtedly metasomatic origin has been y found in the outer zones of some amphibolites of the amphibolite- itegneiss formation (p. 82).

nclusion of staurolite, garnet and biotite by plagioclase porphyro- proves that formation of plagioclase has taken place up to an d stage of the regional metamorphism.

asomatic origin is considered to be certain for at least a large ne potash-feldspar. On page 42 a few points were mentioned this opinion, i.e. the occurrence of microcline-poor, relict ng the microcline-rich rocks, and of microcline veins in the iss formation. In addition to the generally occurring replace- agioclase by microcline, also the decrease—in a regional sense— rocline content from lower to higher units, together with the he distribution of the microcline appears to be independent of structures, suggest a metasomatic origin. Whereas the rocks anite-gneiss formation are microcline-rich and those of the hist formation contain microcline too, this mineral is, in the s micaschist formation, limited to the immediate proximity of ite-gneiss formation. In the amphibolite-staurolitegneiss forma- rocline was not found. The biotite-rich microclinegneiss horizon Kvasstein anticline represents an exception to the said regional ase of the potash-feldspar content in upward direction. In this the sharp boundary with the adjacent microcline-free rocks, solated occurrence with respect to the other microcline-bearing t have been influenced also by the initial composition. On r hand, the occurrence of replacement phenomena between microcline and plagioclase, which are indentical to those found elsewhere, also in this case make a metasomatic origin of the potash-feldspar acceptable.

The fact that the distribution of the microclinization phenomena appears to be independent of the overthrust plane situated below the calciferous micaschist formation (p. 107), evidences that the potash metasomatism proceeded after the overthrusting. The locally observed replacement of microcline by a second plagioclase generation is, obviously, also a result of a late introduction of material.

A potash metasomatism comparable to that found in the region investigated, occurs in the North-western Gneiss Area of Southern Norwa (RAMBERG, 1944, p. 47; ROSENQVIST, 1942, p. 190; STRAND, 1949, p. 36 H. HOLTEDAHL, 1950, p. 47 ff.). For the Surnadalsdistrict (Souther way) STRAND (1952-a, p. 117) concluded, that after a phase in plagioclase was formed, microclinization took place. For the Rau (Finland) ESKOLA (1952, p. 133) assumes "polymigmatization' microclinization as the later phase.

It is remarkable that cataclastic phenomena and retrogres morphism are rare in the investigated region, even in the z thrusting. The strongly tectonically affected amphibolite-sta formation presents a typical example: here cataclastic phe retrogressive metamorphism were only found in a few ca massive basic and ultrabasic rocks (fig. 41, 42).

Comparison with other areas

Some of the most conspicuous features of the region investi

1. The exceptional steepness of the fold axes of the young
2. The plasticity of the rocks.
3. The important part played by feldspathization in compari areas farther east.

These features indicate, that the region belongs to the tecto deeper parts of the Scandinavian Caledonian mountain-system.

So far, only little is known about the relation between tectoni metamorphism in the deeper parts of the Scandinavian Cal Several authors (VOGT, 1941; KAUTSKY, 1947, 1953; O. HOLTE point to the increase in western direction of the reactivation an of the Archaic basement, attended with plastic folding. The relatively young folding, distinguished in the area investigated, is considered to represent this plastic folding phase.

The North-western Gneiss District of Southern Norway (i.a. Oppdal-area), like the region investigated, belongs to the deeper parts of the Scandinavian Caledonides. In this area the basal gneisses are overlain by flagstones which in their turn are overlain by "Trondheimschists". The flagstones are considered to be Eocambrian sparagmites (O. HOLTEDAHL, 1952, p. 80; H. HOLTEDAHL, 1950, p. 51; ROSENQVIST, 1942, p. 128). The Trondheimschists, according to some authors (e.g. ROSENQVIST, p. 142), must be included in the Ordovician Bymark-group of the Trond-im area; according to e.g. O. HOLTEDAHL (1952, p. 80), however, these ks may be of Cambrian age. As regards their composition and ap-rance, the flagstones may be compared with the upper parts of the granite-gneiss formation in the region investigated, whereas the Trondheimschists probably may be compared with the graphiteschist formation or with parts of the calciferous micaschist formation. The basal gneisses are partly, i.c. there where the boundary with the overlying flagstones is sharp, considered to be Pre-Cambrian (STRAND, 1949, p. 32); partly, i.c. there where the basal gneisses show a gradual transition into the flagstones, a Caledonian metamorphism and granitization is assumed (i.a. SVIK, 1951, p. 36). In this South-Norwegian area a plastic folding rs (H. HOLTEDAHL, 1950, p. 57) comparable with the younger folding distinguished in the region south of Russånes. The geology of the above entioned North-western Gneiss District is characterized by a well ined metasomatism (e.g. ROSENQVIST, 1942, e.g. p. 190; RAMBERG, 44, p. 47; STRAND, 1949, p. 36). Potash-metasomatism has taken place the conclusion of most of the orogenic movements (STRAND, 1949, ROSENQVIST, 1942, p. 190; H. HOLTEDAHL, 1950, p. 48). According SENQVIST (1942, p. 190) this potash-metasomatism was immediately preceded by a soda-metasomatism. STRAND (1949, p. 32) assumes that plagioclasegneisses, in the area of Romsdalen, are of Archaic age and that in Caledonian age these rocks were partly altered by a potash-metasomatism.

Besides the similarities above mentioned, the North-western Gneiss istrict shows some differences with the region south of Russånes: y, as far as is known to the present author, no inversion of metamorphic zones has been observed in this South-Norwegian area. Secondy, according to GJELSVIK (1951, p. 35) en ROSENQVIST (1942, p. 189), this area shows a general retrograde metamorphism, representing the last metamorphic phase, whereas in the present region retrograde metamorphism appears to be hardly present.

Another area, which is suitable for comparison, because it also forms a structurally deep part of the Caledonian orogene, is the Caledonian of Eastern Greenland. Here a very thick sedimentary series is found (thickness 16,000 m, WENK, 1956, p. 77) of Algonkian to Silurian age In the higher parts of this series the rocks are only locally affected b metamorphism, while they do not show intensive folding. In the lo parts, however, they are said to grade into granites, migmatites, gneisses, showing an intensive plastic folding characterized by axes. The structure of the migmatite dome of Nigglispids (see H 1955, p. 75 f.f.) shows a resemblance to that of the granite-gne in the region south of Russånes.

The granites, migmatites, and gneisses of the Silva-Ma (WEGMANN, 1935), petrographically, resemble those forming the gneiss formation. In the Silva-Maria-group, HUBER (1950, p. 6 observed a replacement of the plagioclase by potash-feldspar. Fu more, there occur in the leucocratic, migmatic rocks of the Silv M group—like in the rocks of our granite-gneiss formation (p. 25)— masses and bands, which are i.a. characterized by a slighter content o potash-feldspar than the surrounding rocks. According to HUBER (19 p. 66) the feldspathization in the rocks of Silva-Maria-group, in vicinity of the Kejser Franz Josephs Fjord, was caused by introduc of material. HALLER (1953, p. 57) considers the potash-felds feldsparquartzites in the West-Andrées Land and Ost-Fraenkels to be undoubtedly formed by introduction, while he holds tha plagioclase was, on the contrary, formed by "erhöhten Aktivierung de Altbestandes". As discussed before in the present paper (p. 114), the region investigated introduction of potash may be postulated whereas the origin of the main part of the plagioclase remains uncertain (p. 114). The metasomatism in Eastern Greenland is assumed to have been caused by migration of material and simultaneous rise in tempe ture (e.g. WENK, 1956, p. 96) in which connection it is generally as that the folding resulted from the increase in volume and the increase of plasticity, in relation with the granitization and migmatization. The crystallization, i.e. the feldspar-porphyroblastesis, is said to have concluded postkinematically (HALLER, 1953, p. 187; HUBER, 1950, p. 66). In the Scandinavian Caledonides LANDMARK (1951, p. 247), besides other possibilities, mentioned the possibility of migmatization being the cause of folding.

Like in the region investigated, in Eastern Greenland no mylonites and other cataclastic phenomena (except relatively young, late Caledonian ones), are found, which is explained by the continuance of the rystallization into the post-kinematic stage (HALLER, 1953, p. 187).

Summarizing the following hypothesis can be formulated for the in-stigated region: During a first tectonic phase two nappes, consisting of amorphic Cambrosilurian sediments were thrust upon a basement it Eocambrian-Cambrosilurian autochtonous cover. This overthrust re was affected by a younger phase of folding, while introduction al resulted in feldspathization (mainly microclinization), a pro- n, being concluded after the folding, might explain the fact, clastic phenomena are seldom found. The existence of contrasts rphic grades on both sides of the overthrusts, indicates an d influence of the metasomatism on the metamorphic facies.

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Explanation to the map:

Granite-gneiss formation: the transition of the granitic rocks into the overlying microclinegneisses poor in mica, takes place gradually, in a zone measuring several hundreds of metres in width.

Only the larger outcrops of limestones, quartzites, metamorphic ultrabasics, and granitic or trondhjemitic intrusives are indicated on the map.

GEOLOGICAL MAP OF THE REGION **SOUTH OF RUSSÅNES,** SALTDAL, NORWAY

BY **W. F. STEENKEN** SURVEYED IN 1954, 1955 AND 1956 SCALE 1:50.000

0 1 2 3 4 km

GEOLOGICAL MAP OF THE REGION **SOUTH OF RUSSÅNES,** SALTDAL, NORWAY

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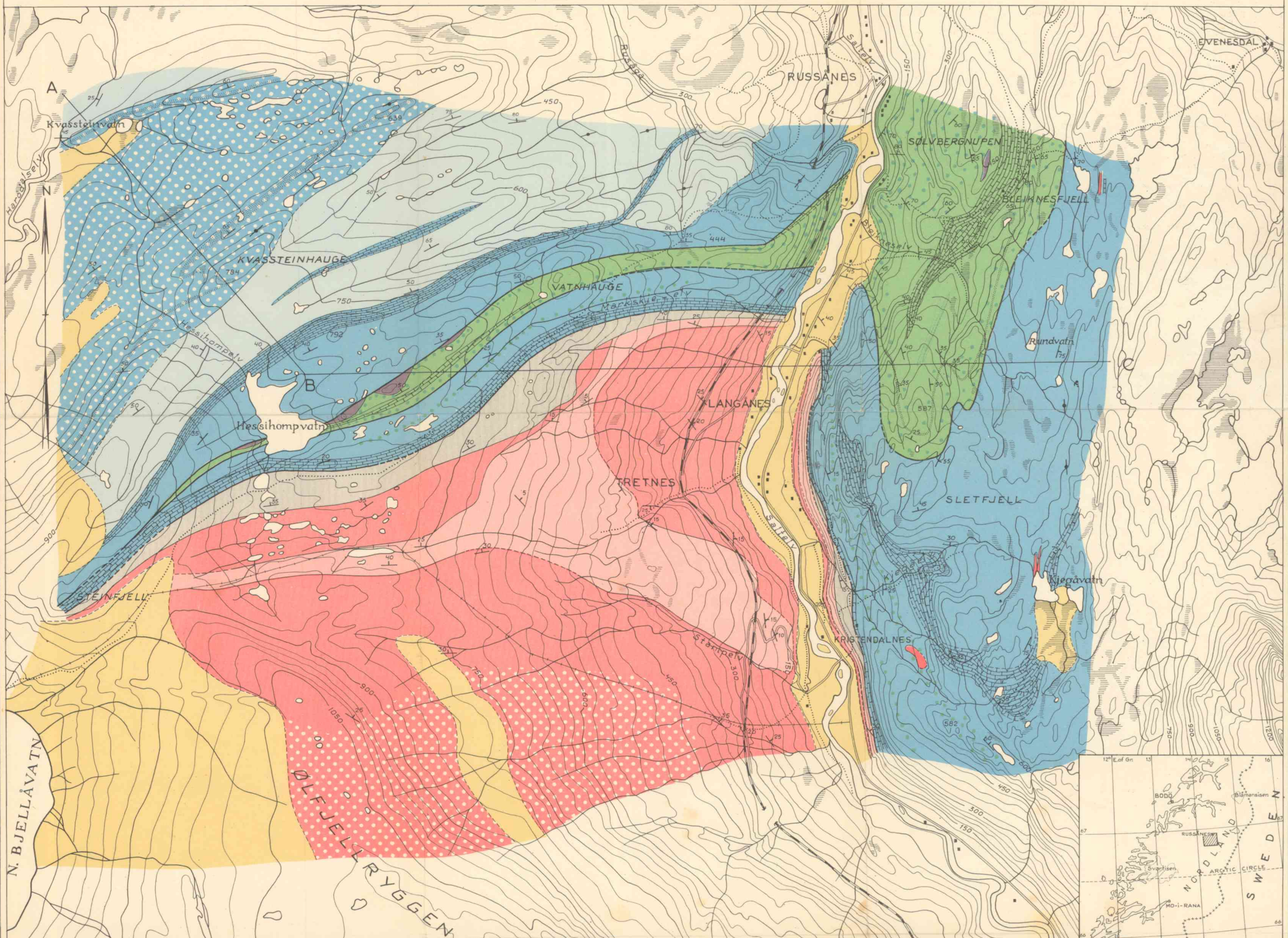
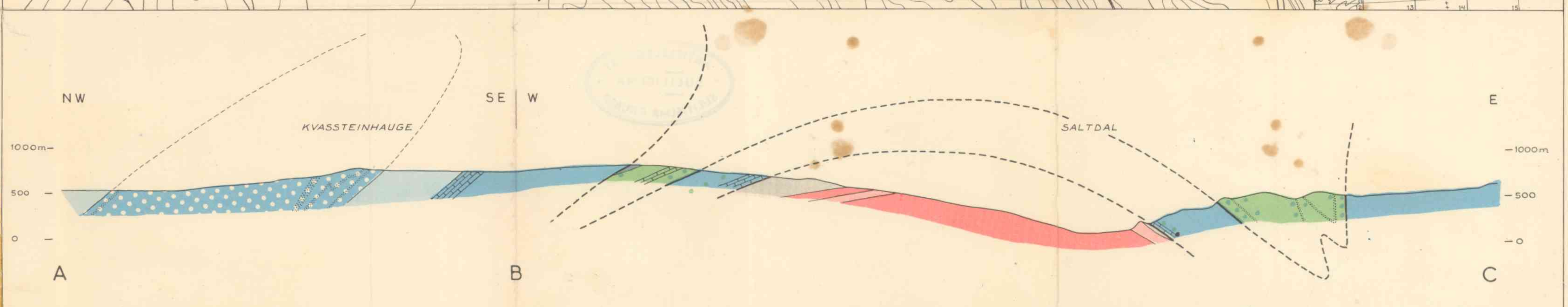
0 1 2 3 4 km

GEOLOGICAL MAP OF THE REGION **SOUTH OF RUSSÅNES**, SALTDAL, NORWAY

BY **W. F. STEENKEN** SURVEYED IN 1954, 1955 AND 1956 SCALE 1:40.000





GRAPHITESCHIST FORMATION

- GRAPHITESCHISTS, QUARTZITES, MICASCHISTS AND -GNEISSES

GRANITE-GNEISS FORMATION

- BIOTITE-RICH MICROCLINEGNEISSES (*with bands, containing varying amounts of biotite and Ca-bearing minerals*)
- MICROCLINEGNEISSES POOR IN MICA
- GRANITIC ROCKS

CALCIFEROUS MICASCHIST FORMATION

- *mainly* PLAGIOCLASE-RICH MICASCHISTS AND -GNEISSES
- AMPHIBOLITES *abundant*
- QUARTZITES
- LIMESTONES
- PLAGIOCLASE-POOR MICASCHISTS
- BIOTITE-RICH MICROCLINEGNEISSES *predominant*
- GRANITIC AND TRONDHJEMITIC ROCKS *intrusive in the calciferous micaschist formation*

AMPHIBOLITE-STAUROLITEGNEISS FORMATION

- *mainly* PLAGIOCLASE-RICH STAUROLITE-MICASCHISTS AND -GNEISSES; GRAPHITESCHISTS *abundant in the lower parts of the formation*
- AMPHIBOLITES *abundant*
- QUARTZITES
- LIMESTONES
- METAMORPHIC ULTRABASIC ROCKS

- QUATERNARY DEPOSITS *over larger surfaces*

- thrust
- geological boundary
- strike and dip
- vertical
- swamp