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Reconnaissance Studies of Gneisses, Ultrabasites, Eclogites and Anorthosites in Outer Nordfjord, Western Norway

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CONTENTS

Abstract.

A reconnaissance map of the geology of Outer Nordfjord is presented with some new structural and petrographic data.

Mesoscopic folds have often steep axes or curved axial planes which indicate rather plastic type of deformation, but the macroscopically recognizable folding of the area has axes with a rather constant gentle plunge towards E or between E and NE. Older linear structures are present in the area around Måløy while younger movements are reflected in EW folds and dislocations along EW lines.

The dominating rock of the area is a biotite-rich banded gneiss of granodioritic composition with zones of pelitic gneiss, quartz-mica-schist and feldspathic quartzite. Other important gneiss types are augen gneiss, granitic gneiss and mangeritic rocks.

Ultrabasites, eclogites and anorthosites (or their altered derivatives) are common as inclusions in the gneisses, while gabbros do not occur.

All gneisses, except the mangeritic rocks, are interpreted as original supracrustal rocks. The biotite-rich banded gneisses with associated pelitic gneiss and quartz-mica-schist are probably essentially isochemically metamorphosed greywackes or volcanites.

Ultrabasites and eclogites occur as tectonic inclusions with internal structures which often are incongruous with those of the enclosing gneisses. The bodies of ultrabasite may have intruded in essentially solid state, but the more numerous and often very small bodies of eclogitic rocks have probably moved only insignificant distances relative to the enclosing gneisses. Some eclogites are probably altered diabase sills and dykes but regular layered structure in some eclogitic bodies and great variation in composition are indicative that the eclogitic rocks have been derived from a variety of basic volcanic and supracrustal rocks. The transformation to eclogite has taken place at high pressures during the initial stages of downbuckeling of a thick geosynclinal pile. The bodies have broken up and moved relative to the gneisses during the main folding of the area. Anorthositic rocks intruded the complex and were later subjected to disruption during deformation.

Introduction.

The present study is the result of reconnaissance studies in the area at both sides of Nordfjord. The study was initiated by The Geological Survey of Norway which called for available information to publish the geological maps at the scale of 1 : 250 000.

It vas decided that the map sheet *Måløy* could be completed in a rather short time, and it was delegated to the author to do large-scale geological mapping of the mainland in the northern part of the map sheet.

To this purpose I have spent about one month in the field each summer 1963, 1964 and 1965, with one or three students as field assistants.

N. H. Kolderup has made reconnaissance studies in Nordfjord as well as at all other places on the Måløy map area, and the writer has had the pleasure to participate in several enlightening excursions with him and other geologists who are working on the *Måløy* map area.

Earlier literature on the geology of the area on both sides of Nordfjord is rather restricted. The large area of gneisses and schists at Bremangerland and the mainland further east was indicated on the map by Irgens and Hiortdahl of 1864. More geological details in the area to the north of Nordfjord were given by Reusch in 1878 and 1884. Ultrabasites from the northern map border were studied by Brögger in 1880 and by Vogt in 1883. Eskola published his classic study of eclogites in 1921, and the major part of his material was taken from Almklov — Sunndalen and Nordfjord. The map by Kolderup in 1928 did not give any new details of the regional geology of the mainland at both sides of Nordfjord, but his work gave some new information on the petrography of the rocks in Davik and at Nordfjordeid.

Gjelsvik and Gleditsch published a geologic map of Sunnmøre and adjoining areas in Nordfjord in 1951. This map gave many new details, both as regards petrography, structural trends of the gneisses and of localization of eclogites and other basic inclusions in the gneisses. Gjelsvik (1951) added to this map a geological description of the main rock types. Some more details were given in the map by Kolderup in the quide of the Congress excursion in 1960.

Detailed petrographical or mineralogical studies of the ultrabasic rocks in the Almklov—Sunndalen area¹) have recently been undertaken by Rost, 1963, O'Hara and Mercy, 1963, and Mercy and O'Hara, 1965 a and b.

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¹) (Added in proof) A new study has quite recently been published by Lappin, 1966 (Norsk Geol. Tidsskr., *46*, 339—495).

The area of Outer Nordfjord is mainly underlain by fine- to medium-grained banded biotite-granodioritic gneisses with interlayered local augen gneiss, feldspathic quartzite, quartz-mica-schist and granitic gneiss (Fig. 1). Mangeritic rocks or syenogabbroic to monzonitic clinopyroxene-garnet-plagioclase-microperthite rocks occur in the western part af the area. Inclusions of ultrabasite, eclogite and anorthosite are widely distributed in the gneiss complex.

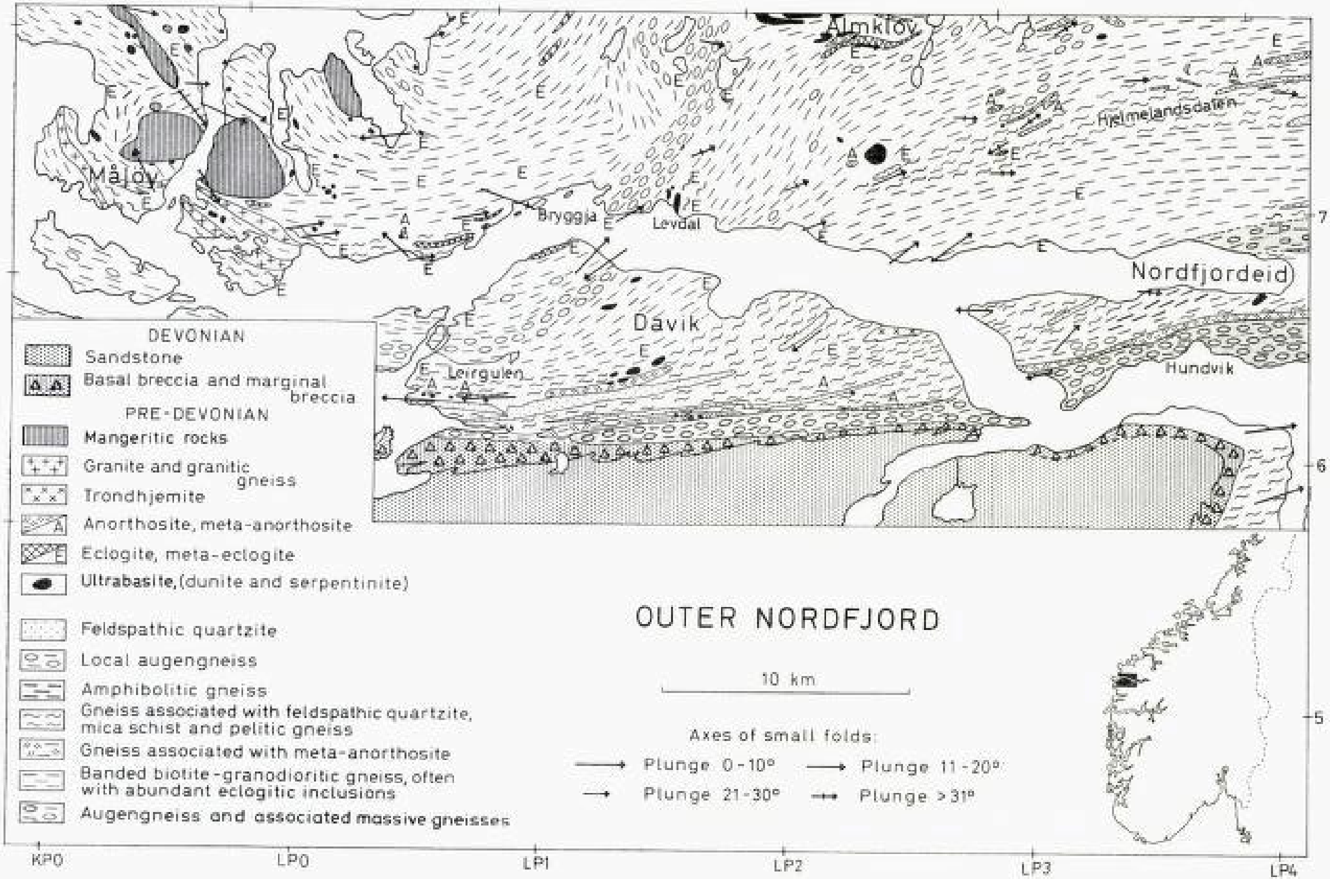
All these rock types except the mangeritic rocks were covered by the studies by Gjelsvik and Gleditsch (1951) of Sunnmøre and adjoining areas of Nordfjord, and our maps overlap in an area north of the fiord. Gjelsvik distinguished between coarse-grained granodioritic gneisses and granodioritic gneisses with frequent bands of fine-grained gneisses in the area north of Nordfjord. We have not followed this practice because the strong mesoscopic variation in the gneiss was found unfavorable for a subdivision of the gneiss on textural criteria, but we have indicated where feldspathic quartzites and mica-schists most frequently are interlayered with the gneiss. Our "Gneiss associated with feldspathic quartzite, mica-schist and pelitic gneiss" is essentially similar to the "granodioritic gneiss with frequent bands of fine-grained gneisses" in the map by Gjelsvik and Gleditsch (1951).

Laboratory studies of the rocks have included examination of 60 thin sections from selected specimens and some hundred sodium cobaltnitrite-stained slabs. Estimates on mineral composition were made on sodium cobaltnitrite-stained slabs combined by microscopic observations. The estimates served to classify the rocks into various mineralogical types where the essential minerals were listed in order of increasing amounts, for example: "(Calcite)-epidote-garnet-plagioclase-quartz-mica-schist" with brackets indicating that the enclosed mineral is a local member of the assemblage.

A few minerals and rocks were selected for supplementary X-ray diffraction examination. Zircon was isolated in 6 samples of gneiss. Plagioclase was mainly determined by the α'index on cleavage fragments and determinations are accurate within limits of less than ± 5 % An.

Per-Reidar Graff, NGU, Trondheim has made two complete silicate analyses of characteristic rock types and one partial analysis of alkali feldspar.

Locality names and standard references refer to the map sheet *Måløy*, 1 : 250 000.


OUTER NORDFJORD
10 km
DEVONIAN
Sandstone
Basal breccia and marginal breccia
PRE-DEVONIAN
Mangeritic rocks
Granite and granitic gneiss
Trondhjemite
Anorthosite, meta-anorthosite
Eclogite, meta-eclogite
Ultrabasite, (dunite and serpentinite)
Feldspathic quartzite
Local augengneiss
Amphibolitic gneiss
Gneiss associated with feldspathic quartzite, mica schist and pelitic gneiss
Gneiss associated with meta-anorthosite
Banded biotite-granodioritic gneiss, often with abundant eclogitic inclusions
Augengneiss and associated massive gneisses
Axes of small folds:
Plunge 0-10°
Plunge 11-20°
Plunge 21-30°
Plunge >31°
Måløy
Almklov
Hjelmelandsdalen
Bryggja
Levdal
Nordfjordeid
Davik
Leirgulen
Hundvik
KP0
LP0
LP1
LP2
LP3
LP4
7
6
5

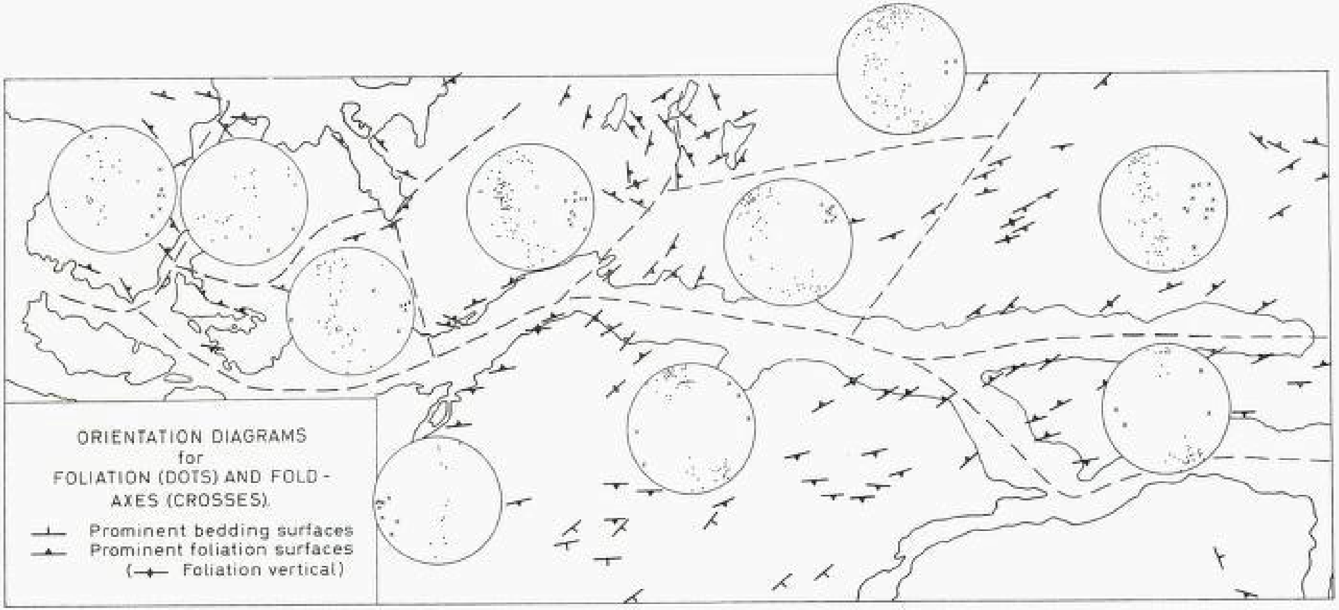


Fig. 1. Geological map and orientation diagrams.

Attempts at regional correlation.

Inferrences about the strathigraphical position of the gneisses and associated rocks of Outer Nordfjord are yet bound to be speculative. A tentative interpretation of a relevant part of the Caledonides is given in Fig. 2. The deepest part in the central Caledonides is the "reworked" basement where Pre-Eocambrian rocks have been remodelled in structural

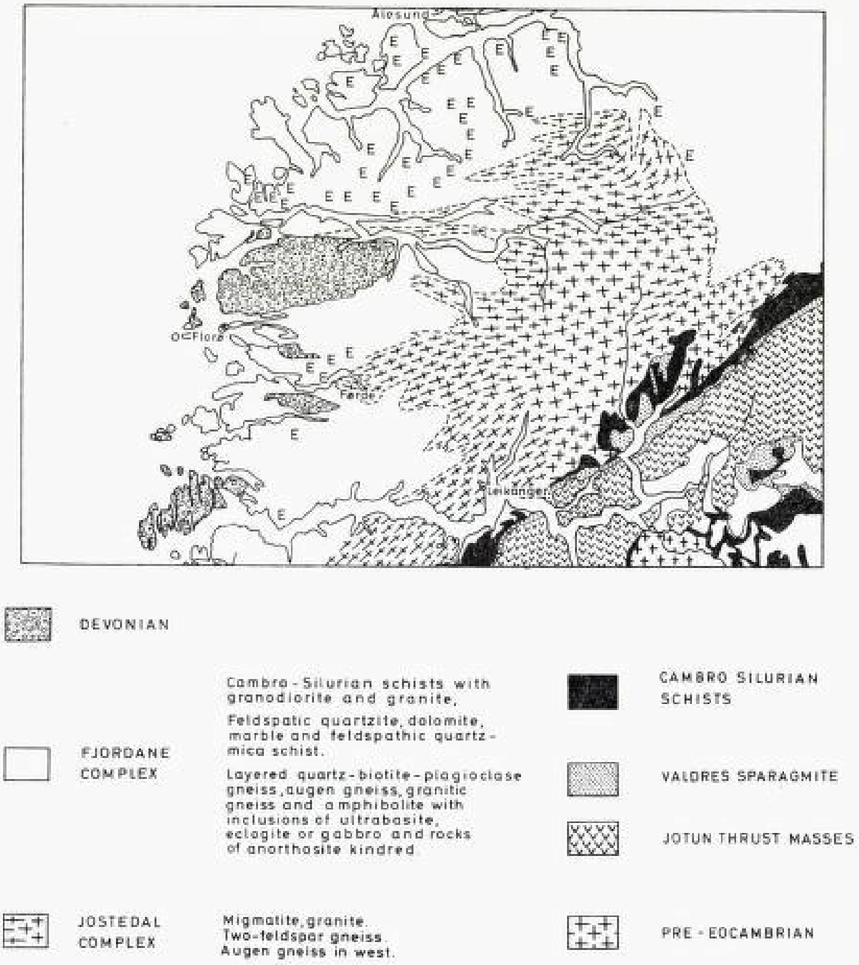


Fig. 2. Tentative geological interpretation of the area between Inner Sogn and Outer Nordfjord. "E": areas with eologites.

congruence with the younger, true Caledonian rocks (Holtedahl and Dons, 1960). The border between the Pre-Eocambrian basement and the overlying rocks is sharp in east but badly defined in west where extensive formation of feldspar augen in the border zone have erased the original contacts. The "reworked" basement has been termed "Jostedal complex" on the map, after the Jostedal valley where these rocks are exposed in å large, continuous area.

The Jostedalen complex form a large culmination which is overlain by Cambro-Silurian rocks, Valdres sparagmite and Jotun thrust masses in east and by a heterogeneous "Fjordane complex" in west. The Fjordane complex probably contain similar rocks and nappes as those east of the culmination, but has suffered much more tight folding into the basement and has been much more thoroughly mechanically and chemically reconstructed during a late Silurian phase of the Caledonian orogeny.

Two narrow branches of the Jostedalen complex probably extends at Nordfjordeid and Hundvik. The rocks are here massive augen gneisses or massive two-feldspar gneisses with layers or dykes of white quartz-monzonite, pink granite and pegmatite. These rocks never contain ultrabasite, eclogite or anorthosite which are so frequently enclosed in the overlying more inhomogeneous gneisses, but the border zone is often a tectonically much disturbed belt with serpentinites and meta-anorthosites.

The inhomogeneous gneisses with ultrabasic and basic inclusions which underlie most of the ground in outer Nordfjord are probably altered supracrustal rocks of similar age as "sparagmites" in Central and Eastern Norway. Mangeritic rocks which occur in the westernmost area, around Måløy and Flatraket, can perhaps be correlated with the Jotun nappes of the Central Caledonides.

Structural geology.

Our large scale of mapping and the lack of well-defined stratigraphical sequence was not encouraging for detailed structural studies, but our reconnaissance might serve as basis for further structural analysis of smaller areas.

The area to the south of Davik is traversed by dislocation zones which are expressed topographically as scarps or narrow valleys and geologically by lithological borders, highly sheared rocks and mylonites. The contact zone between the Devonian and the Pre-Devonian rocks is characterized by mylonites and presents itself as a normal fault, but it is very likely that it has suffered a complex history where also lateral movements have taken place. Dislocation zones in the Pre-Devonian rocks are parallel to the contact towards the Devonian rocks. These zones are characterized by many inclusions of anorthositic rocks and ultrabasite and have suffered much shearing along steeply plunging axes. The most prominent zone can be followed from south of Nordfjordeid (where the road tunnel cuts serpentinite gouge) to the narrow bay south of Leirgulen. Another dislocation zone extends between Davik and Leirgulen. It is characterized by serpenitinites and a very irregularly contorted gneiss- and meta-anorthosite layered rock.

The dislocation zones may represent old thrust zones which have taken up movements during later episodes of deformation, notably Devonian late-orogenic faulting.

Compositional layering is well-developed in most types of gneiss and in some ultrabasites and eclogites as well. The layering in the augen gneisses and associated massive gneisses north and south of Nordfjordeid appear to owe their layered structure partly to original inhomogenities and partly to shearing with different extent of porphyroblastic growth in the sheared zones. The layering displayed by the major part of the other banded gneisses may be related to original bedding. Evidence for this is found in conformity of the layering with contacts between quartz-mica-schist and feldspathic quartzite, but transposition has probably taken place along the original bedding planes.

Migmatization or magmatic/metasomatic modification of the original layering does not appear to have been significant in the banded gneisses. Petroblasts and irregular layers of coarse-grained quartz-feldspar rock (pegmatite) has sometimes been developed between the layering surfaces or in biotite-rich folia. Such secondary growth of minerals have certainly modified the original layering in the gneisses, but is not very common. White non-foliated or foliated quartz-monzonitic to quartz-dioritic layers in the gneiss might represent partly mobilized liquid fractions which have modified the original layering in the same way, but has only local significance.

The mangeritic rocks are often massive without any apparant planar structures. Compositional layering in these rocks is often developed by shearing of feldspar megacrysts or pegmatite lenticles. Layering in these rocks is thus a sencondary effect.

Flow cleavage is parallell to the layering surfaces. It is well developed in feldspathic quartzites and some types of gneiss, but is often poorly developed in the mangeritic rocks and in some biotite-rich gneisses. The lack of surfaces of easy splitting in some of the biotite-rich gneisses is remarkable in consideration of their distinct layering and their high content of mica.

Foliation has been measured where the rock has split along the layering surfaces. The prominent direction of foliation serve as basis for the strike-lines of gneisses on our map. The attitudes are mostly steep with prominent EW to NE-SW strike. NW-SE strike is prominent only in the area around Måløy.

A tight, upright antiform can be distinguished south of Nordfjord and a broad, open synform can be distinguished at Måløy, but the prevailing steep inclination of the rocks and the lack of confirming stratigraphic data make any interpretation of regional fold-structures unreliable.

Attitudes of foliation have been plotted in synoptic diagrams representative for 10 sub-areas (Fig. 1). The poles of the measured foliation surfaces (π S) are distributed on girdles in the diagrams. The axes of these girdles (β) plunge mostly towards between east and north-east. The sub-areas around Måløy offer exceptions, — they are clearly inhomogeneous and should be studied in greater detail.

The great scatter of the poles within the girdles is readily explained by the vast area represented by each subarea and by the presence of bodies of eclogite, anorthosite and ultrabasite which rendered the rock masses very anisotropic during folding.

The axes of the girdles fall in the same area of the diagrams as do the axes of minor folds. This may testify that the area is characterized by relatively simple cylindroidal folding, but this is an oversimplification. Duble closure, cylindrical curved axial surface, disharmonic style of folding and steeply inclined axes are often characteristic for folds seen in the field (Fig. 3 and 4). These observations testify that the rocks have either suffered polyphase deformation or were deformed under plastic conditions. The area around Måløy is most interesting from a structural point of view. A geometric analysis of this area will be carried out, but it can be stated preliminary that older folds in this complex of mangeritic rocks appear to have been refolded along NE-SW axes and the linear structures of both the first and the second generation vary in direction as if the second deformation were a slip folding. Younger than the NE-SW folding is a E W folding which could be illustrated by the nonplane cylindrical fold of Fig. 4. The older lineations have been preserved on the limbs of the fold. It appears that the E W folding dominates in the

Fig. 3. Folds with double closure (»eyed folds»), Nordpollen (LP 0575).

area near the contact to the Devonian rocks, but the structural pattern of outer Nordfjord might well be due to the interplay of all three folding directions. Full eluciation of the structural complexities can, however, only be obtained from detailed studies of small areas where strathigraphic mapping is promising for geometric analysis.

Gneisses.

Reusch (1878) distinguished between three types of gneiss in Nordfjord, and Gjelsvik (1951) found that the gneisses could be subdivided into a) coarsegrained granodioritic gneisses, b) granodioritic gneisses with frequent bands of fine-grained gneisses, c) granitic augengneisses and d) flagstone-gneisses and similar fine-grained original supracrustal rocks.

Our problem during the recent large-scale field-work in Nordfjord was that the different types of gneiss alternate at a too small scale. Most of the ground in western Nordfjord has a fine-grained banded biotite-rich plagioclase gneiss with subordinate potash feldspar. Quartz-mica-schist, feldspathic quartzite and pelitic gneiss with abundant mica occur in this gneiss, but it has been impossible to map their outcrop over long distances. Individual outcrops of quartz-mica-schist and feldspathic quartzite are often too small to show up on a map of our scale, but the localization of them is significant for possible later, detailed studies. A separate symbol for "gneiss associated with feldspathic quartzite, mica-schist and pelitic gneiss" has therefore been used in our map. It has been found convenient to describe the gneisses or gneissic rocks under three headings: *Augen gneisses and associated massive gneisses*, *Banded gneisses* and *Mangeritic rocks*.

Augen gneiss and associated massive gneisses.

Augen gneisses and massive gneisses occur in EW-trending zones south and north of Nordfjordeid.

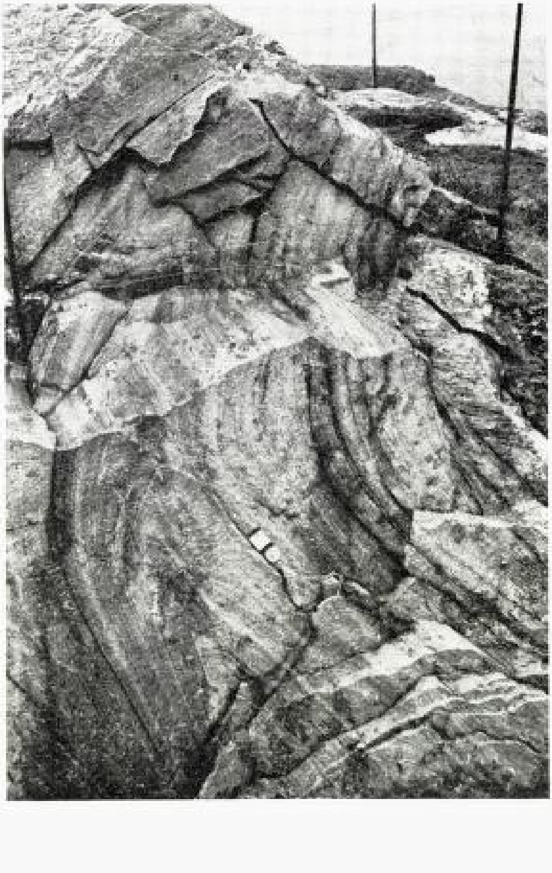


Fig. 4. Nonplane cylindrical fold with EW axis Leirgulen (LP 0664).

The zone south of Nordfjordeid has mainly augen gneiss in a tight, upright antiform below mica-rich gneiss and feldspathic quartzite. The northern border is dislocated with serpentinites and anorthosites in the contact zone. Augen gneiss with 1—3 cm long ovoid Carlsbader-twinned pink porphyroblasts (occasionally as big as 7 by 10 cm) is quantitatively dominating while layers of biotite-rich gneiss, amphibolite and pegmatite occur locally interlayered with the augen gneiss. Even the massive augen gneiss is sometimes layered, — the layering is then defined by different amount and size of the feldspar augen in each layer.

The matrix between the augen is dark due to a high content of biotite. Other characteristic minerals are: epidote, plagioclase, pyrite and sphene.

The zone north of Nordfjordeid has almost vertical layering and the contact against feldspathic quartzite and mica-rich gneiss is not well defined within the map. The contact zone is mylonitized in the area northeast of Nordfjordeid, but it can be confirmed that the augen gneiss is situated structurally below the feldspathic quartzites and mica-rich gneiss.

The dominating rock type is augen gneiss with layers or transecting veins of pegmatite, pink granite, white quartz-monzonite and various types of fine-grained gneiss. The lithological borders are sharp or gradational and the rock is sometimes developed as a migmatic gneiss.

The texture of the dominating type of gneiss is serial with post-tectonic porphyroblasts in a granulated, fine-grained matrix. The mineralogical composition is quartz-monzonitic with about equal amounts of quartz, potash feldspar and plagioclase (oligoclase). Biotite and epidote-minerals are the most common dark minerals, while apatite, black iron minerals, limonitized pyrite, sphene, white mica and zircon occur accessory. Myrmekite, perthitic alkali feldspar and irregular two-feldspar intergrowths are present.

Genesis of the augen gneiss and associated massive gneisses.

The augengneiss and other massive gneisses near Nordfjordeid are not very different from certain gneisses which occur in the gneiss complex further west, but their tectonic position below more inhomogeneous banded gneisses with feldspathic quartzite and mica-rich gneisses may be significant. The position below feldspathic quartzite might indicate that they should be correlated with augen gneisses of the Tingvoll group in Romsdal and Nordmøre (Hernes, 1965), but the author would regard the zones of augen gneiss as expressions of chemical reconstruction in zones of intense mechanical movement rather than as formations of stratigraphic significance. It is believed that the two zones of augen gneiss are products of extensive syn- and postkinematic crystallization of feldspar augen in a strongly tectonized border sone between an Early-Caledonian supracrustal sequence and its basement. This idea has been illustrated in Fig. 2, but detailed geologic mapping and structural studies in Inner Nordfjord will be necessary to bring the idea above the realms of a working hypothesis.

Banded gneisses.

Mica-schist, pelitic gneiss and feldspathic quartzite.

A prominent zone of garnetiferous mica-schist or mica-rich gneiss extends from Måløy to Bryggja. It is probably continuous with similar rocks containing numerous layers of feldspathic quartzite which extends from Levdal to Hjelmelandsdalen in the eastern part of our map. Narrow layers of garnetiferous quartz-mica-schist and feldspathic quartzite also occur just above the massive augen gneiss and massive gneisses south and north of Nordfjordeid. The southernmost of these can be followed over the Davik peninsula to the island Bremangerland west of our map.

The content of quarts, white mica, biotite and plagioclase varies within wide limits in these rocks, and the variation is probably related to an original stratification. Any original bedding in these rocks has, however, been greatly modified by transposition during metamorphism.

Ultrabasites, eclogites and anorthosites are frequently inclosed. Eclogitic inclusions are especially abundant in the zone between Måløy and Bryggja where they appear to have formed layers which have been disrupted by boudinage.

Roks within this group are usually fine-grained, but some mica-schists are medium-grained with 2—5 mm wide books of white mica. Garnets have occasionally diametres in the order 5—10 mm.

The mica-rich rocks often split into plates less than 1 cm thick by the blow of a hammer, but small-scale folding and high content of quartz and feldspar often make schistosity poorly developed. The most common mineralogical types are:

(Calcite) - epidote - garnet - plagioclase - quartz - mica - schist.
Garnet - plagioclase - quartz - mica - schist
and Plagioclase - quartz - mica - schist.

Biotite and white mica are usually both present and either of them may dominate locally. True mica-schists with more than 50 % mica are scarce while plagioclase-quartz-mica-schists with 10—20% plagioclase, 30—40 % quartz and 25—50 % mica are widely distributed.
Calcite, epidote and garnet are locally essential minerals. Accessory minerals are apatite, black iron minerals (mostly magnetite), chlorite, rutile, sphene, zircon and in some rocks red (oxidized) iron minerals and tourmaline. Estimated mineral composition of some of the rocks is given in Table I.

Texture

Platy grains or lenticular aggregates of quartz and lepidoblastic mica usually have a distinct preferred orientation which define the foliation of the rock. Books of white mica are often 0,5—3 mm thick while quartz usually have sizes in the range 0,1—1 mm.

Minerals

Quartz occur as plates or aggregates of grains with a preferred dimensional and optical orientation. Sutured grain boundaries and undulative extinction is characteristic for rocks where the quartz content is high.

Plagioclase is a basic oligoclase which occurs in twinned grains as often as un-twinned. Undulative extinction, irregular distribution of twin lamellae and zonarity are frequently seen.

Biotite has pleochroism: X yellow or colourless, Y, Z dark green, green-brown or yellow green. Parallel intergrowths with chlorite and white mica are common.

White mica occur in books which are thicker than those of biotite and is sometimes intergrown with plagioclase, biotite and chlorite.

Chlorite has pleochroism: X pale green, Y, Z colourless, low interference colours and Z oriented subnormal to cleavage. It appears to be a secondary after biotite.

Garnet contain inclusions of rutile in rocks where rutile is present.

Epidote-group minerals are often zoned with central brown orthite or colourless clinozoisite sharply surrounded by epidote with brilliant interference colours.

Rutile is often enclosed in garnet or black iron minerals.

Zircon appears rounded in thin section. Grains isolated from pelitic gneiss at Raudhjellane are 0,1—0,3 mm long and 0,05—0,2 mm thick, often doubly terminated prisms with slight rounding.

Black iron minerals are magnetic. Magnetic fraction at Raudhjellane consisted of pure magnetite.

The quartz-rich rocks are found mainly as 1—10 metres thick layers. Two more than 100 metres thick zones occour on the mainland south of Nordfjord between Hundeid and Leirgulen. The northern-most of these is probably continuous with an extensive quartzite on the island Bremangerland. Quartzitic rocks are scarce on the north side of the fiord

Locality	Average grain-size of quartz (in mm)	Quartz	Plagioclase	Biotite	White mica	Chlorite	Epidote-minerals	Garnet	Tourmaline	Zircon	Rutile	Apatite	Black iron minerals	Red iron minerals	Pyrite	Calcite
Davikbotten, S. Davik (LP 1966)	1—2	30	15	15	15	×	5	10	×	×	×	×	×	—	—	10
N. Sætertjern, Dombesteinsfjell (LP 2263)	0,5—1	35	20	15	20	×	×	10	—	×	×	×	×	×	×	—
Tunnel N. Eldevikja (LP 0271)	0.2—0.5	40	20	15	15	×	5	5	×	×	×	×	×	—	—	—
N. Stårheimsæter (LP 3073)	0.5—1	40	10	20	30	—	—	×	—	×	—	×	×	—	—	—
N. Stårheimsæter (LP 3073)	0.5—2	60	10	×	30	×	×	—	—	×	—	×	×	—	—	—

Table I Estimated mineral composition of quartz-mica-schists and pelitic gneisses. "x" indicates that the mineral was noted as an accessory constituent.

where they occur mainly in a zone from Kjølsdal eastwards along Hjelmelandsdalen.

The most common mineralogical type is a biotite-white mica-feldspathic quartzite with about 5 % mica where white mica dominates over biotite, 30—40 % feldspar where potash feldspar dominates over plagioclase and 60—70 % quartz. Accessory minerales are apatite, black iron minerals, chlorite, epidote, pyrite, rutile and zircon.

A 10 metres thick feldspathic quartzite from Bauvatn has mesoscopic 1—3 mm broad flakes of pale-green white mica oriented parallel to the bedding-foliation. Feldspar and quartz occur in flattened aggregates parallel to the bedding-foliation. Microscopic investigation reveals that the quartz aggregates contain inequidimensional interlobate grains with average thickness 1/2 mm and average length about 1 mm oriented with longest dimensions in the foliation plane.

A 1—3 metres thick feldspathic quartzite from Hjelmelandsdalen, north of Smørdal is enclosed in a banded potash feldspar-rich gneiss. Flow cleavage or foliation is porely developed, and the texture is granoblastic with interlobate grains with average grain-size 1—2 mm. Feldspar, white mica and biotite often form aggregates between mosaics of quartz.

Mineralogy of the two feldspathic quartzites similar and can be described together:

Quartz has interlobate or sutured grain boundaries and strong undulative extinction. Preferred orientation of c-axes at high angle to foliation is seen by inserting the gybsum plate.

Potash feldspar often has microcline twinning. Perthitic feldspar is rather common, — one type has very small, elongated perthite-inclusions.

Plagioclase is «dusty» due to fine inclusions. Serizitized plagioclase is common and the plagioclase from Hjelmelandsdalen also contain inclusions of biotite and chlorite. The composition of plagioclase in the two specimens corresponded to intermediate oligoclase.

White mica is often intergrown with biotite and chlorite. White mica from Bauvatn has high refrigence and is probably iron-rich muscovite.

Biotite is intergrown with chlorite and probably chloritized. Biotite from Bauvatn has pleochroism: X colourless; Y, Z brown and biotite from Hjelmelandsdalen has X yellow; Y, Z red-brown.

Chlorite from Bauvatn occur in parallel intergrowths with biotite, has Z oriented subnormal to cleavage and weak pleochroism: X pale green; Y, Z colourless. Inclusions of sphene are common, and like chlorite appears to be secondary formed from biotite.

Zircon occur in round grains with diametre 0,1 mm or less.

Pyrite is dominating over dark iron minerals. Among the other accessory minerals is *apatite* common while *rutile* and *epidote* only are present in a few grains within the area of a thin section.

Banded biotite gneiss.

Most of the ground in outer Nordfjord is composed of a fine- or medium-grained banded dark gray gneiss. The overall composition is granodioritic, — layers with often strongly contrasted mineral content not taken into consideration. Individual layers can be classified into many mineralogical types with sharp or gradational contacts. The most common types are here classified by their minerals listed in order of increasing amount:

A. *Biotite-quartz-two feldspar gneiss.*
  White mica-epidote-biotite-quartz-two feldspar gneiss.
  Amphibole-biotite-quartz-two feldspar gneiss.
  Epidote-amphibole-biotite-quartz-two feldspar gneiss.
  Garnet-epidote-(white mica)-biotite-quartz-two feldspar gneiss.

B. *Biotite-quartz-plagioclase gneiss.*
  Amphibole-epidote-biotite-quartz-plagioclase gneiss.
  Garnet-white mica-biotite-quartz-plagioclase gneiss.
  Garnet-epidote-biotite-quartz-plagioclase gneiss.
  Garnet-amphibole-biotite-quartz-plagioclase gneiss.

C. *Biotite-quartz-amphibole-plagioclase gneiss.*

Apatite, black and red iron minerals, chlorite, pyrite, rutile, sphene and zircon are frequently found accessory minerals. Estimated mineral composition of some selected rocks is given in Table II.

The content of essential minerals was estimated on specimens which were cut and stained by sodium-cobaltnitrite and studied by microscope on powder mounts or thin sections. The biotite-quartz-two feldspar gneiss is by far the most widely distributed type, with epidote and white mica as characteristic minor minerals. Epidote, amphibole or both are characteristic minor minerals in some layers while garnet is rather infrequently met with in the biotite-quartz-two feldspar gneisses.

Biotite-quartz-plagioclase gneisses have most frequently amphibole and epidote as characteristic minor minerals, but garnet often occur with either white mica, epidote or amphibole.

Biotite-quartz-amphibole-plagioclase gneisses are not common and it is often difficult to decide whether such roks occur as primary members of the layered gneiss or represent flattened and altered diabase sills or dykes or foreign inclusions in the gneiss complex. Transition to amphibolite occur when the quartz content is low.

Pegmatitic zones, augen gneiss, strings of feldspar augen and layers of granitic gneiss are somtimes found in the banded gneiss. Transecting veins

Locality	Average grain-size of feldspar (in mm)	Quartz	Plagioclase	Potash feldspar	Biotite	White mica	Chlorite	Epidote-minerals	Garnet	Amphibole	Sphene	Zircon	Rutile	Apatite	Black iron minerals	Red iron minerals	Pyrite	Calcite
E. end of tunnel ,Ravneberg, Haus (LP 1871)	0.5—1	25	40 An27	20	15	×	×	×	—	—	×	×	—	×	×	×	×	—
S. of Hagevik, Måløysundet (KP 9976)	0.5	30	30 An28	15	20	×	×	5	—	—	××	×	—	×	×	×	×	—
E. of Isane (LP 2765)	0.5—2	30	20 An27	25	7	10	3	5	—	—	×	×	—	×	×	—	×	—
Maurstad school, Maurstad (LP 1473)	0.5—1	25	30 An29	15	20	×	×	10	—	—	××	×	—	×	×	—	—	—
Vevelset (LP 3067)	0.5—1	40	30 An28	10	10	×	×	10	—	—	×	×	×	×	×	×	×	—
Reknes (LP 2669)	0.5—1	20	30 An27	10	15	—	—	5	—	20	××	×	×	×	×	×	×	—
Maurstad (LP 1473)	0.5—1	35	40 An21	—	5	—	—	×	10	10	×	×	—	×	×	—	×	—
N. Straumen (LP 0175)	0.5—1	35	20 An32	—	20	—	×	20	—	5	×	×	×	×	×	—	—	—
500 m W. Endal, Davik (LP 1469)	0.5—1	20	35	30	5	3	×	4	3	—	×	×	—	×	—	×	×	—
200 m west of oilstore, Taklo (LP 4067)	0.5—1	25	35	10	20	10	—	×	—	—	×	×	—	×	×	—	—	×

Table II Estimated mineral composition of banded biotite gneisses. "xx" and "x" indicate that the mineral was noted as an accessory constituent.

Fig. 5.
Banded gneiss with vein of pegmatite, Levdal (LP 1772).

of pegmatite have been noted (Fig. 5), but pegmatite and strings of feldspar augen are more frequently developed parallel to the banding in the gneiss, and preferentially in layers with much biotite.

Saccharoidal quartz lenticles are common and aggregates of quartz with one or several the following minerals: amphibole, calcite, epidote, scapolite, sphene, white mica and zoisite are occasionally found. Glass-clear pale-green porphyroblasts (idioblasts) of sphene are very characteristic for the banded biotite gneiss and attain lengths up to 5 cm.

Calcite, chlorite, epidote, quartz white mica and zeolites are frequently found vein minerals.

Texture

The banded gneiss has usually a fine-grained texture where the average grain-size is about 0,5—1 mm. Serial texture with 2—3 mm long porphyroblasts of feldspar, amphibole, sphene and epidote are sometimes noted in thin-sections where the matrix has grains as small as 0,1 mm. Dimensional parallellism of prismatic and book-formed minerals is usually good and define a distinct foliation in the rock. Feldspar and quartz are sometimes flattened in this foliation plane, but this is not so common.

Minerals

Plagioclase is basic oligoclase or acid andesine (An 20 — An 35) which often is zoned with slightly higher An-content towards the rim of the grains. A fine polysynthetic twinning is often seen, but the lamellae are not always visible everywhere even within one single grain. The lamellae sometimes dissappear near the rim of the grains. Inversion of extinction (Auslöchungsumkehr, Dresher-Kaden, 1948, p. 53) and undulative extinction has been noted, but is not common. Saussuritized plagioclase has not been noted in any of the thin sections studied, but irregular patches of strongly serizitized plagioclase are occasionally present.

Potash feldspar occurs as porphyroblasts with irregular perthitic veins, as interstitual 'amoeboid' grains and as inclusions in plagioclase. Microcline-twinned grains are about as common as non-twinned grains.

Intimate intergrowths of plagioclase and potash feldspar are common in all gneisses with two feldspars. Potash feldspar sometimes occur as regular 0,05—0,2 mm long discs parallel to (olo) of plagioclase (Fig. 6) or as somewhat bigger, irregular bodies enclosed in plagioclase. The inclusions have continuous traces of twin lamellae end extinguish at the same time. The ratio of the two feldspars in the intergrowths is variable in adjacent grains and even in different parts of the same grain where potash feldspar is concentrated in the central area and plagioclase at the rim. The intergrowths can thus be termed antiperthites of a 'disc' or patch type, but it should be noted that both components of the intergrowths probably are crystallographical continuous grains.

Quartz is usually granoblastic with straight or curved grain boundaries and normal extinction. Specimens from the south side of the fiord (Hundeidlandet and Davik) have inequidimensional grains of quartz flattened in the foliation plane, and undulative extinction which probably is related to a higher concentration of quartz in these rocks.

Myrmekite is found as irregular, less than 0,3 mm grains on the border between plagioclase and potash feldspar as well as without any apparent connection with potash feldspar. Intergrowths of potash feldspar and plagioclase are always present in the rocks where myrmekite occurs, but the amount of myrmekite is very small when potash feldspar only occurs as antiperthitic inclusions and increases to about 1 per cent of the rock when potash feldspar also occurs interstitual and in individual grains.

Biotite has pleochroism: X colourless or yellow; Y, Z green-black or brownish black or more infrequently: X colourless, Y, Z brown. Subordinate chlorite (X colourless; Y, Z green; X subnormal to cleavage; very low berline blue interference colours and: X pale green; Y, Z colourless; Z subnormal to cleavage; low normal interference colours) and sphene has formed at the expence of biotite in some rocks.

White mica occur as about 2 mm high books or as sericitic inclusions in plagioclase. Some grains have very small axial angle and might be phengitic.

Epidote minerals are either epidote or inhomogeneous zonar intergrowths of yellow or brown orthite surrounded by clinozoisite and/or epidote. The contact between the zones is usually sharp.

A specimen taken from the road section just north of Straumen, Sørpollen, has

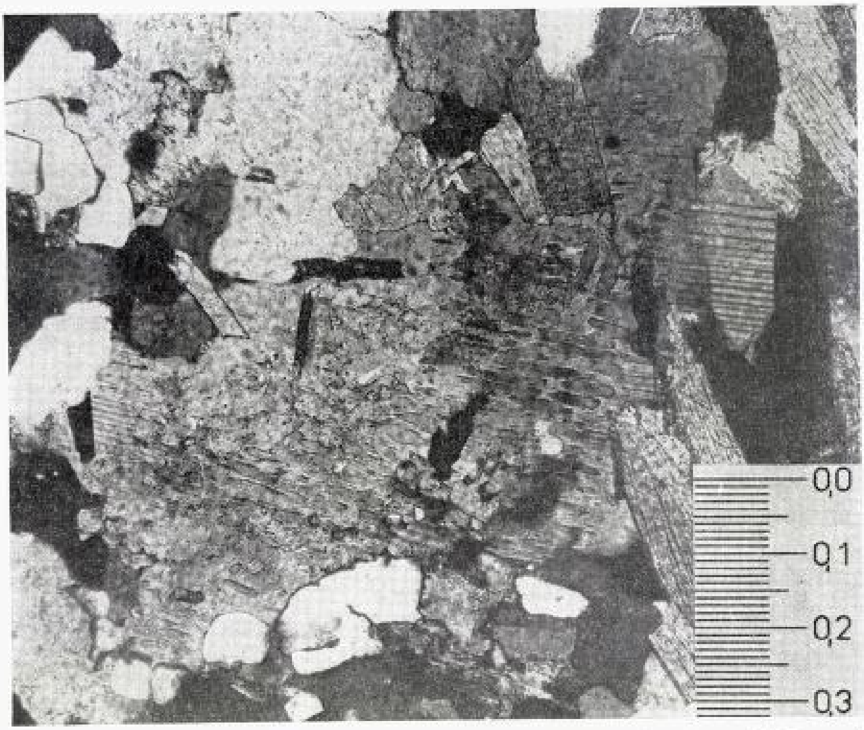


Fig. 6. *Inclusions of potash feldspar in plagioclase, Maurstad school, Maurstad (LP 1473). Scale in mm.*

2—4 mm long porphyroblasts with an interior of zoisite and clinozoisite (with respectively dark brown and berline blue interference colours) sharply bordered by epidote (with brilliant interference colours). Epidote also occurs as individual grains in the granoblastic matrix.

Amphibole is pleochroitic with X pale yellow-green, Y pale green, Z pale blue green, Z/C = 17°, γ about 1,672, 2V = 70° in a biotite-quartz-two feldspar gneiss at Reknes and strongly pleochroitic with X yellow green, Y brown-green, Z dark blue green; Z/C = 20° in a biotite-quartz-plagioclase gneiss at Maurstad.

Garnet is common in gneisses with plagioclase as the sole feldspar and seldom in gneisses with two feldspars.

Garnet in a biotite-garnet-amphibole-quartz-plagioclase gneiss at Maurstad occurs as round grains with average diametres 0,5 mm where d = 11,67 Å and N about 1,79 which probably corresponds to almandine. Garnet in a biotite-quartz-two feldspar gneiss sampled 500 m W. of Endal has less than 0,5 mm wide skeletal crystals which often enclose microcline and give no textural evidence of alteration.

Sphene is always present as an accessory mineral and occur as a) porphyroblasts, b) tiny grains arranged in strings enclosed in chlorite and c) rims around black iron minerals. Porphyroblasts in an especially sphene-rich rock from Dombesteinsfjellet south of Dombestein is finely twinned and has noticable pleochroism. Inclusions of biotite, quartz, rutile and white mica are common in the porphyroblasts.

Apatite and zircon are ubiquitous accessory minerals. Zircon occurs as 0,4—0,1 mm long and 0,2—0,05 mm thick columns where the original idiomorphic forms appear to have been slightly rounded.

Pyrite, red and black iron minerals are often associated, and the red iron mineral has formed at the expence of the other two. It is always easy to obtain a crop of magnetic iron minerals by a hand magnet from a powdered sample. Three specimens of black iron mineral concentrates were checked by X-ray which indicated that two consisted of pure magnetite while the third had magnetite with some ilmenite.

Chemical composition.

Table III gives the chemical composition, norms and estimated chemical composition of a dark quartz-two mica-two feldspar gneiss from the south side of the fiord west of Nordfjordeid. The katanormal composition corresponds to the transition between quartz-monzonite and granodiorite (Trøger, 1938) where plagioclase An_{32} makes up 61 % of total feldspar, but the actual mineral composition is better approached by the mesonorm where ferrous iron and magnesia are calculated as biotite. A still better approximation would be obtained if part of the surplus aluminia (C) were calculated as muscovite.

Granites, granitic gneiss and related rocks.

Granitic rocks form extensive sheets or lenses in the banded gneiss. The contact zones are often migmatitic. Relative massive types are found between Nygård and Angelsvik, but foliation and compositional layering is usually well developed. Books of white mica are sometimes developed on foliation surfaces and calcite, epidote and fluorite occur on joints.

Basic inclusions have not been noted in the massive pink granites, but are common in massive plagioclase gneisses of granitic appearance. Granites at Nygård and Angelsvik are medium-grained pink rocks with about 60 % potash feldspar, 30 % quartz, 10 % plagioclase and accessory apatite, biotite, chlorite, white mica, epidote, fluorite, zircon, a magnetic black iron mineral and partially limonitized pyrite. The magnetic black iron minerals form conspicous 1—3 mm black grains which are abundant in all types of "granitic" rocks, — also those which has plagioclase as dominating feldspar.

A specimen from the road section between Eldevik and Angelsvik is slightly sheared with 3—5 mm porphyroclasts of potash feldspar with mortar texture in a matrix with average grains-size less than 0,5 mm.

	Weight Per Cent	Cation Per Cent
SiO_2	62.57	59.75
TiO_2	0.71	0.52
Al_2O_3	15.97	17.97
Fe_2O_3	0.08 [1]	0.05
FeO	5.47	4.38
MnO	0.10	0.06
MgO	2.54	3.60
CaO	3.18	3.25
Na_2O	2.86	5.30
K_2O	4.08	4.97
H_2O^-	0.07	—
H_2O^+	1.37	(8.75)
CO_2	0.65	(0.86)
P_2O_5	0.18	0.15
	99.83	100.00

Niggli	values
si	231
al	35.2
fm	31.8
c	12.8
alk	20.2
k	0.48
mg	0.44
qz	50.2

Katanorm		
Q	15.3	
Or	25.0	
Ab	26.5	39.0 % An_{32}
An	12.5	
C	2,7	
Hy	8.8	
En	7.2	
Cp	0.3	
Tit	1.5	
Mt	0.2	

Mesonorm		
Q	25.1	
Or	11.7	
Ab	26.5	34.5 % An_{23}
An	8.0	
Bi	21.3	
C	4.5	
Tit	1.5	
Cp	0.3	
Cc	0.9	
Mt	0.2	

Estimated mineral composition	
Quartz	25
Potash feldspar[2]	10
Plagioclase, An_{28}	35
Biotite	20
White mica	10
Sphene	×
Apatite	×
Calcite	×
Epidote minerals	×
Black iron ore	×
Zircon	×

Table III Chemical composition, norms and actual mineral content a quartz-two mica-two feldspar gneiss from road section 200 m W oilstore, Taklo west of Eid Nordfjord, LP 4067. (Analyst Per-Reidar Graff.)

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[1] Too low due to loss in the platina crucible during decomposition (personal information by the analyst). A check of trivalent iron (Analyst Turid Malthe-Sørensen) indicated 0,21 % Fe_2O_3.

[2] Intergrown with, or enclosed within plagioclase.

Potash feldspar is a cross-hatched microcline with abundant small perthitic inclusions.

Acid plagioclase is usually un-twinned and much serizitized.

Chlorite (X yellow green, Y, Z grass green; X subnormal to cleavage) has abundant small inclusions of sphene and is probably formed secondary from biotite with which it often is intergrown.

Biotite has pleochroism: X yellow-brown, Y, Z red-brown.

Sphene occur around black iron minerals.

Blue flourite was not found in thin section, but was isolated together with zircon from the hand specimen.

Zircon is essentially idiomorphic in doubly terminated prisms which are 0,1—0,4 mm long and usually less than 0,1 mm tick. Rounding is not apparent.

The pink granites with microperthite and high content of potash feldspar relative to plagioclase occur in the field much in the same way as relative massive light gray potash feldspar-quartz-plagioclase rocks with low biotite-content. The light gray gneiss is interbanded with biotite-rich gneiss and contain eclogitic and anorthositic inclusions like the banded biotite gneisses.

A specimen of a light gray massive gneiss from the Shell petrol store, Deknepoll has about 15 % potash feldspar, 30 % quartz, 60 % plagioclase and accessory apatite, biotite, calcite, chlorite, magnetite, black iron minerals, orthite, sphene and zircon.

The texture of this rock is granoblastic with average grainsize 0,5—1 mm. *Polash feldspar* is mostly interstitial, non-perthitic and distinctly microcline-twinned. *Plagioclase* (An 10) is slightly zonar, strongly twinned and without sericite inclusions. *Chlorite* (X yellow; Y, Z grass green, X subnormal to cleavage, purple blue interference colours) contain inclusions of sphene, or parallell intergrowths with white mica and biotite (X yellow, Y, Z green-black). *Orthite* is yellow and almost isotropic. *Zircon* in rounded grains have diametres less than 0,1 mm.

Augen gneiss north of Levdal lies structurally below the biotite-rich gneiss and quartz-mica-schist with contain several bodies of ultrabasite at Levdal and Sunndalen. Pink potash feldspar porphyroblasts are usually about 1—2 cm long and attain the size 5 by 5 by 10 cm on the ridge east of Bekselvatnet. Foliation is well developed with the longest dimensions of the minerals in the foliation surface, but flow cleavage is not well developed and the rock is rather massive.

This zone of augen gneiss is inhomogenous with frequent interlayering of granitic gneiss, banded biotite gneiss and pegmatite-veined gneiss. Anorthosite and meta-eclogite are frequently noted as inclusions and white quartz occur in meter-thick veins which cut in the general foliation.

Genesis of the banded gneisses.

The extent of metasomatism or chemical change of the original rocks during metamorphism is not easy to evaluate. Gjelsvik (1951, p. 35 and 1953, p. 83), Kolderup (1960, p. 15) and others have claimed that extensive "granitization" has taken place in the gneiss complex. It is true that the pegmatite material and local augen gneiss in the gneiss complex are indicative that metasomatism has taken place, but this do not necessarily imply that large volumes of rock have been subjected to alterations in chemical composition during metamorphism. The constituents of feldspar in pegmatite veins, migmatites and augen may have migrated only a short distance.

The up to 5 cm long porphyroblasts of sphene which sometimes are found in the gneiss can be in the same respect indicative only of *local* metasomatism. The layers where the porphyroblasts occur may have had an original high content of titanium and the constituents tied up in sphene may have traveled only a short distance from the source.

Antiperthites and intimate two-feldspar intergrowths appear to be characteristic for rocks in the gneisses in the Gneiss region (Strand, 1949, 19—26, Banham and Elliott, 1965, p. 193) and may have bearing on the extent of metasomatism. Strand described how plagioclase gneiss with only small amounts of potash feldspar as antiperthitic inclusions appearently were transformed by metasomatism into granodioritic and granitic gneiss with irregular grains of potash feldspar or two-feldspar intergrowths.

Antiperthite and irregular two-feldspar intergrowths can, however, have formed by as different processes as exsolution, replacement and simultaneous growth. The first process can be eliminated for the antiperthites or two-feldspar intergrowths in Nordfjord because the ratio of the two feldspars is variable in adjacent grains or in different parts of the same grain. The other two processes are hardly possible to distinguish by textural criteria, although some authors (for example Dresher-Kaden, 1948, p. 79) have interpreted intergrowths like those in Nordfjord as replacement-textures. The potash feldspar component of the intergrowths in Nordfjord is concentrated in the central part of the grains as apparent isolated, optical continous inclusions and might be remnants left during an incomplete replacement of original potash feldspar by plagioclase, but the author has not much faith in such textural interpretations and would rather interpret the intergrowths as due to simultaneous growth of the two feldspars.

The biotite-quartz-plagioclase gneiss of Nordfjord is mineralogically similar to gneissic quartz-diorite and meta-dacite which occur in the migmatites and in the over-thrust masses of the Bergsdalen Quadrangle (Kvale, 1946), and is together with the biotite-quartz-two feldspar gneisses very characteristic for the Gneiss region of the Norwegian Caledonides. Rocks of this types are quartz-dioritic or granodioritic in composition, and have usually been interpreted as altered plutonic or volcanic rocks. Eskola (1921, p. 16) claimed, for example, that the gneisses of Nordfjord and Møre were altogether igneous rocks.

Rocks of quartz-dioritic and granodioritic composition can form, however, also from original sedimentary rocks. A sediment intermediate between greywacke and shale would yeld by metamorphism a gneiss similar to that analysed in table III, and the average Norwegian glacial clay (Goldschmidt, 1954, p. 53) has, in fact, broadly similar composition.

The layers of quartz-mica-schist and feldspathic quartzite which are interlayered with the banded biotite gneisses indicate that the gneisses probably represent altered supracrustal rocks. The gneisses might just as well represent altered sediments as original volcanic rocks, but it is probable that both types are represented. The high content of quartz and mica in some layers in the banded biotite gneiss is especially suggestive for an original sedimentary origin, and the somewhat rounded zircons might represent original clastic grains of an immature sediment. The pink granitic gneisses have perthites with much of the plagioclase component and idiomorphic zircons which indicates that they might represent original igneous rocks. The structural position of the granitic gneiss as extensive sheets is most readily explained if the original rocks were volcanic extrusives (rhyolites).

The local zones of augen gneiss have probably been subjected to potash metasomatism. The augen have grown during and after the main metamorphism in zones of intense movement.

Isotope age determinations with bearing on the age of the gneisses have been carried out by McDougall and Green (1964). Gneiss from Totland gave a K-Ar age at 372 million years while eclogitic inclusions in the gneiss were shown to be Precambrian rocks which were affected by Caledonian orogeny at 415 million years K-Ar or 382 and 401 million years Sr-Rb.

The dating of the general metamorphism of the gneiss complex fits well with the recorded K-Ar ages from Geiranger in Sunnmøre (Neumann, 1960, p. 189) and with the assumed general orogeny in the Norwegian

Caledonides at about 400 million years (Broch, 1964, p. 104). This event was probably related to the regional EW to NE-SW folding which dominates the coast area between Nordfjord and Sognefjord but appears to have had negliable influence in the eastern part of the area where K-Ar ages at 590 and 582 million years have been reported (Neumann, 1960, p. 181).

The significance of the isotope ages at 590 and 582 million years has been discussed by Neumann (1960, p. 181), Hernes (1964) and Broch (1964, p. 102—103). These K-Ar-ages might be too low due to loss of argon during a later metamorphism or they may be related to an early Caledonian metamorphic event. We have yet no data to decide between these alternatives, but it is interesting that the eclogites fail to give any indication of an early Caledonian orogeny.

Secondary hornblende in the eclogites gave K-Ar ages at 1850, 1750, 1150 and 980 million years (McDougall and Green, 1964). But do the age of the eclogites have any bearing on depositional age of the gneisses? The answer depends on how the eclogites were formed. If they were originally sedimentary or volcanic rocks downwarped to great depths and metamorphosed together with the gneisses, the depositional age of the complex must be at least as old as the eclogites. But if they have been introduced into the gneisses as solid masses from great depths or from an underlying basement, their Precambrian age would have no concequence for the rocks where they occur.

Eclogite-bearing ultrabasites have perhaps been emplaced from greater depths, but it is difficult to imagine that the myriads of small and big eclogitic inclusions in the gneiss have moved any considerable distance relative to the gneiss. The age of the eclogites therefore has concequences for the age of the gneisses in which they occur. A Precambrian depositional age for the original supracrustal rocks must therefore be admitted if the hornblende-ages in the eclogites are valid.

But are the hornblende ages reliable? The eclogites originally had a very low content of potassium. Build-up of excessive argon in the minerals of the eclogites is very probable when we consider that the basic inclusions are small and the surrounding gneisses are biotite-rich gneisses. The Precambrian age of the eclogites should therefore be confirmed by other radiogenic evidence before it is universally accepted.

The association of gneisses in Nordfjord with feldspathic quartzites and quartz-mica-schists link these rocks lithologically to the Eocambrian rocks of Central Norway where a depositional age of at least 550 million years K-Ar age has been indicated (Broch, 1964, p. 102). Considerable deposits of feldspathic quartzites similar to the "light sparagmites" of Central Norway occur conformably above the banded gneisses south and south-east of the area of our map. It is possible that the border zone is transitional with increasing amounts of feldspathic quartzite and mica-schist in the upper part of the banded gneiss complex.

Our present state of knowledge will not permit definite statements on the stratigraphy and depositional age of the rocks in outer Nordfjord, but it is plausible that the banded gneisses represent a lower part of the depositional sequence which in its higher levels is characterized by rocks which in Central Norway are referred to as Eocambrian. If the hornblende K-Ar ages of eclogites have any bearing for the gneisses, the sequence extends much deeper into Precambrian than has previous been accepted.

Metamorphism of the original rocks into banded gneisses has taken place under the conditions of almandine-amphibolite facies. It is difficult to relate the rocks to any sub-facies because alumina silicates have not yet been found, but the insignificant development of migmatites in the banded gneisses indicates that the temperature during metamorphism has been only moderate. Relict mineral assemblages indicating a former higher metamorphism has not been recorded (if not the eclogites should be regarded as such). Greenschist-facies metamorphism is only indicated locally, for instance in some of the granitic rocks.

Mangeritic rocks.

An outcrop of massive rocks near Måløy has been indicated on recent regional geological maps (Kolderup, 1960 a, p. 7; Holtedahl and Dons, 1960), but petrographic data on the occurrence has not yet been recorded. Another massive rock has been observed at Flatraket (Lappin, personal information, 1965).

We had difficulties to find an appropriate designation for these rocks during our regional-scale mapping in the area. The rocks were often gneissic, but structural types too massive to be termed gneisses were not seldom. The most widely distributed rock types are monzonitic or intermediate between monzonitic and gabbroic in composition, and has been termed "*mangeritic rocks*" in this paper. Mineral assemblages like kyanite-garnet-plagioclase-orthoclase and clinopyrozene-garnet-plagioclase-orthoclase or mesoscopial brown or blue-gray colour, microscopical "clouding" and the microperthitic structure of the feldspars relate these rocks also to the granulites and charnockites. "Granulite" has been used for all rocks with granulite-facies mineralogy (Eskola, 1939 and Hsu, 1955), but this practice will not be followed here. It is admitted that some sheared rocks have attained the characteristic granulite fabric with platy quartz, but the major part of the rock bodies at Måløy and Flatraket are too massive and coarse-grained to be "granulites" in the etymological sense.

The massive structure of some of the rocks might justify the term "charnockite" (Winkler, 1965, p. 124) but they are never hypersthene granites as required by the definition (Subramaniam, 1959) and their content of kyanite make them different from the charnockites of the type area.

Mangerites, granulites and charnockites probably form under the same physical conditions (Rosenqvist, 1956 p. 44; Eskola, 1957 p. 117), and it might be difficult to select any of the terms for a particular rock type or complex of different rocks. "Mangeritic rocks" has been found to be the best descriptive and the least genetically committing term for both the massive and the gneissic rock types that occur at Måløy and Flatraket.

The mangeritic rock at Måløy is a rather massive rock. The mountains carved in it has often a characteristic topography distinct from regions underlain by the banded biotite gneiss and the surface is extensively covered by talus. The most massive type of the rocks has found a limited use as building-stone in Måløy.

The mangeritic rock body of Måløy lies in an open, upright antiform above banded gneiss with mylonites and "tectonic conglomerates" in the contact zone. The corresponding body at Flatraket is also tectonized at the contact. It is probable that the two rock bodies once have been continuous over a tight antiform in the banded gneiss between the present outcrops.

The mangeritic rock bodies embrace several distinct structural types, of which these are most common:

1. Coarse-grained massive type with 5—10 cm long megacrysts of alkali feldspar in a medium- or fine-grained matrix.

2. Fine- to medium-grained massive or slightly banded type.

3. Migmatitic gneiss with lenticles of quartz-monzonitic pegmatite in a fine- to medium-grained massive or slightly banded matrix.

4. Finely laminated or banded gneiss formed by mechanical deformation, granulation and/or neocrystallization of the types mentioned above.

Diabase or meta-diabase, amphibolite and eclogite also occur in the mangeritic rock bodies.

Transition between the structural types are frequent, and they appear to be tectonically controlled. Finely laminated or banded types can often be demonstrated to have formed by shearing of an original massive rock. The blue-gray or brown colour of the alkali feldspar megacrysts gives way for a red colour by incipient stages of alteration in the sheared zones. Megacrysts are by more severe shearing flattened into lenticular or layered aggregates which gives the gneiss a banded structure. Plagioclase turns from white to pale green in the altered zones and extensive formation of biotite parallel to the shearing planes renders the rocks a banded laminated or streaky habit which makes them difficult to distinguish from certain rocks of the banded gneiss complex.

Alteration of the mangeritic rocks has taken place at the borders of the rock bodies, on contact towards diabase and other basic inclusions and in zones affected by movements during the main EW to NE-SW folding in the area. Megacrysts of alkali feldspar are distinctly prekinematic in relation to the movements during the main folding (Fig. 7) and

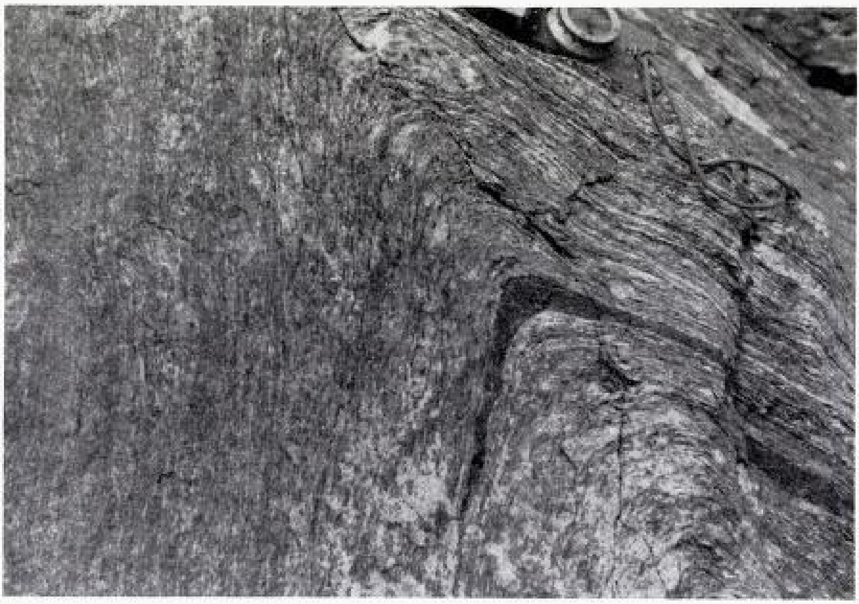

Fig. 7. Prekinematic megacrysts of alkali feldspar in mangeritic rock body. Road section S W. of Refsdalsvatn (KP 9679).

Fig. 8. Secondary foliation developed at contact towards basic dyke. Mangeritic rock body, point N. Flatraket (LP 0478).

so are also transecting dykes of diabase. The dykes have acted as zones of weakness where movements during the main folding were released. Secondary foliation is developed at the contact towards the basic dykes (Fig. 8) which by stronger deformation will appear as conformous basic layers in a foliated gneiss. Some basic layers are very contorted by internal folding and even pulled apart into boudins enclosed in gneiss. Such basic inclusions consist of amphibolite and rocks very similar to the meta-eclogites which are much more common in the banded gneiss complex. Inclusions of eclogites have been noted in the area north of Deknepoll and Måløy.

Pegmatite is common north of Måløy as irregular, closely spaced lenticles and less common as transecting zonal dykes. Quartz, plagioclase and potash feldspar are present in about equal amounts or plagioclase dominates over potash feldspar. Diffuse fine-grained aggregates of garnet and amphibole are often enclosed in the pegmatite lenticles and might indicate that the pegmatite formed more or less in situ by replacement of the original mangeritic rock.

Transecting pegmatite at a point north of Deknepoll has pegmatite with blue-gray quartz at the borders and almost pure, saccharoidal quartz in the core.

The mineral composition of the mangeritic rocks is partly determined by original differences in chemical composition and partly by tectonically controlled metamorphism during the main folding of the area. The following mineralogical assemblages have been recognized.

Clinopyroxene - garnet - biotite - quartz -plagioclase - orthoclase.
Clinopyroxene - garnet - biotite - amphibole - quartz -plagioclase - orthoclase.
Kyanite - garnet - biotite - quartz - plagioclase - orthoclase.
(White mica) - epidote - biotite - quartz -plagioclase - microcline.

The basic rocks which occur in the mangeritic rock body have the following mineral assemblages:

Biotite-orthopyroxene - clinopyroxene -plagioclase (diabase).
Biotite -plagioclase - garnet - clinopyroxene (meta -diabase).
Biotite - garnet - plagioclase -amphibole (amphibolite).
Zoisite - kyanite - micas - amphibole - plagioclase with symplectitic intergrowths (meta -eclogite).
Garnet -clinopyroxene (eclogite).

The most massive rocks have 20—50 % orthoclase, 15—40 % plagioclase, 5—20 % quartz, 4—15 % garnet, 4—15 % biotite and 0—5 % clinopyroxene or kyanite with amphibole, apatite, blach iron minerals, rutile and zircon as characteristic assessory minerals. These "primary" minerals have been altered during the movements that took place during the main EW to NE-SW folding of the area. Altered rocks have aggregates of finely granulated plagioclase with biotite and clinozoisite; granulated orthoclase or cross-hatched microcline; aggregates of biotite, amphibole and epidote formed by destruction of garnet; as well as neocrystallized biotite, epidote, pyrite, scapolite, sphene and white mica.

Texture

The texture is dependent on the extent of shearing and other alteration of the original mangerite. The most massive rock types are serial-grained with porphyroblasts in an allotriomorphic-granular medium- or fine-grained matrix. Intermediate types are protoclastic while sheared types contain lenticular aggregates of granulated minerals which reveal intense micro-folding. Plagioclase of such granulated aggregates have individual grains as small as 0,01—0,02 mm while average grain-size of quartz in lenticular granu-

Locality	Texture	Average grain-size of matrix (mm).	Quartz	Alkali feldspar	Plagioclase	Garnet	Clinopyroxene	Kyanite	Apatite	Rutile	Zircon	Black iron minerals	Amphibole	Biotite	White mica	Epidote minerals	Sphene	Calcite	Red iron minerals	Pyrite
Quarry, Flatraket (LP 0378)	Sp	0.5—2	10	50	30	4	2	×	×	×	×	×	×	4	—	—	—	—	—	—
Road section N. Måløy (KP 9774)	Sg		10	20	30	10	5	—	×	×	×	×	25		×	×	—	×	—	—
Above new school, Måløy (KP 9674)	Sg	0.5—3	20	30	25	10	—	5	×	×	×	×	—	10	—	×	—	—	—	—
Above ferry pier, Deknepoll (KP 9973)	G	0.1	5	30	30	15	—	—	×	×	×	2	—	15	×	3	—	—	—	—
Point south of Trollebø Deknepoll (KP 9874)	Ag	0.5—1	5	25	40	15	5	—	×	×	×	—	10		—	×	—	—	—	—
South side of Refsvikvatn (KP 9679)	Sp	0.2—0.5	10	50	35	—	—	—	×	—	×	×	—	5	×	×	×	—	—	—
South side of Refsdalsvatn (KP 9679)	Sp	0.5—1	15	35	30	—	—	—	×	—	×	×	—	10	5	5	×	×	—	—

Table IV Estimated mineral composition of mangeritic rocks Abbriviations: Ag Allotriomorphic granular, G granulated, Sp serial with megacrysts of alkali feldspar, Sg serial granulated. "x" indicates that the mineral was noted as an accessory constituent.

lated aggregates is about 0,1—0,2 mm. More thoroughly altered rocks have gneissic foliation with lepidoblastic biotite in an essentially homøogranular fabric with average grain-size about 0,5—1 mm.

Minerals

Quartz of the massive rocks is not of the platy type characteristic for granulites, but rather occurs in granular aggregates where individual grains have interlobate or sutured boundaries and undulative extinction. Sheared rocks have platy quartz or lenticular aggregates of granulated quartz where individual grains are saccharoidal and without undulative extinction.

Alkali feldspar sometimes occurs in 5—10 cm long brown or blue gray xenomorphus megacrysts which often are manteled by white plagioclase. Alkali feldspar of the fine-grained rocks is mostly blue-gray or pink while megacrysts of slightly sheared roks often are red.

The brown or blue-gray alkali feldspar is an un-twinned microperthite where abundant 0,01—0,05 mm long rods of plagioclase are aligned at about 74° to a on (010). Extinction $X \wedge a$ on (010) at 3—7°, $X \wedge a$ on (001) at 0° and negative axial angle at 53—64° indicate that the potash feldspar host of the microperthite is an orthoclase and this was substantiated by X-ray diffractometer runs in the region $2\,\theta = 27$—35°. The brown and blue-gray megacrysts had one single 131 reflexion at 3,00 Å while the sheared megacrysts and pink feldspar from pegmatite-lenticles were X-ray triclinic with diffuse reflexions in the interval 2,95—3,03 Å. Obliquity values for these microclines are about 0,8—1,0, but diffuseness of reflexions and partly overlapping plagioclase ($0\bar{2}2$) reflexions at 2,94 Å make measurements unreliable.

A megacryst of blue-gray orthoclase microperthite had the composition $Or_{73}Ab_{22}An_5$ (Table V) where the plagioclase component of the perthite probably corresponds to about An 20.

Incipient alteration of orthoclase is revealed under the microscope by external granulation and development of myrmekitic intergrowths at grain boundaries. Complete granulation and recrystallization into saccharoidal aggregates of un-twinned potash feldspar and plagioclase has taken place in sheared rocks, but transformation to strongly cross-hatched microcline with retention of microperthitic indusions has apparently frequently taken place before complete granulation or recrystallization.

Plagioclase is white and dull on fresh surface of the massive rocks and pale green in the sheared rocks. Irregularly distributed brown 'dust' make the grains clouded in thin sections. Polysynthetic twinning is often developed, but the lamellae have often indistinct boundaries and are partly bent. Plagioclase of the massive rocks are often surrounded by a seam of small garnet crystals.

The massive rocks have andesine (About An 40) which sometimes have been destructed into a very fine-grained aggregate of more acid plagioclase, green biotite and clinozoisite (epidote). More altered types have recrystallized into 0,5 mm wide grains of largely un-twinned basic oligoclase (About An 27) with inverse zoning associated with books of green biotite, epidote and microcline.

Plagioclase of the pegmatite lenticles have a large separation of the (131) and ($1\bar{3}1$) reflexions ($2\,\theta$ about 1,4°) which indicate high ordering (Slemmons, 1962, p. 536).

	I		II
	Weight Per Cent	Cation Per Cent	Weight Per Cent
SiO_2	57.53	53.79	
TiO_2	0.50	0.34	
Al_2O_3	17.43	19.19	
Fe_2O_3	0.04 *	0.02	
FeO	6.23	4.87	
MnO	0.18	0.15	
MgO	4.62	6.44	
CaO	7.43	7.45	0.94
Na_2O	2.58	4.68	2.33
K_2O	2.50	2.98	11.76
H_2O-	0.06	—	
H_2O-	0.42	(26.00)	
CO_2	0.11	(0.13)	
P_2O_5	0.13	0.09	
	99.76	100.00	

Niggli values

si	166.0
al	29.9
fm	35.2
c	23.0
alk	11.9
k	0.39
mg	0.56
qz	18.4

Katanorm

Q	6.3
Or	15.0
Ab	23.5) 52,3 % An_{55}
An	28.8)
Hy	10.2
En	12.8
Wo	2.2
Ap	0.3
Tit	0.9

Estimated mineral composition

Quartz	5 %
Microperthite	25 %
Plagioclase[1]	40 %
Clinopyroxene[2]	5 %
Biotite-amphibole aggregates[3]	10 %
Garnet	15 %
Apatite	×
Rutile	×
Zircon	×
Epidote minerals	×

1) Granulated and neocrystallized with green biotite, white mica and epidote minerals.

2) With dark, almost isotropic cores.

3) Secondary, irregularly distributed aggregates or as brown books of biotite surrounded by small garnet crystals.

Table V Chemical composition and actual mineral content of a massive, fine- to medium-grained quartz-clinopyroxene-garnet-microperthite-plagioclase rock from the small point south of Trollebø, Deknepoll (I) and of orthoclase microperthite megacryst from Hanekam, 575 metres above sea level, east of Deknepoll (II). (Analyst Per-Reidar Graff.) Standard reference: KP 9874 (I) and KP 9974 (II).

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* Too low due to loss in the platina crucible during decomposition (personal information by the analyst).

Clinopyroxene is xenomorphic in 0,1—0,5 mm grains which are pale green or pale brown in thin sections. Pleochroism is not common, but some grains in a basic layer at Flatraket have irregular cores with distinct pleochroism: X pale brown, Y blue-violet, Z red-brown and very strong dispersion which probably is related to a high content of titanium. The central area is also often characterized by abundant submicroscopic 'dust' which renders the grains almost opaque, black schiller inclusions and fine polysynthetic twinning on (100). U-stage measurements recorded that $2V_Z = 62—68°$ and $Z/C = 44—48°$.

External alteration to a green amphibole-rich symplectite is sometimes seen.

Garnet is xenomorphic and occurs in 1/2—2 mm grains or in very fine-grained aggregates around plagioclase, black iron minerals and biotite. Intergrowths with pyroxene are developed on pyroxene-plagioclase contacts. Big grains contain abundant inclusions of quartz, biotite, pyroxene, rutile and black iron minerals.

Index of refrigence is about the same as garnets in the banded biotite gneiss complex (N = 1,78—1,79), but the garnets in granulite gneiss have slightly smaller unit cell (a = 11,54—11,58 Å) and possibly higher ratio of pyrope to almandine.

Garnet has been externally altered to a very fine-grained aggregate of amphibole, biotite and epidote. This alteration has in some rocks taken place at the same time as the garnets were rotated by shearing movements in the rock. More altered rocks contain epidote-biotite-amphibole aggregates without relics of their garnet parentage.

Amphibole is only accessory in the massive rocks, where it occurs in clusters of grains which often enclose other minerals. Pleochroism is distinct: X colourless, Y brownish green, Z green; $Z/C = 19°$; and the amphibole is probably a hornblende formed later than the surrounding minerals. Secondary amphibole is an essential constituent of the more altered rocks, and can sometimes be seen to have formed from garnet and from pyroxene.

Biotite of the massive rocks has distinct pleochroism: X colourless, Y, Z dark red-brown and might well have formed contemporaneously with pyroxene and garnet. Basic inclusions in the mangeritic rock has biotite intimately intergrown with white mica (mica-symplectite).

Secondary biotite forms first in the very fine-grained granulated aggregates of plagioclase. More thoroughly altered gneisses have 0,1—0,5 mm thick books of biotite with pleochroism: X pale yellow-green, Y, Z black-green.

Kyanite is colourless in powder and in thin sections. The laths are usually 1—0,5 mm long, but much smaller grains can occur enclosed in biotite or in the biotite-white mica symplectite of the basic inclusions. Textural evidence of transformation of kyanite was not obtained in the thin sections available, but it is probable that kyanite has been decomposed into micas in the sheared rocks.

Epidote-minerals are scarce in the massive rock types and abundant in the sheared rocks. The first identificable epidote mineral to form in the sheared rocks is clinozoisite which has grown in the very fine-grained aggregate of granulated plagioclase. More altered rocks have 0,5 mm long columns of epidote with brilliant interference colours and often a yellow brown core of orthite.

Zircon mostly occurs in 0,1—0,2 mm sphaeroidal grains. A few grains have diametres up to 0,3 mm, but the "sorting" appears to be very good as far as the roundness and grain-size is considered.

Rutile, sphene and *black iron minerals* are often associated and intergrown with rutile-black iron minerals in the massive types and sphene-black iron minerals in the sheared rocks. Black iron minerals are also enclosed in garnet in the massive rocks and associated with biotite in "trains" in the sheared rocks.

Pyrite has been noted in altered mangeritic gneisses and in the red microclinized augen, but is not common. Secondary *malachite* is sometimes present and indicates that Cu-minerals are present among the opaque constituents.

Chemical analysis of a massive rock characteristic for the mangeritic body at Måløy is given in table V. The chemical composition corresponds to what has been recorded for mangerites in the Bergen Arcs and Jotunheimen (compare analyses 15 and 16 in Kolderup and Kolderup, 1940, p. 97). The katanormal composition corresponds to a syenogabbro (Tröger, 1938) where plagioclase An_{55} makes up 78 % of total feldspar.

Genesis of the mangeritic rocks.

The massive rocks at Måløy and Flatraket are chemically and mineralogically related to rockes of the anorthosite kindred in the Bergen arcs and Jotunheimen. Low water-content and microperthite with inclusions of oligoclase in orthoclase are especially suggestive properties for this correlation.

Some mineralogical differences occur, however. The rocks in Nordfjord are characterized by the mineral pairs garnet-clinopyroxene or garnet-kyanite. Rocks of the anorthosite kindred in the Bergen Arcs and Jotunheimen have plagioclase-orthopyroxene as the most widely distributed association, but garnet-clinopyroxene is developed locally (Kolderup and Kolderup, 1940; Gjelsvik, 1947). Gjelsvik suggested that the latter association had formed at high pressures, possibly corresponding to those of the eclogite facies. The widely distributed association of garnet and clinopyroxene was recognized by de Waard (1965, p. 459) who defined a clinopyroxene-almandine subfacies within the granulite facies. The new subfacies is useful for rocks at Måløy and Flatraket if kyanite could be included among the characteristic minerals. De Waard regarded the kyanite-garnet-orthoclase assemblage as an index for transition into eclogite facies, but kyanite is characteristic for the classical granulites and should rather belong to the proper granulite facies assemblage. The assemblages kyanite-garnet-plagioclase-orthoclase and clinopyroxene-garnet-plagioclase-orthoclase in the rocks of Nordfjord might have formed under conditions where eclogite mineralogy would develop in rocks of appropriate chemical composition, but such mineral assemlages are best grouped in the clinopyroxene-almandine subfacies of granulite facies where kyanite has replaced sillimanite at the highest load pressures.

The original granulite was probably a fine-grained rock which become modified by porphyroblastic growth of alkali feldspar. The prophyroblasts have formed under static conditions above the solvus temperature, and exolved into microperthite and "clouded" feldspars during cooling. Later shearing movements have transformed the original brown or blue-gray orthoclase microperthite into gray or red microcline microperthite and microcline-plagioclase aggregates.

Lenticles of quartz-monzonitic pegmatite with relics of fine-grained mangeritic rock might have formed by concentration of melted fractions of the rock during metamorphism, but the facts that the plagioclase is highly ordered and that the other feldspar is a pink subsolvus microcline indicate that the pegmatite rather formed at low temperature. The zonal structure of transecting pegmatite north of Deknepoll indicates that some of the pegmatites are secretions in former open fissures. Irregular and closely spaced lenticles of pegmatite may have formed in the same way, — as secretions in fissures, — or alternatively as petroblasts in the mangeritic rocks.

The granulite facies mineralogy and the porphyroblasts predate the movements which formed the regional EW to NE-SW folds in Nordfjord. Transformations of the original granulite-facies minerals into new minerals stable in the almandine-amphibolite facies took place on the borders of the rock bodies and in other sheared zones. The most common transformations were:

Granulite facies		*Almandine-amphibolite facies*
Orthoclase microperthite	→	Microcline microperthite, microcline and oligoclase
Andesine	→	Oligoclase and clinozoisite
Brown biotite	→	Green biotite
Garnet	→	Green amphibole, green biotite and epidote
Clinopyroxene	→	Green amphibole
Rutile	→	Sphene
Kyanite	→	Micas?

Many of the minerals which formed during the regional EW to NE-SW folding are hydrous, and transformation would be dependent on the amount of available water. The original mangerite was a "dry" and compact rock in which water could not flow or diffuse easily. Transformation to hydrous minerals would therefore only take place in sheared zones where water could enter. The available water have first been used for transformation of andesinic plagioclase and garnet to oligoclase, green biotite, epidote and green amphibole while clinopyroxene and kyanite were preserved. The fact that completely hydrous assemblages like white mica-epidote-biotite-quartz-oligoclase-microline are less common than intermediate assemblages with relics of garnet and pyroxene or kyanite testifies that scarcity of water was an important factor during the amandine-amphibolite facies metamorphism of the mangeritic rocks.

The metamorphism of the basic inclusions is especially interesting. A sub-ophitic to ophitic biotite-orthopyroxene diabase appears to have been altered to biotite-garnet-amphibolites when water was available and to biotite-garnet-clinopyroxene rocks when water was inavailable. This will be discussed later under the chapter on the origin of eclogites.

The rocks of the anorthosite kindred in the Bergen arcs and Jotunheimen have been interpreted as original plutonic-magmatic rocks which have been trusted into their present tectonic position. The rock bodies at Måløy and Flatraket probably share the same origin. The rocks are often as massive and homogeneous as should be expected for a plutonic-magmatic rock, and the tectonized borders indicate that the bodies have been tectonically emplaced. A tectonic correlation with the Jotun nappes is therefore tempting, but it cannot yet be excluded that the mangeritic rock bodies are relics of plutonic intrusives in a complex which elsewhere have been transformed during the Caledonian orogeny.

The mangeritic rock bodies might comprise rocks of various origin. Some of the basic layers have relict subophitic or ophitic texture which indicate that these rocks are hypabyssal igneous intrusives in the complex. The round and apparent well sorted grains of zircon in the mangeritic rocks is evidence against a magmatic origin, but it should be remembered that these rocks have suffered a granulite facies metamorphism which might have rendered the zircon grains sphaeroidal by resorption and partial recrystallization. Layers of quartz-mica-rich augen gneiss and kyanite-rich varieties within the mangeritic bodies might represent original supracrustal rocks which have suffered the same metamorphism as the plutonic-magmatic mangerites.

White, massive rocks in gneiss complex ("*trondhjemites*").

White, massive rocks occur as conformous layers or as transecting dykes in the gneisses. The composition varies from quartz-diotitic with plagioclase as the sole feldspar to quartz-monzonitic with about equal amounts of plagioclase and potash feldspar. Both feldspars are white, and staining or other laboratory means are usually necessary to distinguish between them. The texture is serial with grains about 1 mm wide lying in a much more fine-grained matrix where the grain-borders are interlobate or irregular. Characteristic minor minerals are: Biotite, white mica, epidote-minerals, garnet and black iron minerals. Apatite, sphene and zircon are always present as accessory minerals.

The quartz-monzonitic types are most common in the massive gneisses at Nordfjordeid. They form less than a few metres thick layers which are conformous with the foliation of the enclosing gneiss. Thin layers are foliated while thick layers are foliated only towards the borders. The border zone is often gradational. The plagioclase is oligoclase An 23—25 with irregular inclusions of potash-feldspar or member of two-feldspar intergrowths associated with myrmekite.

The quartz-diotitic rocks are partly interlayered with mica- and quartz-rich gneisses and partly distinctively intrusive into such rocks. The largest bodies are found east of Davik where intrusive breccias are locally deveoped. The quartz-diotite is often very inhomogeneous with layers of biotite-amphibolite and biotite-amphibole-garnet-quartz rocks. The plagioclase of the quartz-diorite east of Davik is a basic oligoclase (An 28).

Genesis of the white layers in the gneiss.

It has been found justified to describe the white layers and dykes in the gneiss together, because they often have similar mode of occurrence and because laboratory studies often are necessary to differentiate between them. But there are also other reasons for describing them together in spite of their different mineralogical composition: The quartz-diotitic rock east of Davik are very similar to the "granodiorite" (Kolderup 1912) which form a large body at Bremangerland west of our map. The white rock at Bremangerland almost is devoid of potash feldspar, but C. F. Kolderup has shown that it is chemically and mineralogically related to potash feldspar-bearing granodiorites which intrudes Cambro-Ordovician rocks further south in Sunnfjord.

Moreever, the granodiorites of Sunnfjord contain intergrowths between the two feldspars or potash feldspar partially enclosed in plagioclase, — just like the quartz-monzonitic rocks in the gneisses of Outer Nordfjord. The usual conformous relation of the quartz-monzonitic layers to the foliation of the gneiss indicates that they might represent early stages in the development of magmas which have given the bodies of granodiorite studied by Kolderup. According to this hypothesis, the white massive rocks in Outer Nordfjord represent trondhjemitic magmas which have been arrested at different stages of development. The quartz-monzonites in the gneisses have formed more or less in place while the quartz-diorites are allochtoneous and have intruded rocks in higher strathigraphic/tectonic levels.

Inclusions in the gneisses.

Ultrabasites (dunites, peridotites and serpentinites).

Most of the ultrabasites i Nordfjord and southern Sunnmøre occur as 25—200 metres long bodies elongated parallel to the foliation of the surrounding gneiss. A few bodies are much bigger, for example in Almklov—Sunndalen, Kjølsdal—Mysæter and Davik, where the length of the

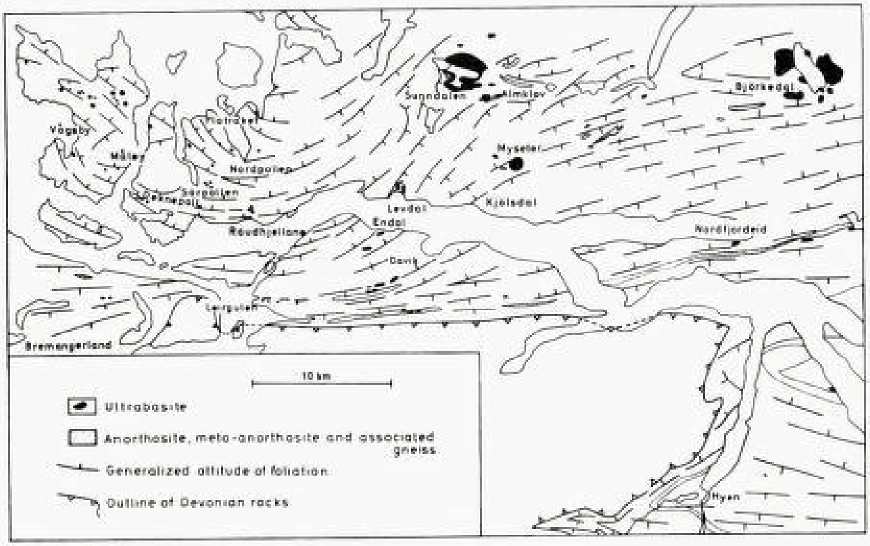

Fig. 9. Ultrabasites and anorthositic rocks on Outer Nordfjord and southern part of Sunnmøre.

bodies is several hundred metres. Some of the largest bodies of ultrabasites in Southern Norway occur just north of our area and have been considered in Fig. 9. Here is indicated the position of about 75 individual bodies of ultrabasite. The ultrabasites from Almklov—Sunndalen in Sunnmøre were described by Reusch (1878 and 1884), Brøgger (1880), Vogt (1883), Gjelsvik (1951), Rost (1963), and O'Hara and Mercy (1963).

It has been demonstrated that the rocks have dunitic or periotitic compositions with mainly olivine ($Fo_{90}Fa_{10}$) and local chlorite, enstatite, diopside, garnet, amphibole and opaque minerals. Serpentinization has taken place on the borders and in zones transecting the big bodies while the small ones often are completely altered into serpentinites. Magnesite and hydrous alteration products of the original femic minerals occur locally. Plastic folding is often revealed in dunite or peridotite when layering or foliation brings out the megascopical structure. The folds are often tight and of similar-type which indicate that even the dunitic rocks are tectonites. Serpentinized ultrabasites are usually shear-folded with axial planes parallel with those of the surrounding rocks.

The ultrabasites of Nordfjord are usually much more altered than those at Almklov—Sunndalen, but geological setting and mineral-pseudomorphs indicate that they have a common early history.

The bodies of ultrabasite in Nordfjord are arranged in clusters and belts. Three or four belts can be distinguished:

1. The Vågsøy - Deknepoll - Sørpollen - Nordpollen association.
2. The Endal - Levdal - Sunndalen - Almklov belt.
3. The Leirgulen - Davik - Myseter - Bjørkedalen belt.
4. Bortnen - Nordfjordeid belt.

The enclosing gneisses are usually steeply inclined and much sheared. Eclogites and anorthosites are common in the enclosing gneisses, but are not confined to the belts. It appears therefore, that the ultrabasites are emplaced in shear zones in a gneiss terrian where the eclogitic and anorthositic inclusion already were present. Thermal metamorphic effects on the surrounding rocks have not been observed.

The association at Vågsøy - Deknepoll - Sørpollen - Nordpollen contains more than 20 bodies of sheared and serpentinized dunite which are emplaced in banded gneiss tectonically below the synform with massive mangeritic rocks at Måløy. Most of the bodies are less than 50 metres long, and contain alteration zones with talc, serpentine, magnesite, asbestos, actinolite, chlorite and talc pseudomorphs after enstatite.

The Endal-Levdal-Sunndalen-Almklov belt contain big bodies of dunite. Porphyritic varieties with several-centimetres long megacrysts of olivine are common in Sunndalen and Levdal. Enstatite occur in Almklovdalen and Endal, — at Endalsvatn in up to 5-10 centimetres long megacrysts. Eclogite inclusions and compositional layering with garnet peridotite and eclogite are developed especially in the body of Sunndalen (Raudkleiva) and between Sunndalen and Kassen (Helghornvatn). Serpentinization has taken place on the borders of the dunite bodies. Veins of talc, magnesite, asbestos, in Sunndalen also with a porous aggregate with diffractometre-pattern very similar to antigorite, transects the bodies of dunite, while chlorite (sometimes pink chromiferous chlorite), smaragdite and anthophyllite are evenly distributed in the somewhat altered dunite.

Even the almost unaltered dunite at Sunndalen has a distinct foliation parallel to the surrounding gneiss, and the more sheared and altered bodies at Levdal and Endal have a foliation which is defined by planar mineral aggregates and closely spaced surfaces of parting. Schistose dunite in the road section at Levdal has a pink lustre on parting surfaces due to books of chromiferous chlorite. The formation of talc has apparently taken place after the foliation had been established. This is borne out by parallel arrangement of enstatite plates and the talc-pseudomorphs after enstatite. Another indication is seen at Endalsvatn where a transecting "dike" of talc has a relict foliation parallel to the foliation of the surrounding serpentinized dunite.

The Davik-Myseter-Bjørkedalen belt contains many small, often talcous serpentinites which have a pronounced schistosity parallel to the surrounding rocks and some big bodies of dunite. This belt estends across Bremangerland to Grotle in the west and to Bjørkedalen in east, — and contain at least 20 isolated bodies.

The four about 40—50 metres long bodies at Leirgulen are emplaced near contact towards quartzite in a dark garnet-biotite-oligoclase gneiss with layers of meta-anorthosite in an obvious dislocation zone.

The two biggest of the five serpentinite bodies at Storetroda, Davik, are several hundred metres long. The southern two bodies are emplaced on the border between anorthosite and garnetiferous mica-schist and the three others are surrounded by garnetiferous mica schist. Talc pseudomorphs after enstatite are common and coarse-grained talc-rich soapstone are present as up to 3 metres thick layers. Actinolite and magnesite aggregates are often met with.

Genesis of the ultrabasites.

The present study was aimed more on the localization of the ultrabasites than on detailed petrographic study of them and cannot pretend to sped any new light on their origin.

The most frequently heard opinion on these rocks is that they represent samples of the mantle which have been emplaced into the rocks where they are now as essentially solid bodies. The localization of the ultrabasites in Nordfjord in belts and dislocation zones where shearing appears to have taken place and the lack of thermal metamorphic effects on the enclosing rocks support a such hypothesis.

Mantle-derivation of ultrabasites might be possible, but I would like to make attention to the common association of ultrabasites in Nordfjord and Sunnmøre with anorthosites and the lack of gabbroic rocks in the areas where the association occurs. Plagioclase is the first mineral to melt in a basic rock like gabbro or amphibolite at the pressures that prevail at the base of the crust (Yoder and Tilley, 1962), and if the first formed melt could be separated from the place where it forms, the remaining residue would change towards ultrabasic composition.

Whatever was the original derivation of the ultrabasites, it should be emphasized that the dunites, peridotites and serpentinites are now metamorphic rocks which have obtained their tectonite fabric and mineral assemblages olivine-chlorite, olivine-garnet, olivine-enstatite, clinopyroxene-garnet under the physical conditions of eclogite or granulite facies. (Rost, 1963). Available water has been combined in chlorite and kelyphitic amphibole which probably formed early during the emplacement of the ultrabasites.

During later stages of Caledonian orogeny enstatite of the ultrabasites would become hydrated to talc. When the themperature had dropped to about 450—500° serpentinization would occur. The hydration of enstatite and the serpentinization would depend on the amount of water present and the rate at which water could enter. Shearing has probably greatly increased the possibilities for inflow of water and facilated neocrystallization.

Ultrabasites north of a line from Leirgulen to Kjølsdalen have been subjected to only marginal or incomplete alteration while those situated south of this line have been almost completely altered. This might be due to the kinematic effects of a late EW folding and continued movement on the older dislocation zones after the emplacement of the ultrabasites.

Eclogites (meta-eclogites).

Eclogites of Sunnmøre were described by Eskola in 1921 and new details were added by Gjelsvik (1951 and 1952); Kolderup (1960 b); Lappin (1960); O'Hara and Mercy (1963); McDougall and Green (1964); Schmitt (1964) and Mercy and O'Hara (1965 a and b). Eskola distinguished a type of eclogite which was enclosed in peridotite (Rødhaugen type) and several types of eclogite enclosed in gneiss. He claimed that the eclogitic inclusions in gneiss were the detached fragments of larger bodies of originally igneous rocks while Gjelsvik suggested that some of them, — at least — were altered gabbroic rocks (metadolerites) of Caledonian age. Kolderup also suggested that the eclogites were detatched bodies of altered Caledonian gabbros or basalts, but McDougall and Green gave radiogenic age evidence that the eclogites and associated garnet peridotites crystallized in Precambrian and that they were only partly affected by Caledonian orogeny. McDougall and Green suggested that detatchment of the eclogite and peridotite bodies had taken place, followed by the incorporation of them into deforming gneiss or alternatively, fragmentation of larger eclogite and peridotite bodies into lenticular "boudins" in the deforming gneiss. O'Hara and Mercy (1963) suggested that the eclogitic inclusions might have formed in the mantle.

Eclogite of the Rødhaugen type forms layers which usually are from a few centimetres to more than 50 cm thick and have sharp or transitional borders to dunite. Complete compositional transition between eclogite and dunite is revealed in layers of garnet peridotite. The dark layers have closely spaced tensional joints which indicate that they possessed higher rigidity during deformation than the enclosing dunite. Folding is well visible by the layers in dunite, and axis of folding is parallel to a lineation defined by drawn-out kelyphitized garnets. Cursory study of the linear structures supports O'Hara and Mercy's studies in Hjørundfjord where the garnet peridotites possessed linear structures different from those of the enclosing gneiss, but the linear structures within a particular body have variable orientation and will probably give valuable information about the emplacement of the ultrabasites.

Eclogitic inclusions in gneiss are widespread on both sides of the fiord Nordfjord. They are most common in pelitic gneiss and other banded gneisses, but occur also in local augen gneiss, mangeritic rocks and anorthosites.

Some of the eclogitic bodies are tectonic inclusions with internal structures out of harmony with those of the enclosing gneiss, but most of them form concordant lenses parallel to the foliation of the gneiss and possess a secondary foliation parallel to the surrounding rocks. Average length of the eclogitic bodies is from less than one metre to about 10 metres, but several bodies are more than 100 metres long and have been indicated on our map. The larger bodies appear to be interlayered with the gneiss and swarms of smaller inclusions appear to define boudins in structural horizons in the gneisses.

Most of the eclogites are massive without regular planar structures, but some have a very pronounced compositional banding which is distinctly different from the secondary foliation which characterize sheared meta-eclogites. The banding is defined by alternating laminae rich in pyroxene and garnet respectively or by 1/2—20 cm thick layers of eclogite and garnet-quartz rock One occurrence of a such compositionally layered eclogite was referred to as "eclogite adergneiss" by Eskola (1921, p. 59) and probably interpreted as eclogites injected by thin lenses and veins of quartz. The two types of layers make up about equal amounts of the bulk volume, alternate very regularly, and indicate a very tight folding in the massive rock. It is thus most reasonable to regard the garnet-quartz layers as original in the banded eclogite.

A large body of banded eclogite west of Totland has well defined folds with axes plunging 10—50° towards NW to N while the surrounding gneiss is folded on axes with a gentle plunge towards E to ENE. The folds in the eclogites might be older than the folds in the surrounding gneisses or they may have rotated in the gneiss. Compositional banding in the eclogite which is distinct near the contact is generally parallel to the banding of the enclosing gneiss, but the gneiss has somtimes intruded the eclogite and separate fragments where the compositional banding is oblique to the gneiss structure (Fig. 10). The relations are similar to those seen at intrusive contacts, but the situation is best explained by higher mobility of the gneiss than the eclogite during deformation. The gneiss apparently had the ability to flow around and into the more rigid eclogite inclusions.

Some of the eclogite bodies contain layers of garnet-quartz-biotite schists and calcareous rocks.

The eclogite bodies are often transected by shear-zones with amphibolite, quartz, quartz and rutile, or amphibole and sphene. Rutile has been found in up to 2 cm long black crystals enclosed in quartz and sphene

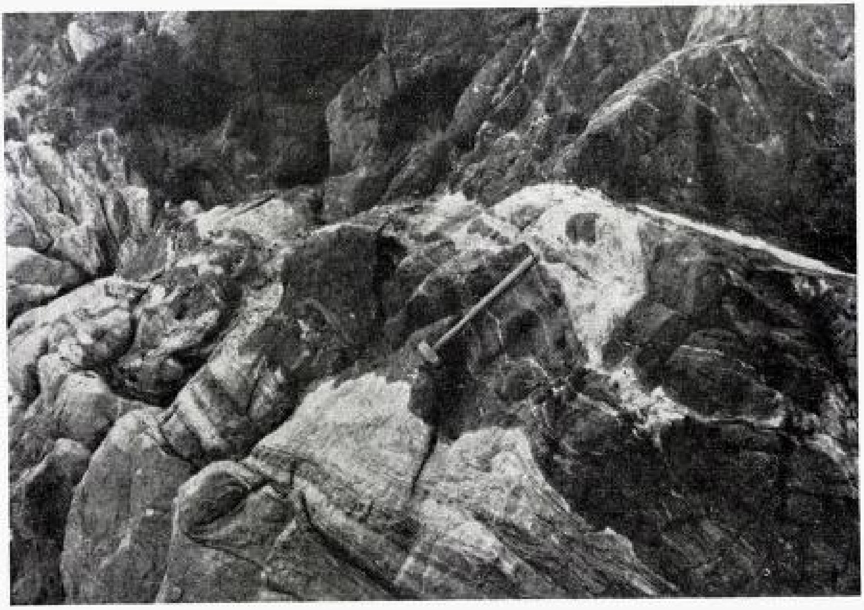

Fig. 10. «Intrusive» contact of gneiss towards banded eclogite. North of Tasken, west of Totland (LP 0971).

has been found in up to 5 cm idioblastic green crystals. Quartz, kyanite and carbonate occur on tension cracks.

Preliminary microscopical examination of a few samples has indicated that the eclogitic rocks correspond to those described by Escola in his classic paper on the eclogites of Norway. The mineralogical composition and structure of the eclogitic rocks vary widely, however, due to original variations in chemical composition, structure and later alteration. The most common types are:

Massive enstatite-olivine-garnet-clinopyroxene eclogite.
Massive amphibole-garnet-clinopyroxene eclogite.
Massive white mica-kyanite-zoisite-garnet-clinopyroxene eclogite.
Banded white mica-zoisite-quartz-garnet rock and amphibole-garnet-clinopyroxene eclogite.
Foliated or banded meta-eclogite with symplectites and kelyphites.
Foliated or banded biotite-epidote-garnet-oligoclase-hornblende-amphibolite.

The first type occur as inclusions in ultrabasites while the other types are common as inclusions in various types of gneiss. Eclogitic inclusions in gneiss have clinopyroxene and garnet as major minerals while amphibole, kyanite, quartz, white mica and zoisite are local characteristic minerals. These minerals are also common as accessory minerals together with apatite, black iron minerals, pyrite, and rutile or secondary minerals as green amphibole, biotite, calcite, pyroxene-plagioclase or amphibole-plagioclase symplectite, mica-symplectite, corundum-plagioclase symplectite, sphene and red iron minerals.

The banded eclogite west of Totland merits special consideration. The rock is banded at the scale 0,2—2 cm. *Light red layers* are composed of about 60 % garnet, 35 % quartz, 5 % white mica bordered by biotite or biotite-carrying symplectite, and accessory rutile, apatite, zoisite or clinozoisite and black iron ore. *Green layers* are composed of about 40 % garnet, 60 % pyroxene with sympectitic borders, accessory quartz, rutile, zoisite, black iron ore and secondary amphibole.

A calcareous layer between two bodies of eclogite north of Tasken, west of Totland, has a distinct compositional layering and dimensional orientation of its minerals parallel to the layering. Calcite, mica, quartz and zoisite are concentrated in the light layers while amphibole is concentrated in the dark layers. Calcite occurs in granoblastic aggregates with average grain-size about 1 mm while the other minerals mainly form symplectitic intergrowths. Approximate modal composition is 30 % calcite, 10 % mica symplectite, 10 % quartz, 45 % amphibole-plagioclase (An 25) symplectite, 5 % zoisite and accessory apatite, black iron minerals, pyrite, rutile and sphene.

Secondary foliation has been imposed on some bodies of eclogitic rocks and nearly always on the border zone of presumed unaltered eclogites. The texture, therefore, will vary much according to the extent of secondary foliation and later mineral alterations. The massive garnet-clinopyroxene eclogites often have dimensional parallelism of pyroxene columns and parallel arrangement of small inclusions of rutile in garnet and pyroxene. Garnet in the presumed unaltered eclogites vary in size from 2 cm to less than 1 mm, but is usually in the order 2—5 mm. Garnet is mesoscopically brown-red, red or purple red and sometimes bordered by dark green amphibole (kelyphite). Pyroxene is mesoscopically bright-green or jade-green in the fresh eclogites and dull jade-green in the symplectitized varities. The symplectites which contain pyroxene and plagioclase are very fine-grained and appears almost isotropic under the microscope, while green amphibole-plagioclase symplectites are more coarse-grained. The other symplectites, biotite-muscovite-feldspar symplectites formed from white mica (phengite) and corundum-plagioclase symplectites formed from kyanite are very fine-grained and appear almost isotropic. Poikilitic texture is often developed when rutile occurs as inclusions in the other minerals or when amphibole and zoisite occur as larger porphyroblasts in the eclogitic rocks.

Chemical examination will be necessary to define the pyroxene, but large axial angle (75—80°) and marginal (or complete) alteration to plagioclase-carrying symplectite indicate that it is omphacitic. Amphibole is often present as colourless or green grains. The colourless type might be primary, but poikilitic texture of some large grains and the fact that the colurless amphibole turns green at the contact towards garnet is more indicative of a secondary origin. Green amphibole (X pale yellow, Y blue green, Z green) sometimes has formed as a kelyphitic alteration product from garnet. The amount of amphibole increases with the perfection of foliation, and it is probable that most of the amphibole is secondary relative to garnet and pyroxene.

Zoisite and kyanite are widespread in the eclogites inclosed in gneiss. Zoisite is sometimes concentrated as layers of white, striated prisms, sometimes developed as porphyroblasts in sheared meta-eclogites but most often evenly distributed as small grains in the rocks. Inclusions of rutile, quartz and kyanite are common in presumed unaltered eclogites while outgrowths of clinozoisite and epidote have developed in meta-eclogites. Low positive axial angle, very low normal interference colours and axial plane parallel to (olo) characterize the mineral as a β-zoisite.

Kyanite occurs in 1/2—1 cm long white or bright-blue laths or more frequently as microscopical grains in the size order 0,2—1 mm. It has been noted as inclusions in garnet, zoisite, white mica and biotite and contains itself zoisite, rutile and quartz as inclusions. Marginal or complete alteration of kyanite has taken place in all meta-eclogites, but adjacent grains often exhibit very different extent of alteration. Incipient alteration is indicated by an inner zone of grey or lilac-brown, almost isotropic very fine-grained hair-like kelyphite and an outer zone of clear acid plagioclase. The zone of clear plagioclase has also developed on the border between diopside-plagioclase-symplectite and apparent unaltered kyanite while it is lacking when the symplectitized kyanite is inclosed in mica or zoisite. This indicates that the outer zone of plagioclase is only indirectly related to the destruction of kyanite, — plagioclase grew more easily on the borders to kyanite (or its symplectitic alteration product) than in the surrounding diopside-plagioclase symplectite.

The composition of the hair-like symplectite was first determined by Lappin (1960) who found that it consisted of a mixture of oligoclase and corundum. X-ray diffractometer studies of 2 samples of almost isotropic kelyphitic alteration products of kyanite from eclogites sampled between Duestøl and Stårheimseter confirmed the identification of a mixture of corundum and plagioclase.

Lappin reported that kyanite had been partially replaced by zoisite, but the evidence for a such replacement were not univocal judged by his microscopical criteria. Zoisite contains inclusions of kyanite and symplectiticed kyanite without any evident replacement relations, and boundaries fail to give indications of instability of any of the two minerals.

Margarite, which was noted by Eskola (1921, p. 51) has not been found in the specimens I have investigated from Nordfjord. White mica is present as aggregates enclosing some eclogitic lenses in the gneiss or as 1—2 mm thick books evenly distributed in some eclogites. The border zone is often symplectitic with brown biotite as one component. Axial angle is low (probably 0—10°) and $\beta = 1.594$. Both white mica from the aggregates bordering eclogitic rocks and the evenly distributed books of white mica have muscovite 3T structure, relative low b parametre ($2d_{060} = 1.511$) and basal spacing ($c \sin \beta = 19.9$ Å) which indicate that they are phengites (Ernst, 1963, p. 1365). The external symplectite is probably finely intergrown muscovite, phlogopite and feldspar which have exsolved from the phengite.

Alteration of eclogite.

Eskola (1921) described the alteration of eclogites to amphibolites through the development of diopside-plagioclase or hornblende-plagioclase symplectite from omphacitic clinopyroxene and hornblende kelyphite from garnet. Lappin (1960) added interesting details on the alteration of kyanite to corundum-oligoclase symplectite and zoisite.

It is difficult to decide the sequence of crystallization in metamorphic rocks, and it may be possible that some minerals have formed during a long time interval while other minerals had shorter periods of growth. The position of white mica, green amphibole and zoisite is especially difficult to place in the metamorphic history of the eclogites. Lappin (1960) did not count these minerals among the stable eclogite mineral assemblages at the Selje and Åheim districts. Green amphibole may be secondary but white mica and zoisite may be primary relative to garnet and pyroxene. As for zoisite, it is clear that this mineral often occurs as porphyroblasts or irregular grains with inclusions of rutile, quartz and kyanite (or symplectitized kyanite) but poikiloblastic relations are sometimes characteristic also for garnet and clinopyroxene. The fact that kyanite sometimes is inclosed in garnet without any zoisite reaction zone while zoisite occurs as inclusions in kyanite and that zoisite is common in apparently unaltered eclogites indicate that zoisite is a primary member of the eclogite mineral assemblage. Growth of zoisite may have continued into the amphibolitic stage as indicated by big poikiloblastic porphyroblasts in some kyanite-garnet-plagioclase-hornblende meta-eclogites. The white micas are concentrated along the boundaries of eclogitic lenses, but their phengitic composition and symplectitic borders indicate that they may well have formed contemporaneous with the zoisite, kyanite and other early minerals in the eclogites.

Particular attention was paid to the alteration of an about 5 m thick and 20 metres long eclogitic inclusion in garnet-white mica-plagioclase-quartz gneiss on the coast between Eldevik and Raudhjellane. The eclogite is here a coarse-grained variety with red-brown garnets set in a green matrix. The border zone, some tens of centimetres from the contact, is darker because amphibole has grown within and around garnet, and the outermost few centimetres of the inclusion contain a biotite-plagioclase-rock with zones carrying books of biotite.

Three thin sections were made to study the alteration of this eclogite, and the estimated content of their essential constituens is given below:

	Eclogite	Meta-eclogite	"Crypto-meta eclogite"
Garnet	45	30	—
Pyroxene	30	—	—
Amphibole	5	25	—
Amphibole-plagioclase symplectite	20	40	—
Epidote	—	5	20
Biotite	—	—	30
Plagioclase	—	—	50

The least altered eclogite which is sampled 1 metre from the contact has about 0,3—0,5 mm big garnets and mesoscopically only barely visible foliation. In microscope is seen dimensional preferred orientation of tablets of pyroxene and inclusions of rutile needles arranged is strings. This eclogite is *essentially a garnet-pyroxene rock* with less than 0,5 mm broad symplectitic borders on the pyroxene grains, kelyphitic zones of amphibole around garnet and accessory rutile, calcite, quartz and apatite.

The meta-eclogites is sampled 20 centimetres from the contact. The garnets are here considerably altered both internally and externally to a dark green amphibole and the matrix has a dull light-green colour. Foliation is not pronounced neither in hand-specimen or under the microscope. This meta-eclogite is *essentially a garnet-amphibole-plagioclase rock* with amphibole, amphibole-plagioclase-symplectite and amphibole-epidote-symplectite with acessory sphene-mantled rutile, zoisite, quartz, apatite, pyrite and black iron ore. Garnet is partly altered to a symplectitic intergrowth of blue-green amphibole and epidote; zoisite has obtained outgrowths of epidote, and rutile is partly or completely altered to aggregates of very fine-grained sphene. Pyroxene has vanished and its place has been taken by symplectitic intergrowths of pale-green amphibole and plagioclase.

The "crypto-meta-eclogite" is sampled on the contact between the eclogitic body and the eclosing gneiss. This rock appears to be coarse-grained like the eclogite rocks, but is by closer inspection composed of black and white clusters of fine-grained minerals. By microscope is identified clusters of biotite and epidote surrounded by granoblastic aggregates of 0,2—0,5 mm big grains of plagioclase. It is thus essentially a epidote-biotite-plagioclase rock. Accessory minerals are sphene with rutile relics, quartz, apatite, zoisite and chlorite which partially replace biotite. The plagioclase is an oligoclase with slight twinning, zonarity and with strong undulative extinction. The alterations seen in these eclogites are therefore:

1. Amphibole forms on borders of garnet.
2. Garnet is transformed to symplectitic intergrowths of epidote and amphibole.
3. Pyroxene is externally altered into a fine-grained symplectite at the grain boundaries. The pyroxene is later completely transformed into symplectite where amphibole and plagioclase can be identified.
4. Rutile is altered into sphene.

   Other rocks give evidence of additional alterations:

5. Phengitic mica is decomposed into biotite-muscovite-feldspar symplectite.
6. Kyanite is transformed into corundum-plagioclase symplectite.

The transformation on the border of the eclogitic body cannot be explained by hydration and by simple rearrangement of the constituents of the original eclogite. The high content of biotite and epidote in the "crypto-meta-eclogite" indicates that potassium and water metasomatism has taken place. Such potassium and water metasomatism has probably affected many of the small eclogitic bodies and rendered them undistinguishable as meta-eclogites.

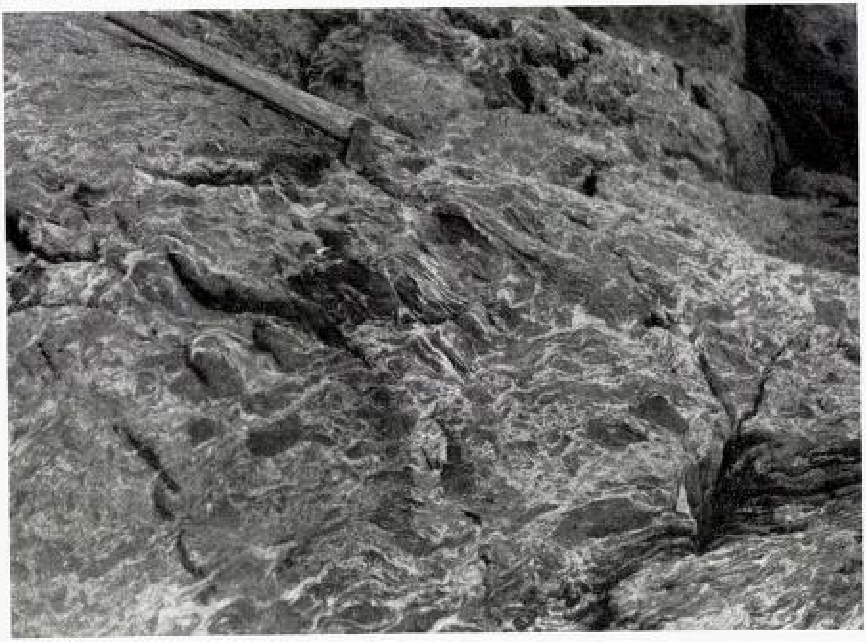

Fig. 11. «Breccia gneiss». Coast section between Levdal and Kjølsdal (LP 2971).

A peculiar "*breccia-gneiss*" with dark inclusions in quartz-rich matrix occurs between Levdal and Kjølsdal and on the Davik peninsula. (Fig. 11.)

The dark inclusions often occupy more than 50 % of the bulk volume of the rock, and are commonly 5—10 cm long lenses which in tectonized zones are flattened into inconstant bands. The dark inclusions are often acutely folded, and some are actually fold-hinges which have been sheared off their limbs.

Foliation, in the sense of parallel-oriented mica and alternation of layers of different composition, is often developed, but schistosity or parting surfaces are not very common.

The composition of the dark inclusions, as deduced in the field, is mainly biotitic, biotite-plagioclasic, biotite-amphibolitic and amphibolitic. Eclogitic inclusions are noted locally and are similar in size and apparence as the other dark inclusions or are bigger bodies which the biotite-rich inclusions bend around.

The matrix between the dark inclusions consists mainly of quartz with some plagioclase, white mica and biotite. The mica is often symplectitic.

The dark inclusions are essentially composed of biotite-plagioclase-amphibole-epidote, biotite-plagioclase or quartz-zoisite-garnet-pyroxene. The latter mineral composition corresponds to eclogite, and the rock was also identified in the field as a folded eclogitic inclusion in gneiss.

The plagioclase is a basic oligoclase with undulative extinction and tight twinning.

The breccia-gneiss is similar to what would be expected if it were an altered agglomerate, but the fragments are often isolated fold-hinges which indicate that this rock has rather formed by folding and transposition of a layered sequence of a competent basic and an incompetent acid rock. The breccia structure has also formed by intrusive fragmentation of basic rock bodies by the gneiss.

The basic fragments reveal every transition between eclogites and biotite-plagioclase gneisses. It is believed that they represent metasomatic derivatives of volcanic fragments and layers which have been flattened, transposed and transformed into eclogites and other basic metamorphic rocks.

Genesis of eclogites in gneiss.

Able geologists speculate that the eclogites are derived from the mantle as fragments pushed up into the geosynclinal pile as solid intrusions. Such speculations gain some support from the isotope age contrast between the eclogites and the enclosing gneisses (McDougall and Green, 1964), field evidence that linear structures of the eclogitic bodies often are incongrous with those of the enclosing gneiss and that eclogites are enclosed in ultrabasites. Some of the eclogites in Nordfjord are not now in the place where they formed. They might have rotated and flowed passively into the gneiss which was much more mobile during deformation, but we have no indication how far they have moved relative to the enclosing gneiss. It is very difficult to visualize how the thousands of small and large bodies of eclogitic rocks in the gneisses have been transported any large distance relative to the enclosing gneiss and the proponents of mantle-derived eclogites have as yet failed to give any satisfactory mechanism for such a sampleing of the mantle and the distribution of the specimens in the crust.

The occurrence of the eclogites in rocks which are thought to represent altered supracrustals and the occurrence of them as layers and boudins in structural horizons in the gneiss raises the possibility that the eclogites also are altered supracrustal rocks, and Schmitt (1964) has already explained eclogites in an adjacent area as such.

The presence of layers of coarse-grained garnet-quartz-biotite schists and calcareous rocks in the eclogites makes it necessary to take into consideration the possibility of eclogite production from carbonate rocks, — a possibility which was suggested by Gosh (1941) and Hahn-Weinheimer (1959).

The calcareous layers in eclogites at Nordfjord might represent calcified alteration zones, but the concordant layering suggests that it shares the metamorphic history of the enclosing rock. If it was an original layer of impure limestone which suffered the same metamorphism which imposed eclogite mineralogy of the rocks around it, the calcareous layers could be classified as lime-silicate rocks. Their compositions are, however, very different from those of true lime-silicate rocks further north in Sunnmøre. It would be most safe, at present, to regard the calcareous layers in the eclogites as members of the enclosing mica-rich para-gneisses which have been interlayered with, or injected into the eclogitic rock bodies.

The basic inclusions in the mangeritic rocks may have important bearing on the origin of the eclogites. Some of the amphibolites and eclogites in the mangeritic rock bodies at Måløy and Flatraket appear to be altered diabases, and a plagioclase-garnet-clinopyroxene rock has, in fact, retained the parental sub-ophitic texture. An explanation that the original diabase has been transformed into eclogite when water was unavailable ("Dipsenic metamorphism" by Rosenqvist, 1952 p. 91—94) and into amphibolite when water was available, lies readily at hand. Gjelsvik (1952 p. 124) claimed that "dolerites" in Sunnmøre and Romsdal were transformed into rocks transitional into eclogite, and this interesting hypothesis should be tested by further petro-chemical studies. The kyanite-eclogites have probably a much higher content of aluminia than the ordinary diabases and would require porphyritic parental rocks if the transformation has taken place isochemically. Other eclogites also exhibit a wide range in mineral composition which would indicate that they may have formed from a variety of parental rocks, probably mainly differentiated diabase sills and dykes, basalts and pyroclastic material which remained dry during metamorphism.

The variable mineralogical composition of the dark fragments in the breccia-gneiss can be explained by different accessibility of water and potash during metamorphism. The layering with quartz-garnet bands in some eclogites might be a reflection of original bedding, but should rather be explained by a mechanism of rhytmic crystallization during formation of the eclogites.

The eclogitic mineralogy of the various original supracrustal or hypabyssal basic rocks has probably been imposed at very high pressure and rather low temperature. Yoder and Tilley (1962, Fig. 43) have shown that basalt will be converted to eclogite over a PT interval. Transition at 400 °C will take place in the pressure interval at 9—13 kb (depth approximately 32—45 km) while transition at 500 °C will take place at approximately half a kilobar higher pressure. The presence of phengite in the eclogites of Nordfjord indicate that the temperature was less than 500—600° (Velde, 1965, p. 906). If the pengite was formed during the same physical conditions as the assemblage quartz-kyanite-zoisite, temperatures at about 550° would probably require that the load pressure was in excess of about 7 kb (Newton, 1966, p. 215). The overburden must thus have been at least 24 km thick and probably much thicker. A combination of the relatively low temperature and high pressure would be expected at the bottom of a rapidly downbuckled thick geosynclinal pile, and the position of the gneisses in Nordfjord in the deepest structural part of the late-Precambrian early-Caledonian geosynclinal sequence fits with these requirements. The rather low temperature would be retained in the first stages of downbuckling because of the insulating effect of the supracrustal blanket, but as temperature increased some high-pressure mineral assemblages would be unstable. The symplectitic reactions:

omphacite → diopside-plagioclase
kyanite → corund-plagioclase
and phengite → biotite-muscovite-feldspar

have probably formed as a concequence of rising temperature or decreasing pressure in the geosynclinal pile. These effects were probably related to the general almandine-amphibolite-facies metamorphism which succeded the initial stage of down-buckling.

Anorthosites (meta-anorthosites).

Anorthositic inclusions are very common in the gneiss at both sides of Nordfjord. A body af anorthosite and related rocks can be followed along a dislocation zone almost continuously from Bortnen to Hornindalsvatn and probably many kilometres further eastwards on the south side of the lake. Other big bodies of anorthosite are found north af Hjelmelandsdalen, at Bauvatn, Steinsvik and Almklovdalen. In addition to these are found several small layers and inclusions like that illustrated in Fig. 12.

The contact towards the gneiss is usually conformable, but small-scale discordant relations are often displayed. The contact relations often indicate that the anorthositic bodies are tectonic inclusions in the gneiss. Especially the small bodies indicate that anorthosite was more rigid than the enclosing gneiss during deformation, and broke up into fragments which flowed and even rotated in the deforming gneiss. Meta-anorthosites have behaved different because neocrystallication facilated flow during metamorphism.

As yet have intrusive relations to the surrounding gneiss not been demonstrated, but any such would easily have vanished during the strong tectonization which these rocks have suffered. Syntectonic neocrystalli-

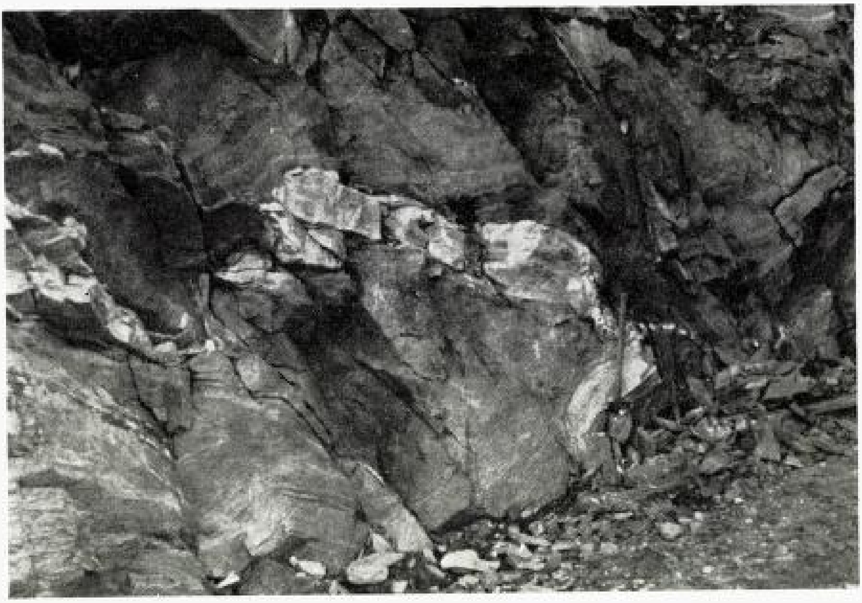

Fig. 12. Layer of meta-anorthosite, E. of Kvalvikja, Vågsøy (KP 9579).

zation has taken place and often transformed the original anorthosite to a meta-anorthosite with tight internal folding and distinct foliation. Anorthosites of Nordfjord are usually rather massive and homogeneous, but primary or secondary foliation is usually seen by closer inspection. The foliation is defined by dimensional parallelism of platy plagioclase or aggregates of amphibole, biotite, chlorite, epidote and white mica which sometimes impart on the rock surfaces of easy splitting. Varying extent of granulation, veins of recrystallized plagioclase or green chromiferous muscovite serve to emphazise the foliation of some meta-anorthosites.

The anorthositic rocks are usually fine-grained with most of the plagioclase grains in the order 0.5—1 mm. The most common mineralogical types are:

Green amphibole-plagioclase anorthosite.
Green amphibole-epidote-plagioclase anorthosite.
Biotite-margarite-epidote-plagioclase anorthosite.
White mica-chlorite-epidote-plagioclase meta-anorthosite.

Apatite, biotite, black iron minerals, calcite, kyanite, pyrite, quartz, red iron minerals, rutile and zoisite occurs accessory.

All anorthositic rocks in the area have suffered metamorphism during the main EW to NE-SW folding and it hard to tell which minerals are "primary" and which are "secondary". Plagioclase in the most massive anorthosites is mesoscopically white and is highly twinned, distinctly zoned, and sometimes antiperthitic with irregular inclusions of potash feldspar. The rim is slightly more basic (An 55—60) than the core (An 40—50). Meta-anorthosites have recrystallized "'chessboard" andesine (An 35) or un-twinned oligoclase. The amphibole is a green variety with no textural indications of being secondary, but epidote, chlorite and sphene have obviously been at least partly derived by destruction of other dark minerals. It is interesting to note that epidote occurs in apparent stable equilibrium with plagioclase of andesine-labradorite composition. White mica is usually a muscovite, but an anorthosite from Duestøl carry abundant pink margarite enclosed in muscovite aggregates. Chromiferous muscovite occur only locally and is similar to green mica described from other meta-anorthosites (Bryhni, 1964).

The rather massive and homogeneous structure of the anorthosites in Nordfjord make these rocks very different from the banded gneiss/meta-anorthosites which are characteristic for the Florø—Eikefjord area in Sunnfjord. Banded meta-anorthosites do occur in the southern part of our map, however. A dark rock alternate here with meta-anorthosite in 2—200 cm thick layers which reveal tight folding. The contact between the layers is sharp and estimated mineral content is:

Dark layers		White layers	
Amphibole	30 %	White mica	10 %
Epidote	30 %	Zoisite and epidote	15 %
Chlorite	15 %	Chlorite	5 %
Plagioclase	15 %	Plagioclase	65 %
Quartz	10 %	Quartz	5 %

The dark layers contain apatite, limonitized pyrite, rutile, sphene and white mica as accessory minerals.

Genesis of the anorthosites.

The anorthositic rock look very much like disected sills, but the major EW to NE-SW folding and neocrystallization has erased the original contact relations and laid the original structure and mineralogical composition open for speculation. Some indication about the original properties of the anorthositic rocks may perhaps be obtained by going to Fiskå and Sandsøy north of our area where the rocks are exceptionally coarse-grained (Gjelsvik, 1951, p. 23) and composed of essentially anhydrous minerals. Plagioclase is here brown or violet-brown and attains the size of 50 cm while megacrysts of hypersthene are up to 20—30 cm long. Among the various coronas or reaction structures are garnet coronas around ilmenite most conspicious.

The coarse-grained anhydrous anorthosites at Fiskå and Sandsøy have locally been granulated, and the more fine-grained zones are very similar to the anorthosites in Nordfjord. It is thus possible that the anorthosites of Nordfjord also have been original coarse-grained anhydrous rocks which have been granulated and partially hydrated. Another possibility, which should be preferred until evidence for any such granulation and partial hydration has been demonstrated, is that the texture and hydrous minerals in the anorthosites of Nordfjord are to some extent original properties. Margarite, zoisite and in some measure also green amphibole, biotite and epidote may have been original constituents and testify that the water-pressure was high when the anorthosites were formed. Plagioclase is the first phase to melt from a basic rock under high water-pressure (Yoder and Tilley, 1962) and the presence of primary hydrous minerals in the anorthosites of Nordfjord would make a magmatic origin of them acceptable. Anorthositic liquids can probably form at the conditions which prevail at the base of the crust, and it is tentatively suggested that the anorthositic rocks in Nordfjord were formed by injection of such liquids into the geosynclinal pile of supracrustal rocks.

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Norsk sammendrag.

Det foreliggende arbeid gir resultatene av geologiske studier på begge sider av ytre del av Nordfjord. Kartleggingen har vært et ledd i arbeidet med kartbladet MÅLØY som skal gies ut som geologisk kart i målestokk 1 : 250 000.

Det er gjort et forsøk på å plassere bergartene i Nordfjord i en tektonisk sammenheng med andre deler av Fjellkjeden. I Fig. 2 er det antydet at bergartene langs ytre deler av Vestlandet danner et inhomogent kompleks av overveiende kaledoniske bergarter som overleirer et eldre, kaledonsk gjennombeveget Prekambrisk kompleks omkring Jostedalen. Ifølge dette kartet, som ikke må oppfattes som annet enn en arbeidshypotese, kan det Prekambriske kompleks være representert ved to smale kiler av øyegneis på begge sider av Nordfjordeid.

Mesoskopiske folder i Ytre Nordfjord viser ofte kurvete akseflater, dobbelt lukning og andre trekk som tyder på at deformasjonen av bergartmassen har funnet sted under plastiske forhold. Mesteparten av området viser likevel et relativt enkelt makroskopisk foldningsmønster dannet ved en gjennomgripende cylindroidal foldning om akser som heller mot E til NE. Bare området rundt Måløy avviker fra dette mønster og er inhomogent i den skala vi har undersøkt det i.

Dislokasjoner om EW linjer representerer et sent stadium i bergartenes deformasjonshistorie, og har særlig gjort seg gjeldende i den sydlige del av feltet.

Den dominerende bergart i området er en biotitt-rik båndet gneis med granodiorittisk sammensetning. I denne opptrer soner med glimmer-rik gneis, kvarts-glimmer-skifer og feltspatholdig kvartsitt. Andre viktige bergartstyper er øyegneis, granittisk gneis og mangerittiske bergarter.

De mangerittiske bergarter har kjemisk sammensetning som svarer til syenogabbro, men mineralassosiasjoner som klinopyroksen-granat-plagioklas-orthoklas og kyanitt-granat-plagioklas-orthoklas viser at bergartene krystalliserte under fysikalske betingelser som svarer til granulittfacies.

De mangerittiske bergarter kan ha en tektonisk posisjon som svarer til de overskjøvne Jotundekkene i mer sentrale deler av Fjellkjeden eller de kan representere rester av plutonsk-magmatiske intrusiver i bergartsmassen.

Hvite bånd eller ganger av kvarts-diorittisk eller kvarts-monzonittisk sammensetning opptrer hyppig i gneisene. De kan representere forskjellige utviklingstrinn ved dannelsen av trondhjemittiske magmatiske bergarter.

For øvrig antas gneisene å representere omvandlete opprinnelig suprakrustale bergarter: overveiende gråvakker, feltspatiske sandsteiner og vulkanitter.

Ultrabasitter, eklogitter og anorthositter opptrer som inneslutninger i gneisene og har ofte internale strukturer som er inkongruente med strukturene i den omgivende bergart. I Fig. 9 er angitt ca. 75 forekomster av ultrabasitt. Ultrabasittene opptrer i klynger eller på rekke og rad langs tektoniske linjer.

Nord for en linje mellom Leirgulen og Kjølsdalen består ultrabasittene overveiende av olivinstein. Syd for denne linje består de overveiende av serpentinitt.

Eklogitter opptrer som lag eller boudiner langs strukturelle horisonter i gneisene, og omfatter både massive og båndete typer. De båndete eklogitter kan vise betydelig internal foldning. Den ofte lagvise opptreden av eklogittene og det store antall av slike inneslutninger i gneisene tyder på at de er dannet stort sett der hvor de ligger i dag. Det er derfor rimelig å se dem som resultat av omdannelse fra diabas-ganger og basiske suprakrustale bergarter slik som tidligere antydet av bl. andre Gjelsvik 1952 og Scmidtt, 1964. Eklogitt-omvandlingen kan ha funnet sted i «tørre» bergarter under et tidlig stadium av fjellkjededannelsen da jordskorpen ble buklet ned til store dyp og utsatt for meget høye belastningstrykk mens temperaturen til å begynne med var relativt lav.

Anorthositt og mangerittiske bergarter (?) kan ha intrudert som lagganger og større plutoner under dette stadium med dyp nedbukling av jordskorpen.

Omvandlingen av eklogitter til meta-eklogitter, anorthositter til meta-anorthositter og olivinstein til serpentinitt og den alminnelige metamorfose i gneisene skyldes en senere almandin-amfibolittfacies omvandling. Denne omvandling kan ha funnet sted ved lavere belastningstrykk og høyere temperatur enn eklogitt-omvandlingen, men kunne bare gjøre seg gjeldende i bergarter hvor vanninnholdet var tilstrekkelig høyt til å danne vannholdige mineraler.

References cited.

Banham, P. H. and *Elliot, R. B.*, 1965: "Geology of the Hestbrepiggan area Preliminary account". Norsk geol. Tidsskr., *45*, 189—199.

Bryhni, I., 1964: "Contributions to the mineralogy of Norway No. 26. Chromian muscovite in meta-anorthosite". Norsk geol. Tidsskr., *44*, 353—363.

Broch, O. A., 1964: "Age determinations of Norwegian minerals up to March 1964". Norges geol. Unders., No. 228, 84—113.

Brøgger, W. C., 1880: "Über Olivinfels von Söndmöre". Neues Jb. Miner. Geol. Paläont., II, 187—192.

De Waard, D., 1965: "A proposed subdivision of the granulite facies". Am. J. Sci., *263*, 455—461.

Drescher-Kaden, F. K., 1948: "Die Feldspat-Quartz-Reaktionsgefüge der Granite und Gneise". Springer-Verlag. Berlin, Göttingen, Heidelberg. 259 p.

Ernst, W. G., 1963: "Significance of phengitic micas from low-grade schists". Am. Miner. *48*, 1357—1373.

Eskola, P., 1921: "On the eclogites of Norway". Skr. Vidensk. Selsk. Christiania, Mat.-Naturv. Kl., I, No. 8.

— 1939: "Die Entstehung der Gesteine". Barth, T. F. W., Correns, C. W., and Eskola, P. p. 263—407. Berlin: Julius Springer.

— 1957: "On the mineral facies of charnockites". Journ. Madras Univ., B, 27, No. 1. Centenary Number.

Gjelsvik, T., 1947: "Anorthosittkomplekset i Heidal". Norsk geol. Tidsskr. *26*, 1—58.

— 1951: "Oversikt over bergartene i Sunnmøre og tilgrensende deler av Nordfjord. Med geologisk oversiktskart av Tore Gjelsvik og Chr. C. Gleditsch". Norges geol. Unders. No. 179.

— 1952: "Metamorphosed dolerites in the gneiss area of Sunnmøre". Norsk geol. Tidsskr. *30*, 33—134.

— 1953: "Det nordvestlige gneis-område i det sydlige Norge, aldersforhold og tektonisk-stratigrafisk stilling". Norges geol. Unders., *184*, 71—94.

Goldschmidt, V. M., 1954: "Geochemistry". Alex Muir (editor), Oxford Univ. Press, 730 p.

Gosch, P. K., 1941: "The charnockite series of Bastar State and W. Jeymore". Prof. Pap. India geol. Surv., *75*, No. 15.

Hahn-Weinheimer, P., 1959: "Geochemische Untersuchungen an den ultrabasischen und basischen Gesteinen der Münchberger Gneissmasse-Fichtelgebirge". Neues Jb. Min. Abh., *92*, 203—278.

Hernes, I., 1964: "Anzeichen einer frühkaledonischen Metamorphose. Ein Deutung radioaktiver Altersbestimmungen". Neues Jb. Miner., *4*, 110—116.

— 1965: "Die kaledonische Schichtenfolge in Mittelnorwegen". Neues Jb. Geol. Paläeont. Mh., *2*, 69—84.

Holtedahl, O. and *Dons, J. A.*, 1960: "Geologisk kart over Norge. Berggrunnskart 1 : 1000 000". Norges geol. Unders. Nr. 208.

Hsu, K. J., 1955: "Granulites and mylonites of the region about Cucamonga and San Antonio canyons, San Gabriel Mountains, California". Univ. Calif. Publs. geol. Sci., *30*, 223—252.

Irgens, M. and *Hiortdahl, Th.*, 1864: "Om de geologiske forhold paa kyststrækningen af Nordre Bergenhus Amt". Universitetsprogram, annet halvaar 1864, Christiania.

Kolderup, C. F., 1912: "Sogneskollen og Bremangerlandets granodioriter". Bergens Mus. Aarb. 1911, 3dje hefte, Nr. 18.

Kolderup, C. F. and *Kolderup, N.-H.*, 1940: "Geology of the Bergen Arc System". Skr. Bergens Mus. Nr. 20.

Kolderup, N.-H., 1928: "Fjellbygningen i kyststrøket mellom Nordfjord og Sognefjord". Bergens Mus. Årb. 1928, Nat.vit. rekke nr. 1.

— 1960 a: "The relationship between Cambro-Silurian schists and the gneiss complex in the deep-Caledonides of Sogn and Fjordane, West Norway". Guide to excursions no. A5 and no. C2, Int. geol. Congr. Oslo 1960.

— 1960 b: "Origin of Norwegian eclogites in gneisses". Norsk geol. Tidsskr., *40*, 73—76.

Kvale, A., 1946: "Petrologic and structural studies in the Bergsdalen quadrangle. Western Norway". Part I. Petrography. Bergens Mus. Årb. 1945. Nat.vit. rekke Nr. 1.

Lappin, M. A., 1960: "on the occurrence of kyanite in the eclogites of the Selje and Åheim districts, Nordfjord". Norsk geol. Tidsskr., *40*, 289—296.

McDougall, I. and *Green, D. H.*, 1964: "Excess radiogenic argon and isotopic ages on minerals from Norwegian eclogites". Norsk geol. Tidsskr., *44*, 183—196.

Mercy, E. L. P. and *O'Hara, M. J.*, 1965 a: "Chemistry of some garnet-bearing rocks from the South Norwegian peridotites". Norsk geol. Tidsskr., *45*, 323—332.

— 1965 b: "Olivines and orthopyroxenes from garnetiferous peridotites and related rocks". Norsk geol. Tidsskr., *45*, 457—461.

Neumann, H., 1960: "Apparent ages of Norwegian minerals and rocks". Norsk geol. Tidsskr., *40*, 173—191.

Newton, R. C., 1966: "Some calc-silicate equilibrium relations". Am. J. Sci., *264*, 204—222.

O'Hara, M. J. and *Mercy, E. L. P.*, 1963: "Petrology and petrogenesis of some garnetiferous peridotites". Trans. R. Soc. Edinb., *65*, 251—314.

Reusch, H. H., 1878: "Grundfjeldet i søndre Søndmør og en Del af Nordfjord". Forh. Vidensk Selsk. Krist., 1877, No. 11.

— 1884: "Nye opplysninger om olivinstenen i Almklovdalen paa Søndmøre". Forh. Vidensk Selsk. Krist., 1883, No. 1.

Rosenqvist, I. Th., 1952: "The metamorphic facies and the feldspar minerals". Univ. Bergen, Årb., 1952, Nr. 4.

— 1956: "Granulite-mangerite-eclogite". Norsk geol. Tidsskr., *36*, 41—46.

Rost, F., 1963: "Ultrabasite der Kruste und ihr Mineralbestand". Neues Jb. Miner. Mh., 263—272.

Schmitt, H. H., 1964: "Metamorphic eclogites of the Eiksund area, Sunnmøre, Norway". Trans. Am. geophys. Un., *43*, 128 (Abstract).

Slemmons, D. B., 1962: "Observation on order-disorder relations of natural plagioclase". Norsk geol. Tidsskr., *42*, 533—554.

Strand, T., 1949: "On the gneisses from the north-western gneiss area of Southern Norway". Norg. geol. Unders. Nr. 173.

— 1951: "The Sel and Vågå map areas". Norges geol. Unders. Nr. 178.

Trøger, W. E., 1938: "Eruptivgesteinsnamen." Fortschr. Min. Krist. Petr., *23*, 41—90.

— 1959: "Optische Bestimmung der gesteinsbildenden Minerale, Teil 1". E. Schweizerbartsche Verlagsbuchhandlung, Stuttgart, 147 p.

Subramaniam, A. P., 1959: "Charnockites of the type area near Madras — a reinterpretation". Am. J. Sci., *257*, 321—353.

Turner, F. J., 1958: "Mineral assemblages of individual metamorphic facies" in "Metamorphic reactions and metamorphic facies" by W. S. Fyfe, F. J. Turner and J. Verhoogen. Mem. geol. Soc. Am., *73*, 259 p.

Velde, B., 1965: "Phengite micas: synthesis, stability and natural occurrence". Am. J. Sci., *263*, 886—913.

Vogt, J. H. L., 1883: "Olivinstenen i indre og søndre Søndmør". Nyt. Mag. Naturvid. XXVII, 1882.

Winkler, H. G. F., 1965: "Die Genese der metamorphen Gesteine". Springer-Verlag Berlin. Heidelberg. New York. 1965. 218 p.

Yoder, H. S., Jr. and *Tilley, C. E.*, 1962: "Origin of basalt magmas: An experimental study of natural and synthetic rock systems". Journ. Petr., *3*, 243—532.