GABBROIC AND QUARTZ DIORITIC INTRUSIONS IN GNEISSES ON SOUTHERN ASKØY, WEST NORWEGIAN CALEDONIDES

by

Helge Askvik[1])

Contents.

[1]) **Norges geologiske undersøkelse, boks 3006, 7001 Trondheim.**

Abstract.

Light- and dark-coloured biotite gneisses and in part amphibole gneisses, of supracrustal origin have been intruded by a Precambrian basic pluton. Later a quartz diorite was intruded into the basic rocks. By assimilation of basic xenoliths in the quartz diorite a hybrid rock was formed. The whole area was penetratively folded and metamorphosed during a late Ordovician — early Silurian Caledonian orogenic event. The gneisses were partly migmatized and augen gneisses were formed. Most of the gabbroic and quartz dioritic intrusive rocks were more or less altered, but the basic bodies still have large areas of relatively unaltered rock with primary texture and mineralogy.

Introduction.

The island of Askøy is situated a few km north-west of Bergen, and the investigated area comprises the southern part of the island.

Morphologically the island belongs to the strandflat, with an altitude of 50—70 m and with some ridges and low hills in the central parts. The highest mountain, Askøyfjellet, alt. 231 m, is reckoned as one of the seven mountains surrounding Bergen. A conspicuous topographic feature is the saw-toothed profile of the island when viewed from the north or the south. This is the result of erosion being governed by the mainly eastward dipping foliation and the steep north-south jointing of most of the rocks.

Earlier works. — C. F. Kolderup and N.-H. Kolderup dealt with the rocks of southern Askøy in their paper: Geology of the Bergen Arc System (1940). Previously Hiortdal & Irgens (1862) and C. F. Kolderup (1903) had presented some details from the area. Reusch (1900) described similar rocks from the islands further west. Storetvedt (unpublished thesis 1962) has made a gravimetric study on the basic pluton, and Skeie (unpublished thesis 1968) investigated the gneisses and schists of the north-eastern part of the island.

For the field work a very good topographic map on the scale 1 : 5000 was used, prepared by Askøy Oppmålingsvesen. The mineral determinations have generally been done by optical methods, based on data in Trøgers «Bestimmungstabellen» (Trøger 1959).

The paper is based on work carried out for a cand. real. thesis at the University of Bergen. The field work was financed by grants from the university and from Norges geologiske undersøkelse; to both these institutions the author wishes to express his thanks.

The author is very grateful to Professor Niels-Henr. Kolderup and Professor Anders Kvale for their inspiring teaching and guidance; and to

Lecturer, now State Geologist Tore Torske for stimulating discussions and useful advice, and for critically reading the manuscript and suggesting improvements. He is also indebted to Amanuensis Brenda Jensen, Mineralogisk-Geologisk Museum, Oslo, for the chemical analyses, and to First Amanuensis Dr. Karsten Storetvedt, Geofysisk institutt, Bergen, for his generous permission to publish the important age determinations on the basic pluton.

Further, thanks are due to the technical staff at Geologisk institutt, Bergen, and at Norges geologiske undersøkelse, for all assistance.

Geological relations (map, fig. 15).

The investigated area is situated west of the Minor Bergen arc of Cambro-Silurian rocks in the Bergen district of the West Norwegian Caledonides.

Kolderup and Kolderup (1940) treated it in their section on «The Migmatites» under the heading «The Western Gneiss and Granite Complex», which very adequately expresses the setting of the area.

In the present work the rocks in the area are grouped as follows:

1. Gneisses.
2. Norite/gabbro and metagabbro.
3. Quartz diorite.
4. Dykes.

The gneisses (1), occurring mainly to the south and to the north-east, make up approx. 60 per cent of the area. The two fields of gneiss are almost separated by the composite gabbroic/quartz dioritic body (2 + 3) which occupies the central and western part of the area. This intrusive complex (2 + 3) has the form of a thick north-easterly dipping lens, consisting mainly of norite/gabbro; within the lens quartz diorite (3) occurs as an east-west striking dyke through the central part, and as thick, concordant layers in the metagabbro in the northern part. The dykes (4) comprises mostly granite pegmatites, granite dykes, a gabbro dyke and some amphibolite dykes.

Structure. — The foliation of the metamorphic rocks varies in trend owing to folding on east-west fold axes, but on a regional scale the strike direction in the southern part of the area changes from north-south at the southernmost tip to north-west further north; in the northern area the regional strike is north to north-west. Parallel to the easterly plunging fold axes there is a marked mineral lineation.

Gneisses.

The gneisses show considerable variations both in composition and in structure. There are generally no distinct boundaries between the different types, gradational boundaries being ubiquitous. In places the rock has the character of a migmatite, granitic veins are common, and in addition to an irregular porphyroblastesis this makes the rock very inhomogeneous.

Allowing for some variation the following rock types have been recognized:

a. Granodiorite – granite gneiss.
b. Quartz-diorite gneiss.
c. Granitic bands and lenses in the quartz-diorite gneiss.
d. Augen gneiss.
e. Granite gneiss.
f. Mylonite.

Modal compositions of representative samples from the gneisses are given in Table 1.

The texture of the gneisses is granoblastic-lepidoblastic, even-grained and fine- to medium-grained, apart from the augen gneisses where porphyroblasts consisting of one or more feldspar crystals, commonly microcline, are set in a fine- to medium-grained matrix. In all the gneisses cataclastic features such as fractured mineral grains and bent twin lamellae in plagioclase are common. In the augen gneisses, textural features are indicative of one post-porphyroblastic and possibly one pre-porphyroblastic deformation (Fig. 2). The mylonites have a cataclastic texture with varying amounts of cataclasts (usually feldspar) in a fine-grained matrix (Fig. 4), often with a distinct planar structure.

Granodiorite – granite gneiss.

This rock-type makes up most of the southern gneiss area and is bordered to the west and south-east by the sea, to the north by the gabbroic body or via an augen gneiss which grades into the granitic gneisses near the gabbro.

The rock is a fine- to medium-grained, light grey or reddish, foliated gneiss which in places shows a faint small-scale banding. Dark, concordant bands and lenses rich in amphibole or biotite also occur, their thickness varying from a few cm to about thirty cm. In part the gneiss is migmatitic with numerous light-coloured veins and schlieren, commonly

Table 1. Modal composition of the gneisses.

	Granodiorite — granite gneiss					Quartz diorite gneiss					Augen gneiss				Granite gneiss
Sample no.	101	223	230	231	239	244	248	275	280	281	323	235	*	341	84
Quartz	35,8	23,4	25,2	29,3	18,9	24,5	23,5	22,1	19,2	14,3	17,2	25,0	25,0	36,0	29,4
K-feldspar	29,2	10,3	30,5	45,7	8,5	5,4	—	—	11,0	5,4	—	9,5	22,0	37,8	34,2
Plagioclase	23,4	56,8	39,2	20,4	48,5	48,0	43,9	44,8	42,1	39,8	47,9	38,8	36,5	18,6	23,7
Biotite	7,5	6,8	3,1	1,6	11,4	19,8	15,2	28,1	23,6	x	x	17,0	9,6	4,8	9,6
Muscovite	—	—	—	—	—	1,5	12,8	—	—	—	—	—	—	x	x
Amphibole ...	2,0	1,2	—	x	9,2	—	—	x	1,0	20,2	33,1	x	4,5	—	—
Epidote-min. ..	x	x	x	1,4	1,1	—	—	2,5	1,3	8,3	x	3,1	1,0	1,6	x
Garnet	—	—	—	—	—	—	—	x	x	—	—	4,0	—	—	—
Chlorite	x	x	x	1,3	x	x	4,4	x	x	9,0	1,2	x	x	x	x
Sphene	x	x	1,8	x	x	—	—	1,0	1,0	x	x	1,8	1,1	x	x
Zircon	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Apatite	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Calcite	x	x	x	—	x	—	—	—	—	—	—	x	—	—	—
Ore min.	x	x	x	—	x	x	x	x	x	x	x	x	—	—	x
Plagioclase composition per cent An. ..	23	24	23	21	26	23	25	37	23	25	33	23	21	18	12

* = sample and thin section no. I Bb IV 14, from the collections at Geologisk institutt, Bergen.
x = minor amounts (< 1 %).
— = not observed.

strongly folded. In the most strongly folded parts and near the gabbroic pluton and the granite gneiss, a more or less distinct augen gneiss is developed.

The modal compositions given in Table 1 show a range from granodiorite to granite.

Quartz-diorite gneiss.

This lithology occurs in the western part of the north-eastern gneiss area, bordered to the west by the gabbroic/quartz dioritic pluton and the sea, while to the east it grades into the augen gneiss through an irregular transition zone. Near the contact with the basic rock a porphyroblast gneiss zone is partly developed, together with some coarse granite dykes.

The rock is even-grained, fine- to medium-grained, and well foliated. The modal compositions given in Table 1 are quartz dioritic, and the colour index is relatively high, near 30. While, in general, biotite is the dominating mafic mineral, one variety is characterized by amphibole. The amphibole gneiss is most widespread in the northern part, south of Ingersvatn; it is also found further south, but seems not to form a continuous zone.

Granitic bands and lenses in the quartz-diorite gneiss.

Many bands and lenses of granitic composition occur in the quartz-diorite gneiss; the bands are especially abundant in the east, while the lenses occur in the strongly folded north-western part. The shapes of the lenses are governed by the structure of the gneiss; they are often folded and have their longest dimension parallel to the fold axes.

The texture is even-grained, medium-grained, granoblastic often with strongly developed post-crystalline cataclastic features. The modal composition is granitic with quartz, microcline and plagioclase as essential minerals, and with minor amounts of biotite, epidote, chlorite, sphene, zircon, apatite and hematite. The plagioclase is saussuritized, the present composition varying from An 4 to An 14 and the most calcic occurring in the concordant bands to the east.

Augen gneiss.

The augen gneisses dominate the eastern part of the northern gneiss area, but are very inhomogeneously developed with transitions to dark

Fig. 1. — Dark augen gneiss with quartz dioritic matrix.

quartz-diorite gneisses containing granitic bands similar to those further west. There are also many small mylonite zones in the rock.

The augen gneiss is a foliated, porphyroblastic rock with greyish white or reddish feldspar augen set in a medium- to fine-grained biotite-bearing matrix. The amount of dark minerals and the abundance of augen varies greatly. The size of the augen ranges up to 4 cm (Fig. 1+2).

The modal composition of the representative samples given in Table 1 ranges from granodioritic to granitic.

Granite gneiss.

Along the southern border of the basic pluton granite gneisses occur from Klampevika to Hetlevik, (Fig. 3), interrupted in some places by augen gneisses. The granite gneisses often alternate with metagabbro or amphibolite lenses and also occur within the gabbroic pluton.

The rock is a reddish, occasionally greyish, even-grained, medium-grained, well foliated and often slightly banded gneiss of granitic composition (Table 1).

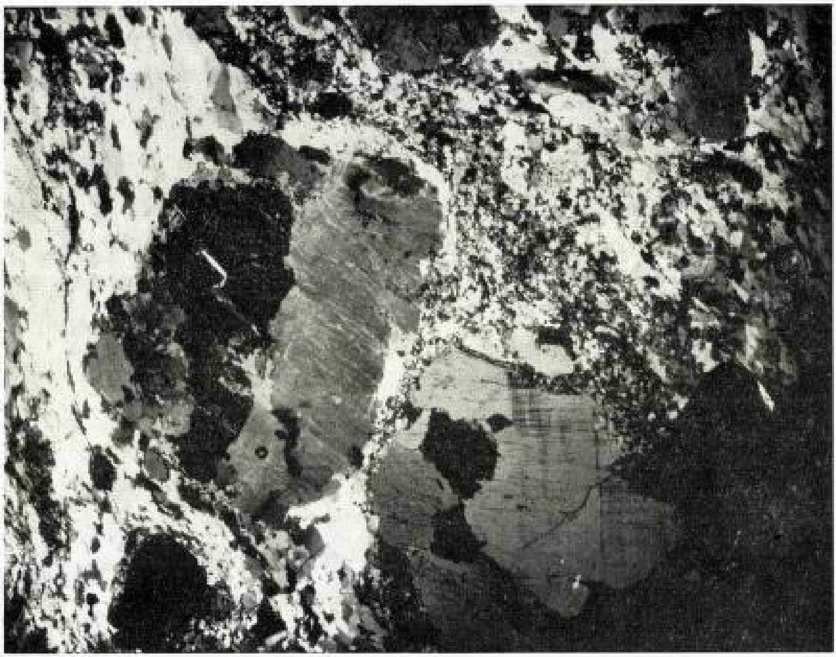

Fig. 2. — Augen gneiss showing post-porphyroblastic cataclasis. Crossed nicols, x13.

Mylonites.

Signs of cataclasis are seen in all parts of the gneiss area, and true mylonites have also been formed in restricted zones.

A wide mylonite zone occurs in the gneisses along Byfjorden from Skarholmen and north-east-wards over Kleppestø. The gneisses are here granodioritic-quartz dioritic in composition. Topographically this zone is very marked. The rocks occurring along the zones are brecciated and mylonitized to varying degrees.

The mylonites proper are commonly flinty, dark green rocks commonly containing small, round feldspar cataclasts (Fig. 4). The rock is usually crossed by numerous thin fissures containing epidote, chlorite, and calcite. Red, fine-grained bands are also very common.

Mineralogy of the gneisses.

Quartz occurs as lenticular aggregates and as single grains and commonly shows undulatory extinction.

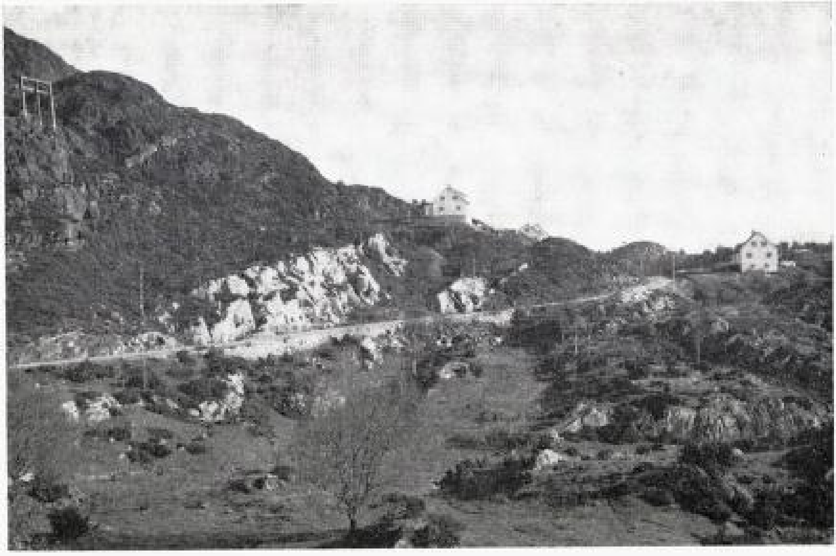

Fig. 3. — Granite gneiss zones in the southern part at the basic pluton.

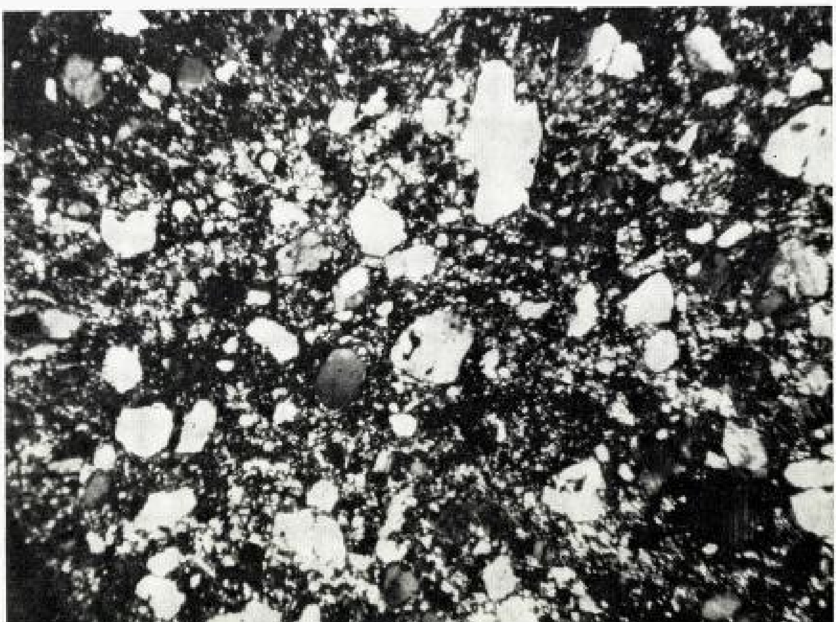

Fig. 4. — Mylonite. Loc.: Klampevika. Crossed nicols, x33.

Microcline cross-hatching is seen in a few of the potassium feldspar grains in all types of gneiss except in the quartz-diorite gneiss. String perthites also occur occasionally. Most of the porphyroblasts in the augen gneisses are microcline.

Plagioclase, commonly weakly saussuritized, has a composition varying within the oligoclase range (Table 1). Twinning according to the albite and pericline laws is common, except in the granite gneiss where the pericline twins seem to be absent.

Biotite, with pleochroism light yellow — brown in the quartz-diorite and granodiorite gneiss, light yellowish brown — olive green in the more granitic gneisses, is a lepidomelane with the highest content of iron in the granitic types. Biotite may be partly altered to chlorite; a supposed transitional stage with a green colour and the birefringence of biotite occurs in some cases (Moorhouse 1959, 84). In the quartz-diorite gneiss the biotite is remarkably rich in allanite-epidote and zircon inclusions, both surronded by dark pleocroic haloes.

The amphibole in the gneisses is a green-coloured common hornblende, although in a granodiorite gneiss in the southern area a bluish green hastingsite is present.

The epidote minerals are commonly zoned, the birefringence and extinction angles indicating an increasing content of iron outwards; the maximum variation in individual epidote grains is from clinozoisite in the core to pistasite with approx. 20 per cent Fe-epidote in the margin, but this range is commonly smaller. In alle the rock-types a yellowish brown allanite is present, frequently mantled by epidote. The allanites are more or less metamictic.

Garnet occurs in a few samples, as does muscovite. Calcite is especially common in the southern gneiss area. Apatite, sphene, chlorite, zircon and ore minerals are the principal accessory constituents. The zircons are generally slightly rounded.

In the mylonite, the plagioclase is saussuritized and has a composition of An 10—17. In part the plagioclase is altered to a zeolite; optical data and an X-ray powder pattern indicate a laumontite. Adularia is also formed and occurs as clear, anhedral grains. Chlorite is present in varying amounts. Zeolite, epidote, chlorite, and sphene occur in the frequent fractures. The red colour of some bands in the mylonite is due to a finely disseminated dust of hematite.

Discussion.

The granoblastic-lepidoblastic textures and distinct mineral lineation suggests that the gneisses were completely recrystallized under metamorphic conditions. Generally, equilibrium seems to have been established by the last main recrystallisation. Based on the mineral composition this main metamorphic event took place under almandine amphibolite facies conditions (Turner & Verhoogen 1960). The chlorite, which at least is partly formed by alteration of biotite and amphibole, is assumed to be a product of retrogressive metamorphism.

The origin of the gneisses is not obvious. No primary textures have been seen. The slightly rounded zircons may, however, indicate a sedimentary origin, but this is inconclusive. The quartz-diorite gneiss, which seems to be the least altered, is of such a homogeneous nature as to make a derivation by metasomatism quite unlikely. The map picture, showing little variation in composition in the direction of strike and the small grain-size make a supracrustal origin appear probable (Moorhouse 1959, 400). The rock may have a volcanic origin, but it may also have been a sediment such as a marly pelite. C. F. Kolderup and N.-H. Kolderup (1940) mention that some of the gneisses further north have textures suggestive of sediments. K. Skeie (1968) assumes the gneisses of northeastern Askøy to be metasediments.

The inhomogeneous nature of the augen gneiss (relics of darker gneisses, large variations in amounts of quartz and K-feldspar) in the northeastern part of the area indicates that metasomatism played a large role in the formation of these rocks.

To the south, metasomatism to a varying degree together with partial migmatisation were instrumental in converting original supracrustal (?) rocks into the granodiorite – granite gneiss.

The granitic bands and lenses in the quartz-diorite gneisses are believed to have been formed either prior to, or more probably during the main folding and metamorphism of the area. The possible cataclasis in the rock before the porphyroblastesis in the augen gneiss may explain why the granitic material here was dispersed throughout this rock-type.

The granite gneiss near to and within the southern part of the gabbroic body is thought to be intrusive, the magma probably originating palingenetically as a result of the high-temperature field near the pluton. The formation of this gneiss, may also be explained by a penetrative recrystallisation of gneiss zones near to or enclosed by the basic rocks. The composition of the gneiss, being more granitic than the others in the area, would, however, favour the former hypothesis. Gribble (1966) reports a similar mobilisation of country rocks near the Haddo House Norite in Aberdeenshire. A similar genesis is also suggested for the porphyroblast gneiss and the granitic dykes at the contact between norite and gneiss east of Kråkås.

The dynamic metamorphism that caused the mylonitisation is a later phase of deformation. It seems rather reasonable to assume that the formation of laumontite and adularia in the mylonite occurred shortly after the cataclasis. These minerals indicate zeolite facies conditions.

Norite/gabbro and metagabbro.

Field relations. — The gabbroic rocks occur in the central and western part of the mapped area. Besides the main body there are also some zones at Hetlevik, separated from each other by bands of gneiss. These may constitute a folded sheet. Minor amphibolite dykes and a saussuritized gabbro dyke occur in the gneisses south and east of the main body and are probably related to the same intrusion. (Rock terms: The terms «norite» and «gabbro» refer to a basic plutonic rock with orthopyroxene and clinopyroxene, respectively, as the main mafic mineral. The term «gabbroic» comprises norite and/or gabbro *sensu stricto*, while the term «metagabbro» is here taken as meaning the metamorphic equivalents of either of these.)

An intrusive quartz diorite occurs in the basic rock as a thick east-west dyke and several smaller dykes, and as layers alternating with metagabbro in the northern part of the pluton. Granite pegmatites and dykes are relatively abundant in the southern and western part of the pluton. The basic rock is commonly amphibolitized near the dykes. Light-coloured, medium-grained quartz-plagioclase veins occur throughout the whole pluton and are thought to be late magmatic differentiates of the gabbroic magma.

The contacts with the surrounding gneisses are entirely concordant. No chilled margins are seen, but the rock is generally amphibolitized near the contact and possible primary features may have been obliterated. The gneisses often show a porphyroblastesis near the contact. East of Kråkås this porphyroblastic gneiss is of a special type; it is inhomogeneous and varies from dark and biotitic to light varieties rich in quartz and microcline. Under the microscope the microcline can often be seen to be replacing plagioclase. The rock is frequently garnetiferous, and

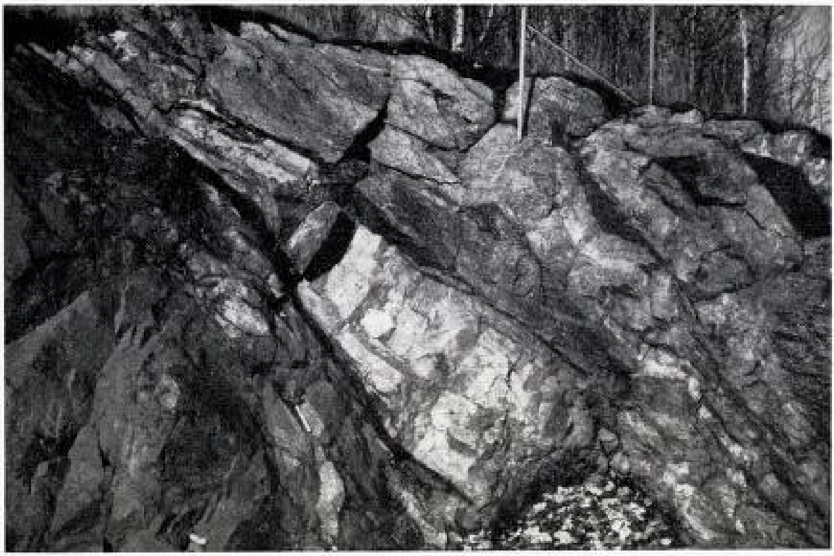

Fig. 5. — The contact norite/gneiss. Uralitized norite to the left, porphyroblast gneiss and pegmatite dykes to the right. Loc.: The yard of the school west of Kleppevatn.

granite and pegmatite dykes are abundant throughout (Fig. 5). The relations of the granite gneisses at the southern and south-western border of the pluton were described earlier (p. 9).

At the south-eastern border, near Kleppestø, no signs of a metamorphism which could possibly be related to the intrusion of the gabbroic pluton are seen in the gneiss. The quartz diorite dyke in the pluton seems to be truncated by the gneiss. This may indicate that the contact here is tectonic.

Alteration. – Most of the gabbroic rocks are altered and metamorphosed to varying degrees, indicated by uralitisation of pyroxenes, saussuritisation of plagioclase or complete recrystallisation of the rock. These various types grade into each other, and their distribution is rather irregular. The map shows the general distribution of the rock-types, but within each zone there may be gradations into patches of the other types.

Petrography of norite/gabbro.

The rock is dark brownish green in colour with dark violet-grey plagioclase and dark brownish green pyroxenes. Minor amounts of black

Table 2. Modal and mineral compositions of norite/gabbro.

Sample no.	292	293	11	Gb. 1, 3 *	Gb. 1, 5 *	179	221
Locality	WSW of Brenne-klubben	Brenne-klubben	Kråkås	Skogen	Hetle-vik	NE of Dyrdals-fjell	W of Struss-hamns-vatn
Quartz	—	0.2	1.0	—	—	—	—
Plagioclase ..	60.1	60.8	61.0	61.4	60.0	43.2	43.1
Orthopyroxene	31.6	30.4	30.0	32.2	28.7	8.4	3.5
Clinopyroxene	6.6	4.1	5.0	5.2	8.0	32.7	39.0
Ore minerals ..	0.6	2.5	1.5	0.3	1.3	10.6	12.0
Biotite	1.1	1.0	1.5	1.0	2.0	3.3	1.6
Apatite	—	1.0	x	—	—	x	—
Garnet	—	—	—	—	—	1.8	0.8
Plagioclase composition[1])	An 60	An 54	An 55	An 59	An 53	An 55	An 54
Orthopyroxene Composition[1])	En 72	En 68	En 70			En 69	En 68
Clinopyroxene composition[1])	Ca 42 Mg 44 Fe 14	Ca 41 Mg 39 Fe 20	Ca 41 Mg 40 Fe 19			Ca 41 Mg 40 Fe 19	Ca 41 Mg 39 Fe 20

x = minor amounts (< 1 %)
— = not observed
* = samples and thin-sections from the collections at Geologisk institutt, Bergen
[1]) Optical determinations.

ore minerals and biotite may be seen. The grain size varies from fine- to medium-grained, the latter predominating, and the lath-shaped feldspars being the largest grains. The grain size may be constant over large areas, but in places fine-grained patches and schlieren occur in the medium-grained rock.

Igneous lamination, generally indistinct, resulting from an alignment of platy minerals, especially feldspar laths but also pyroxenes, can be seen in patches within the whole area of unrecrystallized gabbroic rock. The lamination is not developed in all specimens and may also be difficult to detect. Where present the fine-grained schlieren are parallel to the lamination. The orientation of the lamination is shown on the map.

The modal composition of a representative selection of thin-sections of the gabbroic rocks is given in Table 2. According to the relative amounts of pyroxenes, both norite and gabbro are present. Samples with equal amounts of orthopyroxene and clinopyroxene have not been found.

Leuco-norite. — About 200 m north-west of Follesevatn a small outcrop of uralitizezd leuco-norite occurs in a poorly exposed area, surrounded by amphibolites. The leuco-norite consists of about 75 per cent plagioclase (An 50), uralitized pyroxenes (the uralite formed from clinopyroxene contains varying amounts of fine-grained opaque inclusions), and minor amounts of biotite, ore minerals, apatite and garnet.

Because of the alteration the relative amounts and distribution of the rock-types is not known, but norite seems to predominate in the pluton with gabbro occurring mainly in the eastern central part and the leuco-norite present only north-west of Follesvatn.

Partial chemical analyses were carried out on a gabbro (Sample no. 179) and a norite (Sample no. 293):

	SiO_2	Al_2O_3	FeO Total	MgO	CaO	K_2O	Na_2O	Total
Norite	51.95	15.22	11.10	10.21	6.94	0.52	2.44	98.38
Gabbro	44.93	14.74	18.47	6.77	9.86	0.40	2.62	97.79

The essential differences are that the norite is higher in silica and magnesium while the gabbro is higher in iron, calcium and sodium.

Textures. — The rocks are hypidiomorphic-granular with a seriate fabric where the size of the crystals in the medium-grained rock ranges from 10 mm to less than 0.1 mm; in the fine-grained rock the range is smaller. Igneous lamination is prominent in many samples (Fig. 6). Examination of a thin-section cut parallel to the lamination reveals a weakly developed linear parallelism. The fine-grained schlieren have uneven outlines, but are oriented parallel to the lamination (Fig. 7). Weak protoclastic features such as healed breccia-like textures and plagioclase-twin lamellae are often seen. Narrow kelyphitic rims around mafic minerals are common. Chlorite is formed along fractures and joints.

Mineralogy.

Quartz occurs as small interstitial grains in a few of the norite samples.

Plagioclase forms hypidiomorphic or allotriomorphic grains reaching 10 mm in length. The grains are generally flattened parallel to (010). Where in ophitic intergrowth with augite plagioclase may show very well

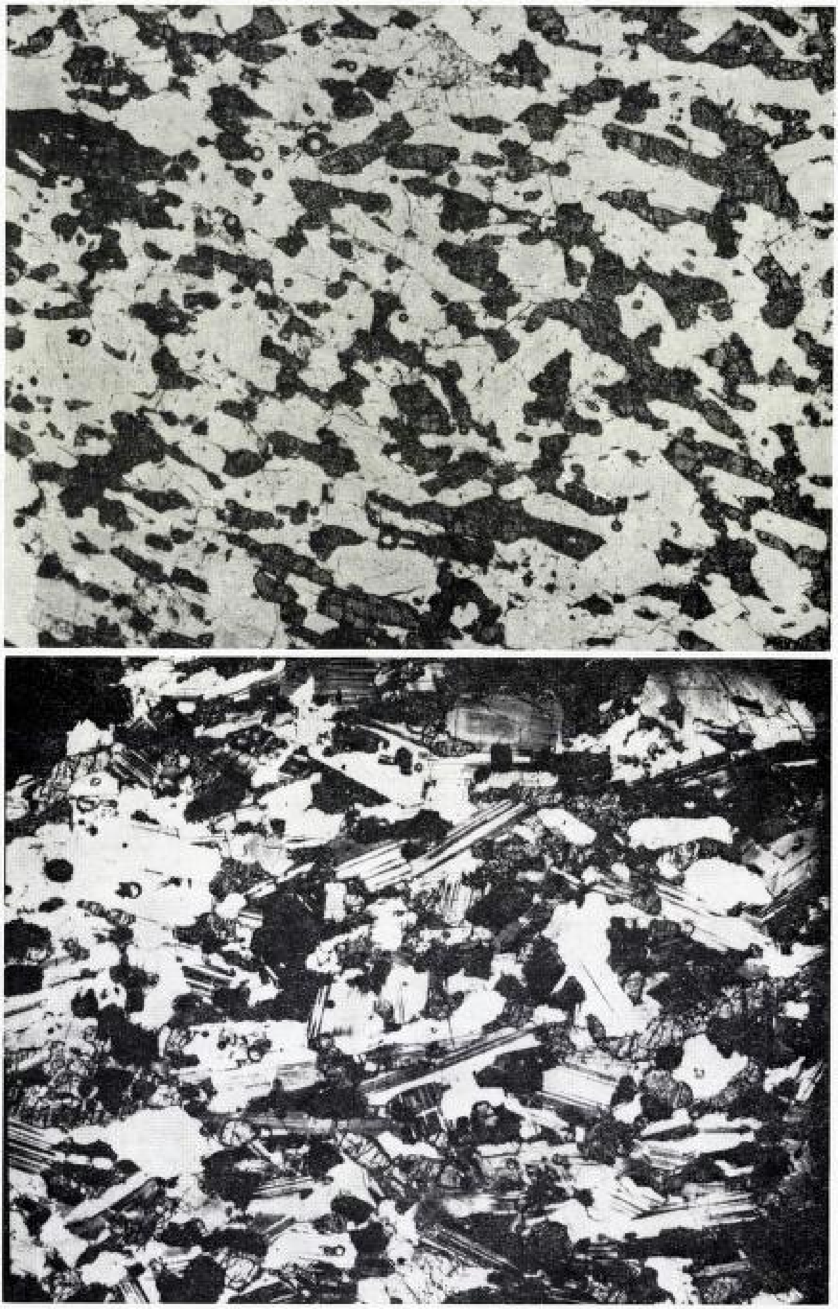

Fig. 6. — Norite. Igneous lamination.
a) plane polarised light, x13. b) crossed nicols, x13.

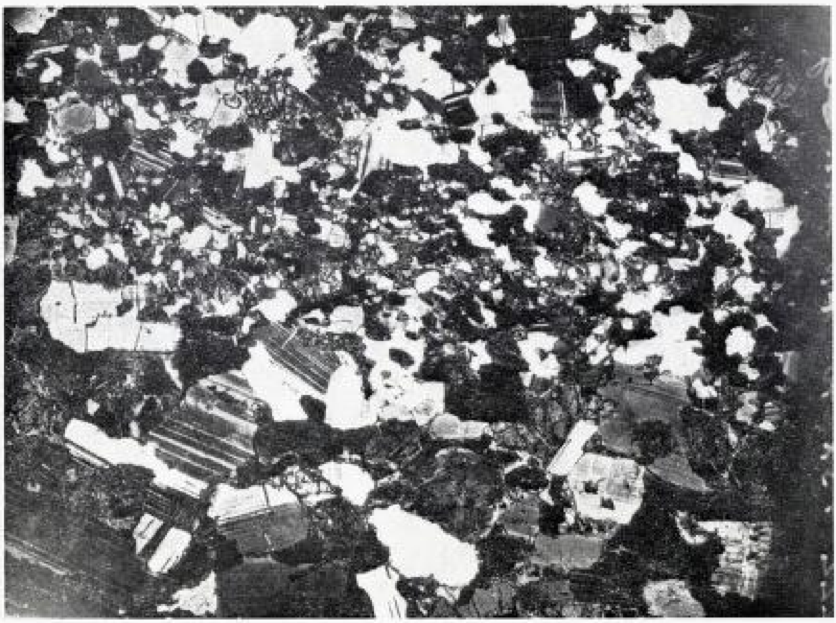

Fig. 7. — Fine-grained schlieren in gabbro.
Crossed nicols, x13.

developed crystals. Twinning according to albite-, pericline-, Carlsbad-, and Manebach laws is common. Clouding, consisting of a finely disseminated opaque dust throughout the whole grains and oriented needles of rutile in the inner parts of the grains, is frequently seen; such feldspars appear brownish grey microscopically. The composition of the plagioclase as determined by universal stage methods is given in Table 2 and ranges from An 60 to An 50. Zoning is weak or absent.

Pyroxenes. – Both orthopyroxene and clinopyroxene occurs in all examined thin-sections.

Orthopyroxene commonly has the shape of rounded hypidiomorphic grains elongate parallel to (001) and flattened parallel to (100), reaching a length of 4 mm and a thickness of 0.5 mm. The outlines of the grains suggest corrosion of the orthopyroxene; this is especially evident where the grain is enclosed in clinopyroxene. The orthopyroxene is almost colourless with a faint pink pleochroism. Evenly distributed, thin, flaky, brown inclusions oriented parallel to (100), and thought to be ilmenite (Freund 1955), are present in all the orthopyroxenes, together with an unidentified dust which clouds the grains. In the vicinity of cracks an

Fig. 8. — Orthopyroxene with clinopyroxene exsolution lamellae. Uralite along cracks. Crossed nicols, x120.

opaque dust can often be observed. The composition of the orthopyroxene determined by refractive index n_z and optic angle is given in Table 2, and according to these data it ranges from bronzite En 72 to hypersthene En 68.

The clinopyroxene is present in allotriomorphic grains. In the gabbro, which contains abundant clinopyroxene, it tends towards hypidiomorphic, flat and elongate grains reaching 3 mm in length while in the norite it forms larger poikilitic grains enclosing orthopyroxene, ore minerals, and plagioclase. The colour is light green and the mineral is pleochroic. Evenly distributed small ilmenite flakes are common, and a fine dust causes clouding. Twinning on (100) is seen. The composition of the clinopyroxene determined by measurements of optic angle, extinction angle, birefringence, and refractive index n_y, is given in Table 2 and is indicative of a diopsidic augite with some variation. A secondary clinopyroxene almost devoid of inclusions is seen at the margin of some orthopyroxenes.

Exsolution lamellae are developed in both the pyroxenes parallel to (100) of the host crystal (Fig. 8, 9). Besides, small exsolution blebs

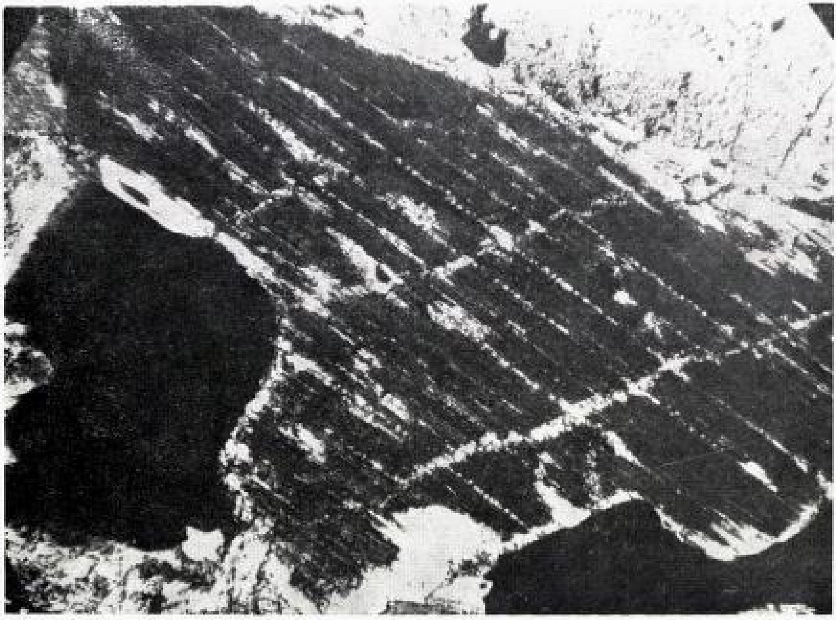

Fig. 9. — Clinopyroxene with orthopyroxene exsolution blebs and lamellae. Crossed nicols, x120.

whose optical properties coincide with the lamellae are sometimes seen. Near the margin of some clinopyroxene grains small flakes of dark ore minerals occur on the (001) plane. Pyroxene lamellae along this plane cannot be seen.

Ore minerals. — Magnetite is the dominating ore mineral both in gabbro and norite. It occurs both interstitial to other minerals and as equidimensional grains up to 2 mm. Exsolution lamellae could not be detected under the ore microscope. Pyrite occurs as a few, small, allotriomorphic grains in the rock and along narrow fractures.

Biotite is present with varying frequency, closely associated with magnetite which it often encloses more or less completely. The pleochroism is light yellow — reddish brown, which together with the determined optic angle and refractive index n_γ indicates a titaniferous meroxene with 40—50 per cent iron end member.

Apatite forms partly hypidiomorphic, partly interstitial, allotriomorphic grains.

Zircon occurs commonly as inclusions in biotite, producing dark, pleochroic haloes in the latter.

Late stage minerals. – Even the least altered norites and gabbros show late stage minerals in rims around the mafic minerals. As the same reaction rims may also result from metamorphic events it is not possible to decide exactly whether these are the result of deuteric reactions or of metamorphic processes.

Amphibole is always present at the pyroxene-plagioclase boundaries as narrow rims of fibrous amphibole, a few μ thick. Light green colour, (strongest colours near the plagioclase), pleochroism, extinction angle and birefringence indicate an actinolitic hornblende. Bordering the clinopyroxene an unidentified, colourless, narrow zone of lower relief occurs just inside the amphibole. Amphibole fringes are also seen at other grain boundaries such as plagioclase-magnetite, between pyroxenes and around apatite.

Garnet, idiomorphic to allotriomorphic, may occur in zones around magnetite. These zones often consist of an inner biotite rim and outer amphibole rim, but all combinations of biotite, amphibole, and garnet, apparently distributed non-systematically in relation to each other and to magnetite and plagioclase, may be seen.

Amphibole-plagioclase symplectite. – In relatively unaltered specimens a symplectite of one main mineral with myrmekite-like rods of another mineral occur in lobate forms in plagioclase at the junction with another plagioclase grain, or as round clots within plagioclase grains which often show fractures. The symplectite is commonly less than 0.5 mm across. The main mineral, based on colour, relief and birefringence, appears to be an amphibole. The vermicular rods, commonly a few μ thick, in places are seen to consist of plagioclase with twin lamellae and optical orientation coinciding with the enclosing plagioclase. A gradual transition is seen from a symplectite with very thin plagioclase rods to an amphibole almost free of inclusions. In places tiny flakes of biotite occur within or adjacent to the symplectite.

An unidentified symplectite at the junction of uralite rims and plagioclase is seen in one thinsection. It consists of thin, straight rods, possibly quartz and plagioclase, oriented at a right angle to the junction.

Light-coloured veins.

Thin, light-coloured, medium-grained veins consisting of about 30 per cent quartz, 65 per cent plagioclase (An 27), and minor amounts of biotite, magnetite, apatite, zircon, schorlite and chlorite occur in the basic rock; they are thought to be late magmatic.

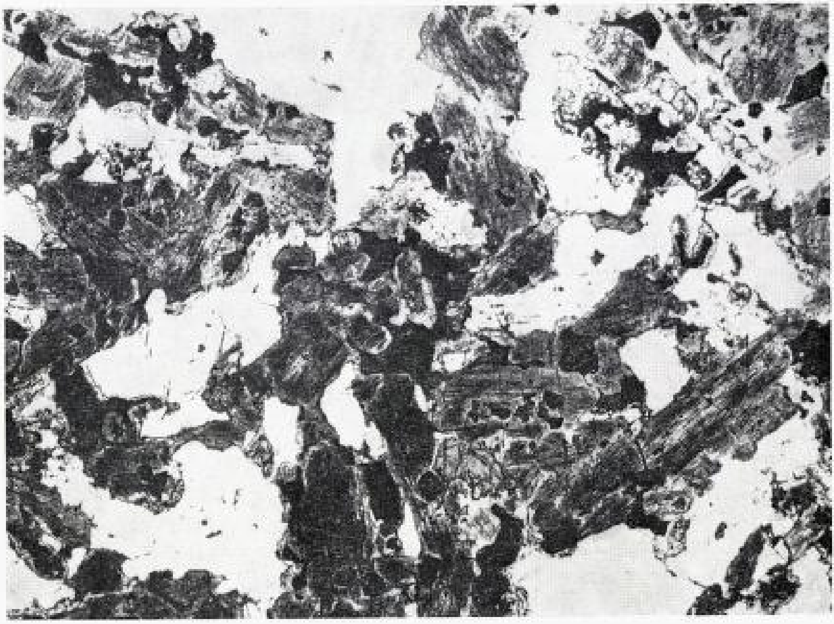

Fig. 10. — Inhomogeneous uralitized gabbro. Plane polarised light, x33.

Petrography of the metagabbro.

The main steps in the alteration and metamorphism of the basic rocks of southern Askøy are uralitisation, saussuritisation and ultimately a recrystallisation of the entire rock.

Macroscopically the uralitisation is indicated by the appearance of a green amphibole instead of pyroxene, giving the rock a distinctive green colour, but with no essential changes in the texture. Saussuritisation is indicated by a light greyish green plagioclase. The ultimate recrystallisation has produced an amphibolitic metagabbro, in a few cases garnetiferous. The amphibolites in Askøy are commonly foliated, folded and lineated parallel to the structures in the gneisses, but isolated patches of amphibolite within areas of unrecrystallized rock may be massive.

Under the microscope the rock may show a very inhomogeneous alteration, especially in the uralitized and saussuritized varieties.

The uralitisation shows gradations from narrow kelyphitic rims to completely altered pyroxenes (Fig. 10). The amphibole fibres grow from the margin, especially at the ends of the pyroxene crystals, but also from cracks within the pyroxenes. As the alteration proceeds the almost

Fig. 11. — Uralitized norite. Amphibole is also formed at boundaries between plagioclase crystals (upper right). Plane polarised light, x33.

colourless fibrous amphibole aggregates become darker green, pleochroic, and eventually recrystallize to amphiboles with distinct cleavage, occasionally twinned. The opaque dust and brown ilmenite flakes survive tre first stage of uralitisation, but later disappear.

Orthopyroxene is more easily altered than clinopyroxene, the latter often being only slightly transformed while orthopyroxenes may be completely altered. It has not been possible by optical methods to make out any differences between the uralite products from the two types of pyroxene, but at the same time the data are insufficient to conclude that they are identical. The large optic angles, together with refractive indices, extinction angles and pleochroism indicate an actinolitic hornblende.

Morphologically the uralite aggregate resembles the shape of pyroxene, but has very often grown at the expense of the plagioclase. Amphibole fibres are also formed at grain boundaries between plagioclase grains or along cracks in the crystals (Fig. 11). Biotite flakes are sometimes seen within the uralite aggregate, especially in rocks near the granite zones.

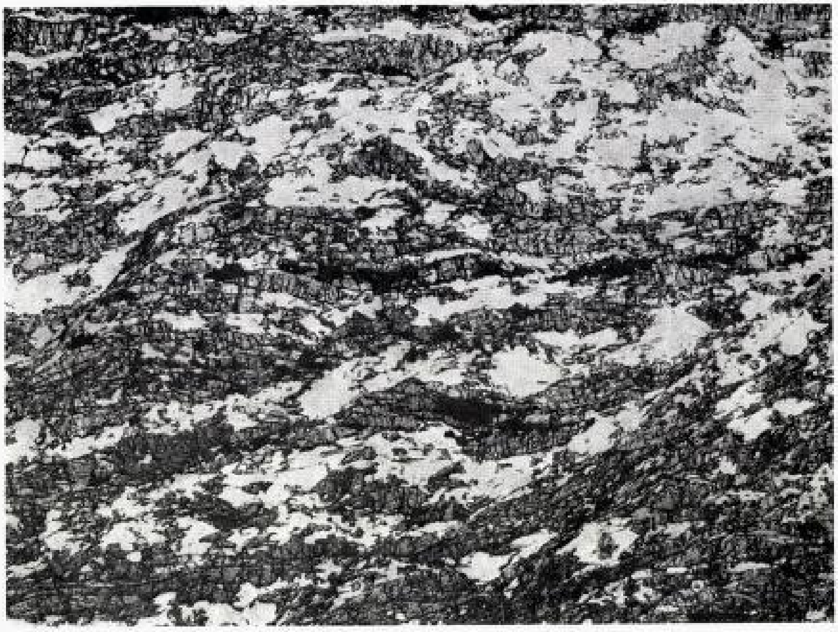

Fig. 12. — Amphibolite (metagabbro) consisting essentially of plagioclase, hornblende and minor amounts of ore minerals. Section normal to the foliation, parallel to the lineation. Plane polarised light, x33.

During the uralitisation the plagioclase may remain unaltered, though a slight saussuritisation may sometimes occur.

By further alteration of the rock the plagioclase is saussuritized, with fine-grained inclusions of zoisite-clinozoisite, sericite and calcite, the composition of the plagioclase being An 32—34. Biotite and amphibole are also frequently developed in the plagioclase. At this stage the uralite is commonly recrystallized to a poikiloblastic hornblende with inclusions of plagioclase, epidote and sphene. Sphene occurs in colourless grains, but also in faint, pleochroic, yellowish brown grains associated with ore minerals and often surrounded by colourless sphene. The brownish sphene is supposed to be rich in iron (Deer, Howie, Zussman 1963). Minor amounts of a light green chlorite and of hematite are also formed.

The amphibolites resulting from a penetrative recrystallisation have the same mineralogy as the saussuritized gabbros and norites and consist essentially of equal amounts of plagioclase (An 33) and hornblende with accessory amounts of sphene, epidote, biotite, quartz, chlorite, garnet, apatite and ore minerals. The texture is anhedral, even-grained, fine- to medium-grained with generally a pronounced foliation and lineation of minerals and mineral aggregates (Fig. 12). The grain size varies and fine-grained and medium-grained types may be intimately intermingled.

Kyanite aggregates in metagabbro.

In an amphibolite within the norite at Kråkås kyanite aggregates have been found. The amphibolite is fine-grained with a distinct lineation and has the same composition as the other amphibolitic metagabbros. The kyanite aggregates attain diameters of more than 10 cm and consist of kyanite crystals up to 3 cm in length. The colour of the kyanite is light greenish blue, often with a darker blue band in the middle. Under the microscope the kyanite is seen to be partly altered to foliated, fine-grained aggregates of a light-coloured muscovite-like mica thought to be damourite (Deer, Howie, Zussman 1963), and to small flakes of a mineral with high birefringence and optic angle about 60°, which is probably pyrophyllite.

Discussion.

The gabbroic rocks form a concordant, thick, lens-shaped intrusive body somewhat modified by a later intrusion of quartz diorite and by folding (see geological sections, Fig. 16). The lack of chilled margins together with the porphyroblastesis and possibly partial anatexis in the gneisses indicate that the gabbroic pluton was intruded into a region of high temperature conditions. The relations between the quartz diorite dyke and the gneisses to the east suggest that the border of the pluton, there at least, is tectonic. The lack of cataclasis may be explained by plastic behaviour of the rocks during the movement.

Although partly altered the pluton seems to consist mainly of norite with gabbro in the eastern central part and leuco-norite in a minor area north-west of Follesvatn. This may be explained as resulting from a differentiation of the magma, but may also be a result of injection of magmas of different composition.

The textures provide no definite evidence as to whether solidification of the rock was a accompanied by crystal settling, and it is therefore difficult to decide whether or not the rock should be regarded as a cumulate. It may well be mesocumulate (Wager & Brown 1968) with plagioclase, orthopyroxene, and in part clinopyroxene and magnetite cumulus crystals, but the textures are also consistent with crystallisation of a magma with the same primocrysts, but without pronounced crystal settling.

No visible layering is seen in the pluton. As to cryptic layering, the most calcic plagioclase and pyroxenes highest in magnesium occur in norites near the southern margin while the plagioclase in the leuconorite is the most calcium-poor of the non-saussuritized plagioclases.

The densities of pyroxene and plagioclase are about 0.7 and 0.1 respectively higher than that of the magma, and these minerals should therefore be expected to sink. The larger size of the plagioclase crystals would perhaps approximately balance the greater density of the pyroxene, giving about the same sinking velocity (Hess 1956). The corroded outlines of some pyroxenes might then be due to partial resorbtion of crystals sinking through hotter parts of the magma (Jaeger 1968).

Igneous lamination, which is weakly developed in patches in all parts of the unrecrystallized norite/gabbro area, is commonly explained as being the result of settling crystals being oriented by convective currents in the magma (Grout 1918, Wager & Brown 1968, Wager 1968). Wager writes: «Similar textures might be produced by other means, for example by the flow of a crystal mush subjected to shearing stress, but the writer believes that in rocks produced by crystal settling the cause of igneous lamination is usually convective flow of the magma.» In layered igneous rocks the igneous lamination, if present, is always parallel to the layering.

The orientation of the igneous lamination in the pluton is shown on the map. Especially in the central and eastern parts the lamination is steep, up to 75°. With a tentative rotation of the whole body about 30° eastwards, to a position giving the lowest angle of dip, the lamination would dip maximum 45°. The various parts of the unrecrystallized body do not seem to have been mutually folded or rotated, even though it is cut by the quartz diorite and poossibly by faults.

In most basic layered intrusions the evidence suggests that layering resulting from crystal settling was close to the horizontal at the time of formation (Wager & Brown 1968). On the other hand, in the Skye ultrabasic layered intrusion the layering dips at 45°; there is some doubt whether this is the original dip or whether it has been induced by central subsidence and relative movements of large masses of earlyformed cumulates either during or after the settling of the crystals (Wager & Brown 1968). In the Narssaq-Tugtutôq olivine gabbro dykes in Greenland, certain sections possess a synformal structure as indicated either by banding or by the feldspar orientation or by both of these features. The maximum dip of the structural elements does not normally exceed 45° (Upton 1961). These rocks are belived to be cumulates.

Igneous lamination has also been described from other rocks, as for example some syenites in Greenland. In the Kûngnât syenites the layering and the igneous lamination dip at angles normally not exceeding ca. 40° in the western part and ca. 50° in the eastern part, and are believed to have been formed by crystal settling from a convecting magma, especially peripherally near the foot of the wall where the velocity was reduced (Upton 1960). In the Kangerdlugssuaq quartz syenite-feldspathoidal syenites a platy parallelism of tabular feldspar is found in certain places, dipping inwards at about 30°–60°, and is belived to have resulted from the deposition of the crystals on the successive, inwardly inclined top surfaces of already solid material, by the flowing of magma parallel to those surfaces (Wager & Brown 1968). In the Grønnedal-Íka nepheline syenite and carbonatite the lamination of the syenites commonly dips inwards between 0° and 70°, and the whole group of layered rocks is believed to be result of crystal settling (Emeleus 1964).

Based on the difference between the common low-angle dip of layering and lamination in basic rocks and the more steeply inclined structures of syenites and nepheline syenites, Emeleus (1964) discusses the factors affecting the stability of inclined layers: the viscosity of the magma, the density contrasts between the magma and the cumulus phase, and the rate of deposition of the cumulus phase in relation to the rapidity of crystallisation of the intercumulus liquid. Emeleus regards the syenite magma as probably being more viscous than basaltic magma, but Wager & Brown (1968) suspect that the viscosity is important only in so far as it concerns the occurrence of vigorous convection. The density contrasts and the rapidity of crystallisation of the intercumulus liquid are highly important factors for the stability of the sloping cumulate.

In the Askøy pluton the poor development of igneous lamination suggests very weak convective currents, and this could be a favourable factor for peripheral accumulation at the bottom of the magma chamber and lead to a high dip of the cumulate. The relatively high viscosity indicated by weak currents might cause a low settling rate and therefore a correspondingly high rate of crystallisation of the intercumulus liquid to cement the cumulate. A dip of the lamination very often near the maximum slope does not seem unreasonable although no slump structures have been found.

The steep lamination in the eastern parts with dip angles reaching 70°–75° may be explained by a post-consolidation tilting of the pluton about 30° westwards, the primary maximum dip would then have been about 45°; alternatively it may be explained by subsidence and movement of large masses of cumulate during or after the settling, as proposed by Wager & Brown (1968) for the Skye intrusion. During the crystallisation a differentiation probably took place, giving rise to the variation in rock-types. The fine-grained schlieren and patches are believed to be earlier crystallized rock from the top of the magma chamber possibly broken up by movements.

The kyanite aggregates found at Kråkås are thought to be metaxenoliths. The grain size and abundance of kyanite, and the fact that it is not found elsewhere in the rock, makes it unlikely that it is an ordinary mineral of the rock, primary or secondary.

The pyroxene exsolution lamellae parallel to (100) of the host crystal indicate exsolution temperatures below the pigeonite inversion line (Poldervaart & Hess 1951). The exsolution blebs seen in some thin-sections may be exsolved just above the inversion temperature (Wager & Brown 1968). This seems highly probably with minerals of the present composition.

The formation of biotite as a late stage mineral associated with magnetite is a feature described by many authors. The kelyphitic rims are also quite ordinary, but the distribution of the minerals in concentric zones is, however, not very pronounced.

The amphibole-plagioclase symplectite seems identical to that described by Sederholm (1916) and is undoubtedly of deuteric origin.

The texture and mineralogy of the amphibolites which represent the end stage of the metagabbro series in Askøy, indicates that equilibrium was reached under amphibolite facies conditions. The inhomogeneity of the alteration seen in many of the metagabbro samples is supposed to be due to variations in water content during the metamorphism. The location of the most intensely metamorphosed rocks in the southern and northern parts of the body, and the east-west direction of fold axes and lineation in the metagabbro, indicate that the metamorphism occurred under a north-south compression which chiefly affected the northern and southern parts of the pluton and there made an increase in water content possible.

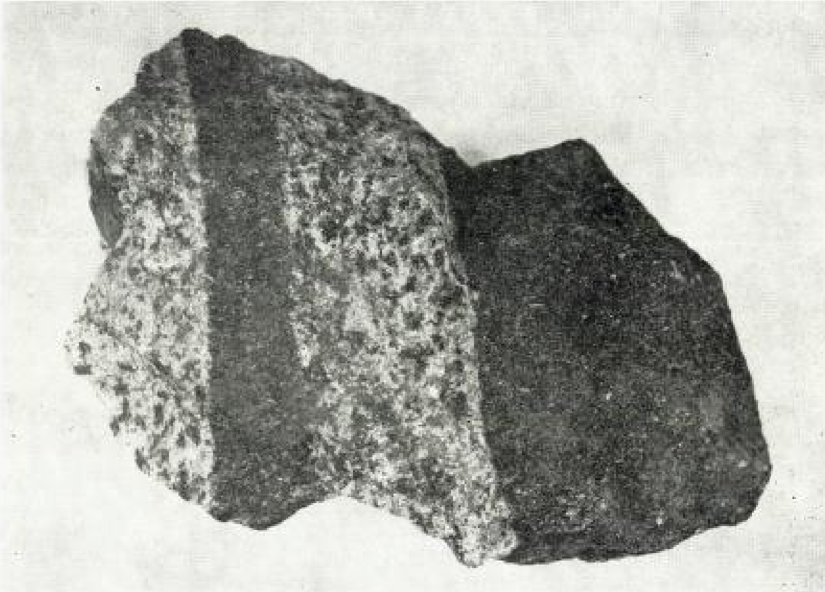

Fig. 13. — Thin quartz diorite dykes in saussuritized gabbro. Natural size.

Quartz diorite.

Field relations. — The quartz diorite occurs in a large east-west-striking dyke and many small dykes in the central part of the basic pluton, and as thick, concordant layers in metagabbro in the northern part.

Except for some of the smallest dykes which are massive (Fig. 13), the rock is weakly foliated and gneissose with generally a northerly strike and a dip of 10°—25° to the east, and a strong lineation parallel to fold axes which plunge at 10°—25° to the east.

Xenoliths of metagabbro are abundant, and together with the igneous breccia at some places near the contact, and the many small dykes, this confirms the intrusive character of the rock. The xenoliths are commonly flattened and elongated parallel to the structures of the quartz diorite.

Partial or complete assimilation of the basic xenoliths to varying degrees has more or less changed the composition of the quartz diorite, in places resulting in a hybrid rock intermediate in composition between the gabbroic and quartz dioritic rocks. Especially in parts of the northern area hybrid rocks rich in diffuse, dark schlieren are common (Fig. 14). The hybrid nature of the rocks, in addition to the scarcity of outcrops

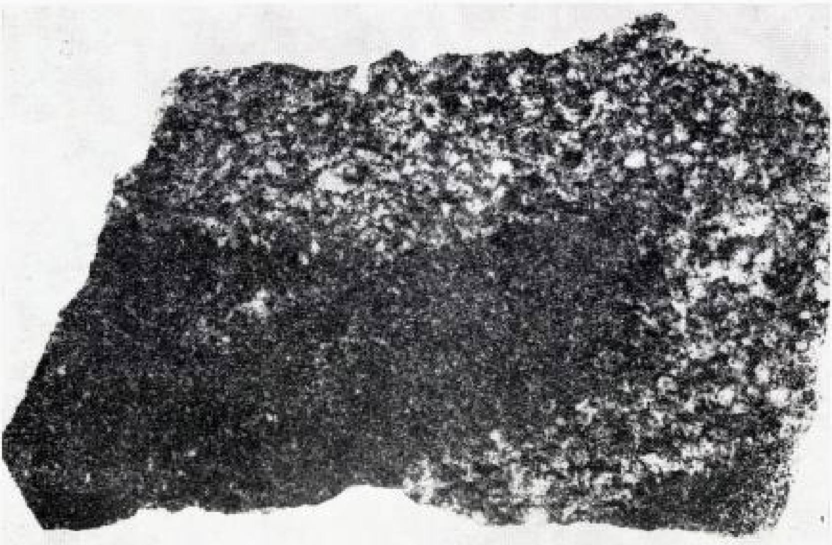

Fig. 14. — Contaminated quartz diorite with basic xenoliths. Natural size.

made a precise mapping difficult and the distribution of the rocks in the northern part of the complex has therefore only been indicated by symbols on the map.

Near Follese, where the quartz diorite forms flat-lying sheets, it also cuts the granitic gneisses which there forms xenoliths within it. Garnets are present 5—10 cm from the gneiss contact.

Petrography.

The quartz diorite is grey-coloured, even-grained, medium-grained with a colour index of 15—20, reaching 40 in the most contaminated varieties in the north. The essential minerals of the rock are greyish quartz, light greenish grey plagioclase, flakes and aggregates of biotite and — in the darker varieties — amphibole.

The texture is allotriomorphic medium-grained, even-grained with the plagioclase grains being a little bigger than the other minerals. Foliation and mineral lineation is well developed in specimens with macroscopic parallel structures.

The modal composition of the rock is given in Table 3. According to these data the rock has a quartz dioritic composition. The varying amounts of potassium feldspar may in places give a granodioritic composition. Partial chemical analyses of a quartz diorite from a small dyke thought to be uncontaminated and of a dark-coloured hybrid rock show that the hybrid rock is intermediate between the gabbroic and quartz dioritic rocks in chemical composition.

Table 3. Modal composition of quartz diorite.

Sample no.	219	122	120	123	126	314	334	318	270	78
Quartz	31.4	28.7	25.5	33.4	29.0	20.7	27.8	21.8	16.2	20.0
K-feldspar ..	—	7.1	13.0	—	—	—	2.0	—	—	—
Plagioclase ..	53.6	48.1	41.6	49.0	53.8	48.3	53.6	52.2	45.1	33.4
Biotite	11.2	10.6	10.4	13.4	11.5	13.7	13.6	2.4	1.5	2.5
Hornblende ..	—	—	—	—	2.0	12.0	—	22.6	34.0	40.6
Hastingsite ..	—	3.1	7.2	—	x	—	—	—	—	—
Sphene	—	1.7	1.8	x	x	x	x	x	x	x
Ore min.	1.8	x	x	2.0	1.2	—	—	x	x	x
Epidote min. .	x	x	x	x	x	3.6	2.8	x	x	2.2
Garnet	x	x	—	2.0	1.7	—	—	—	—	—
Zircon	x	x	x	x	x	x	x	x	x	x
Apatite	x	x	x	x	x	x	x	x	x	x
Chlorite	x	x	x	x	x	x	x	x	x	x

x = minor amounts, ($< 1\ \%$).
— = not observed.
Sample no. 219 is from a small dyke within the pluton; nos. 122, 120, 123, 126 are from the large east-west dyke; nos. 314, 334, 318, 270, 78 are from the northern area, showing varying degrees of contamination.

The metagabbro xenoliths are partly or wholly biotitized and may also be more or less assimilated. They commonly weather more easily than the quartz diorite and often produce a pitted weathering surface.

Mineralogy. — Quartz forms allotriomorphic grains with undulatory extinction, very often as lens-shaped aggregates.

Potassium feldspar, allotriomorphic, sometimes perthitic, only occasionally shows weak and incomplete microcline twinning.

Plagioclase, allotriomorphic, has a grain size of less than 3 mm. It is commonly slightly saussuritized, and is also clouded by a finely disseminated opaque dust. Twinning according to the albite-, pericline-, and Carlsbad laws are common. The larger grains have inclusions of amphibole, biotite, epidote, ore minerals, chlorite and apatite. Myrmekite occurs in some specimens. The plagioclase is often zoned, the composition being An 26—28 in the core and An 24 in the margin. In the darkest hybrid rocks the plagioclase is more calcic, reaching An 34.

Biotite occurs as small single flakes and as aggregates. The pleochroism is light yellow — dark brown. Biotite is often associated with magnetite.

Two amphiboles have been identified: a green common hornblende and a bluish green hastingsite. Hornblende occurs in the darker rocks while hastingsite is found in the light-coloured types.

The epidote minerals are epidote and allanite. Allanite is often surrounded by a rim of epidote. The epidote is commonly zoned with about 12 per cent Fe-epidote in the core increasing to 20 per cent in the rim.

Minor amounts of sphene, zircon, apatite, chlorite, calcite, garnet and magnetite are commonly present.

Discussion.

The quartz diorite is younger than the basic pluton, into which it was intruded possibly under stress. The foliation and lineation in all parts of the quartz diorite, except in some of the small dykes and parts near the border of the east-west dyke, indicate that the north-south compression which gave rise to the folding was in operation during or after the intrusion.

The mineral composition of the rock indicates equilibrium under almandine amphibolite facies conditions, while the zonar structure of the epidote may be a result of retrogressive metamorphism (Miyashiro and Seki 1958).

The variation in modal composition is explained by an assimilation of the metagabbro xenoliths which in the field is seen to have been most effective in the northern part. The reason for this may be the greater total thickness of the quartz dioritic rocks there which caused a slower cooling and consolidation and therefore more favourable conditions for assimilation.

Dykes.

Small amphibolite dykes and lenses are rather common in the southern gneisses. North-east of Klampevika a saussuritized gabbro dyke occurs in the gneisses. It seems very probable that these basic rocks are related to the same intrusive phase as the larger pluton.

Light-coloured felsic dykes, both medium-grained aplites and coarse-grained pegmatites, occur in all main groups of rocks.

Vein minerals.

Minerals are usually absent along joints in the gneisses, but in some cases there is a coating of chlorite, epidote and a little pyrite. At Florvågøen the following minerals were found in joints along the road: calcite, as well developed crystals and as a fine-grained coating; fluorite, as small green cubes, as violet cubelets and fine-grained aggregates alternating with calcite flakes, and as very fine-grained, greyish green crystals or kidney-shaped aggregates; chalcedony, in pseudomorphs probably after calcite. The crystallisation order seems to be: quartz and green fluorite (early), violet fluorite and calcite, greyish green fluorite and chalcedony (latest).

In the gabbro and norite the joints may have a coating of chlorite, often with pyrite. At one locality at Kråkås globular aggregates of a light green prehnite are found. Optic angle $2V_z = 65°$, and refraction indices $n_x = 1.612$, $n_y = 1.619$, $n_z = 1.634$ give an Al-prehnite almost free of iron. Calcite and quartz are also found in cavities in the rock.

Structural geology.

Folds, lineation. — As seen from the map the direction of fold axes and lineation is very constant in trend, N 84° E, the plunge being to the east. The folds are commonly asymmetrical, with axial planes dipping south. The intensity and amplitude of the folds vary greatly. Besides these dominating folds a few recordings have been made of small scale folds trending N 42° W. These are thought to be earlier.

A microfabric analysis of quartz axes and mica poles in an augen gneiss shows a monoclinic pattern with very strong orientation, the b-axis conciding with the regional east-west fold axis. The penetrative mineral lineation and the microfabric indicate that the folding took place at the latest peak of metamorphism. The folding was later than the norite intrusion and either later than or contemporaneous with the quartz diorite intrusion.

Joints. — The metamorphic rocks show very prominent vertical joints with a northerly strike. These are believed to be related to the main folding as tensional cross joints. Vertical joints striking N 35° E and N 50° W are also very marked, and these are classified as diagonal joints.

Faults. — The offset of the norite/granite gneiss contact at two localities near Strusshamn indicates the presence of faults along the marked valleys Strusshamn—Kråkåsvatn and Strusshamn—Kleppevatn, the latter continuing along the straight shore line to Hjeltneset. Slickensides with dominating vertical striations are found in the partly brecciated gneisses in the area Strusshamn—Marikoven. These relations indicate two nearly vertical faults, the western block moving down in each case. The faults must be later than the folding.

Tectonic conglomerates are found in metanorite west of Kråkås and in gneiss east of Kråkås. Both continue northwards as eastward dipping schistose rocks. These conglomerates and the downfolded (?) gneiss zone north of Kråkås suggest a shear movement during which the norite of Kråkås moved both up and northwards.

The norite/gabbro pluton. — Joints are developed mainly in two directions: one vertical set striking N 80° E and another striking N 40° W and dipping 75° NE. As mentioned previously, the form of the basic pluton is thought to approximate to a thick lens somewhat modified in shape by folding and by the intrusion of the quartz diorite. A gravity survey of the pluton by Karsten Storetvedt (1962) indicates that the body reaches a depth of about 900 m.

Age relations.

Dating at micas from the gneiss area west of Bergen by the K-Ar method gave Caledonian ages of 413 m. y. (Hernes 1964), 425, 434 and 450 m. y. (Neumann 1960).

Recently, a dating of the norite/gabbro pluton at Askøy was carried out by FM Consultants Ltd. (report no. FMK/712 1970). The specimens, altered to a varying degree, gave the following results (Storetvedt, personal communication):

Three whole rock total degassing conventional K-Ar age determinations: 513 ± 31, 546 ± 22, 545 ± 22 m. y.

Duplicate total degassing $^{40}Ar/^{39}Ar$ age determinations on biotite separations: 474 ± 14, 444 ± 13, 569 ± 17, 444 ± 13 m. y.

The conclusion of FM Consultants Ltd. is that the rock is a Pre-Cambrian basic intrusion involved in subsequent Caledonian orogeny around 444 ± 13 m. y.

This implies that the gneisses into which the basic body was intruded are also Pre-Cambrian, and this agrees well with the fact that the gneisses further north in Askøy dip below the schists of the Minor Bergen Arc (Kolderup and Kolderup 1940). According to Kolderup and Kolderup the Minor Bergen Arc is to be correlated with the fossiliferous Major

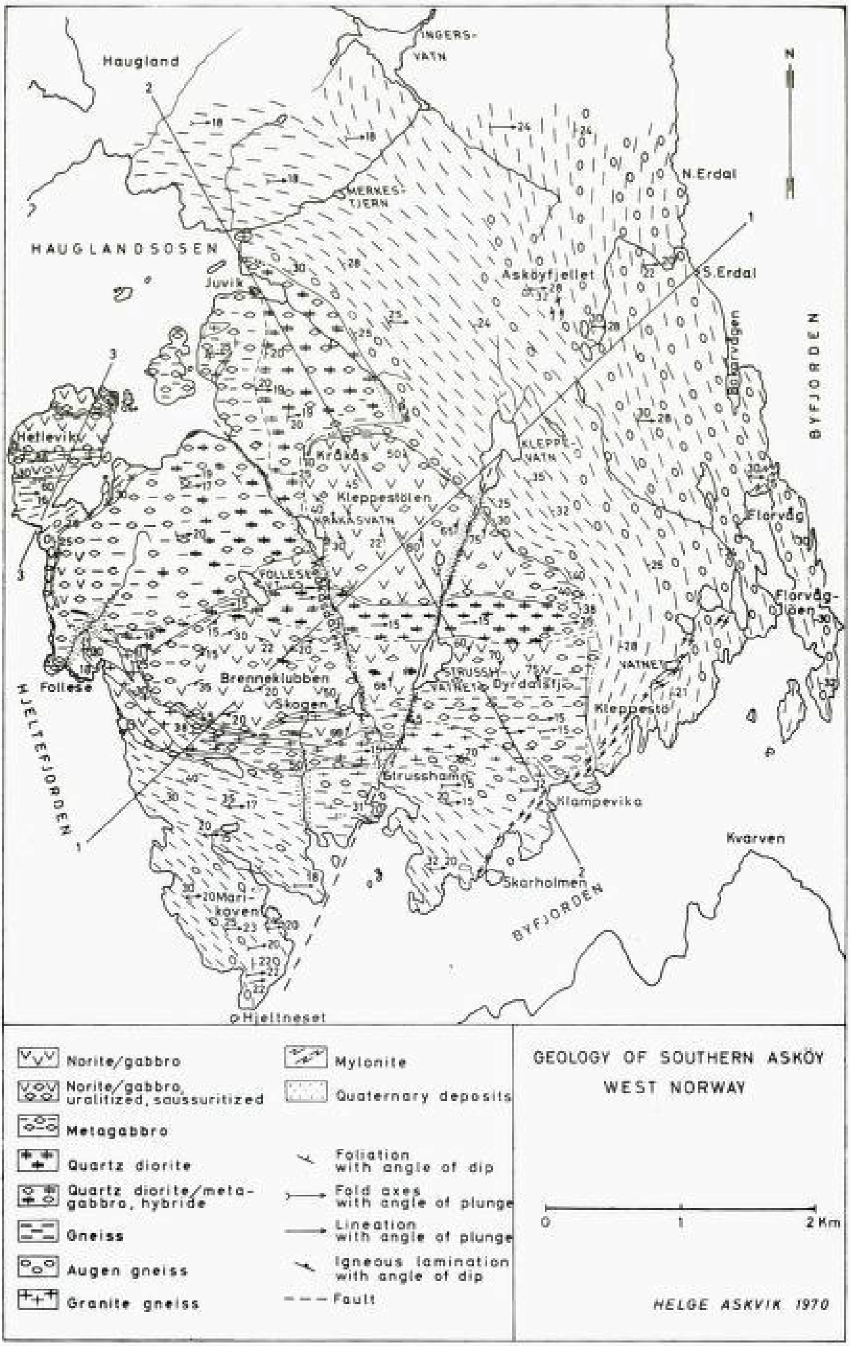

Fig. 15. — Geological map.

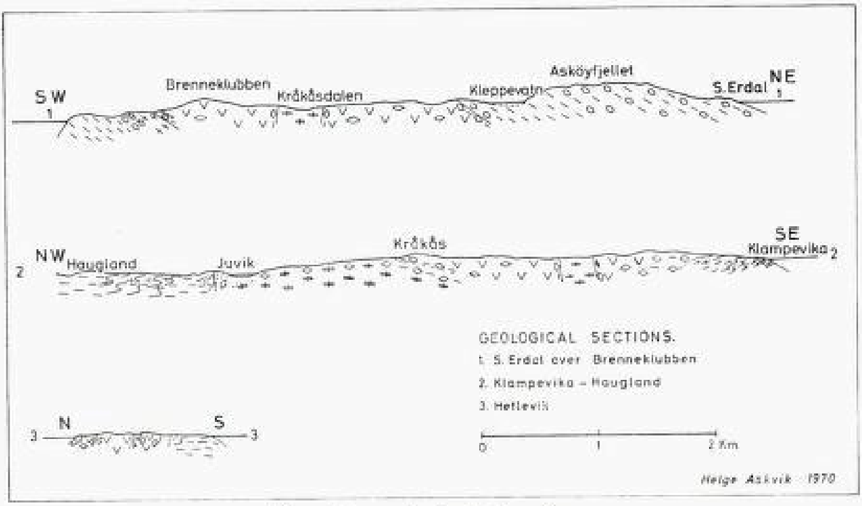

Fig. 16. — Geological sections.

Bergen Arc of Cambro-Silurian age. Hernes (1966) is of the opinion that the western gneisses, the Minor Bergen Arc, and the gneisses and anorthosites east of this arc form the Pre-Cambrian part of a Caledonian stratigraphic sequence, the Major Bergen Arc being the Cambro-Silurian part. To the present writer, however, the great similarity between the several rocktypes of the Minor and Major Arcs suggest that they must be correlated.

The folding about east-west axes under almandine amphibolite facies conditions is clearly the last penetrating deformation of the Askøy area, and it seems reasonable to assume that this deformation is reflected in the 444 ± 13 m. y. age in the dating of the basic body and the similar ages from micas in the Western Gneiss Area. Consequently, it is concluded that this orogenic event occurred around end Ordovician-early Silurian times. The quartz diorite was intruded prior to or during this deformation.

Literature Cited.

DEER, W. A., HOWIE, R. A., ZUSSMAN, J., (1963): *Rock-forming minerals.* Longmans, Green and Co. Ltd. London.

EMELEUS, C. H. (1964): The Grønnedal-Íka alkaline complex, South Greenland. *Medd. om Grønland, 172,* No. 3, 4—73.

FREUND, H. (1955): *Mikroskopie der Silikate.* — Handbuch der Mikroskopie in der Technik, vol. 4. Umschau Verlag. Frankfurt a.M.

GRIBBLE, C. D. (1966): The thermal aureole of the Haddo House norite in Aberdeenshire. *Scott. J. Geol. 2,* 306—313.

GROUT, F. F. (1918): Internal structures of igneous rocks, their significance and origin; with special reference to the Duluth gabbro. *J. Geol. 26*, 439—458.

— (1918): Two phase convection in igneous magmas. *J. Geol. 26*, 481—499.

HERNES, I. (1964): A possible western continuation of the Scandinavian Caledonian arc system. Nature 204, No. 4964, 1186—87.

— (1966): Age of the anorthosites in the Norwegian Caledonian chain. *Nature 209*, No. 5019, 191.

HESS, H. H. (1956): The magnetic properties and differentiation of dolerite sills: discussion. *Amer. J. Sci. 254*, 446—51.

HIORTDAL, TH. & IRGENS, M. (1862): Geologiske undersøkelser i Bergens omegn. Universitetsprogram.

JAEGER, J. C. (1968): Cooling and solidification of igneous rocks. In Hess, H. H. & Poldervaart, A.: *Basalts*. Interscience Publishers, New York.

KOLDERUP, C. F. (1903): Die Labradorfelse des westlichen Norwegens II. Die Labradorfelse und die mit denselben verwandten Gesteine in dem Bergensgebiete. *Bergens Museums Årbok 1903* Nr. 12.

KOLDERUP, C. F. & KOLDERUP, N.-H. (1940): Geology of the Bergen Arc. System. *Bergens Museums Skr.*, 20.

MIYASHIRO, A. & SEKI, Y. (1958): Enlargement of the composition field of epidote and piemontite with rising temperatures. *Amer. J. Sci. 256*, 423—430.

MOORHOUSE, W. W. (1959): *The study of rocks in thin section*. Harper & Brothers, New York.

NEUMANN, H. (1960): Apparent ages of Norwegian minerals and rocks. *Norsk Geologisk Tidsskrift, 40*, 173—191.

POLDERVAART, A. & HESS, H. H. (1951): Pyroxenes in the crystallisation of basaltic magma. *J. Geol. 59*, 472—489.

REUSCH, H. (1900): Skjærgården ved Bergen. *NGU, 32*.

SEDERHOLM, J. J. (1916): On synanthetic minerals and related phenomena. *Bull. Comm. Geol. Finl., 48*.

SKEIE, K. A. (1968): *En petrografisk undersøkelse på strekningen N. Erdal—N. Haugland*. Unpublished thesis, Univ. i Bergen.

STORETVEDT, K. (1962): *Gravimetriske og magnetiske undersøkelser av en noritt-pluton på Aksøy*. Unpublished thesis, Univ. i Bergen.

TRØGER, W. E. (1959): *Optische Bestimmung der gesteinsbildenden Minerals. Teil 1. Bestimmungstabellen*. E. Schweitzerbart'sche Verlagsbuchhandlung, Stuttgart.

TURNER, F. J. & VERHOOGEN, J. (1960): *Igneous and metamorphic petrology*. McGraw-Hill Book Co., Inc., New York.

UPTON, B. G. J. (1960): The alkaline igneous complex of Kûngnât Fjeld, South Greenland. *Medd. Om Grønland, 123*, No. 4, 5—145.

— (1961): Textural features of some contrasted igneous cumulates from South Greenland. *Medd. om Grønland, 123*, No. 6, 6—29.

WAGER, L. R. (1968): Rhytmic and cryptic layering in mafic and ultramafic plutons. In Hess, H. H. & Poldervaart, A.: *Basalts*. 537—571. Interscience Publishers, New York.

WAGER, L. R. & BROWN, G. M. (1968): *Layered igneous rocks*. Oliver & Boyd, Edinburgh and London.

Manuscript received in September 1970.