GEOLOGY OF MOSKENESØY, LOFOTEN, NORTH NORWAY[1]

by

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Abstract.

Moskenesøy, Lofoten, forms part of the Lofoten—Vesterålen Precambrian high grade granulite metamorphic province. The dominant basal rock type of the island is a porphyroblastic monzonitic gneiss interbanded with, and grading into, a dioritic gneiss and a leucocratic quartz monzonitic gneiss. Chemically, it is distinct from the widespread massive intrusive porphyritic mangerites occurring on other islands in Lofoten. The subordinate rock type constituting the basal gneiss sequence consists of a series of veined and layered gneisses of variable composition (dioritic-monzonitic) and mineralogy (granulite→amphibolite facies mineral assemblages) together with minor occurrences of thin quartz-magnetite bands.

The basal gneiss sequence is intruded by small gabbroic and ultramafic masses. In the south a dome-like anorthosite occurs in the core of an anticline. Late stage dolerite and pegmatite dykes are commonly found. The pegmatites represent the last igneous event recorded and may be related to the widespread retrograde metamorphism of the granulite facies assemblages. This retrogression varies from microscopic garnet corona formation to complete recrystallization.

Chemically the rocks show high K/Rb ratios, generally > 300. Extreme K/Rb values (> 2000) occur in the anorthosite and the gneisses in contact with the anorthosite. Small mangerite veins, dykes and intrusions with K/Rb>1000 possibly represent melting of the gneisses at the time of the anorthosite emplacement.

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Introduction.

The geological mapping of Moskenesøy, Lofoten, has been completed as part of a general project of geological mapping, petrology and geochemistry of the high grade metamorphic province of the Lofoten—Vesterålen Islands. The mapping (Fig. 1) was done on a scale of 1:50 000, using the AMS series, 1952 editions as base maps (AMS M711 1031 III Moskenesøy and AMS M711 1830 I Lofotodden). These topographic maps are enlargements of older maps with a scale of 1:100 000 and they were occasionally observed to have major errors. This places some limits on the accuracy of the geological mapping. Aerial photograph coverage is only available for the eastern coastal strip Fredvang—Å on a scale of approximately 1:15 000.

Moskenesøy is one of the most rugged of the Lofoten Islands and road access is limited to the northern part of the island from Fredvang to Selfjord and the eastern part of the island from just north of the Kråkern Bridge to as far south as Å. Large, fresh road cuts abound along this road. Small boats provide the best means of access to the parts of the islands connected by fjords to Reine, but larger boats are needed to proceed south of Å, and to reach the west coast of the island south of Hermansdalen. Traverses across to the west coast from the fjords west of Reine were possible at Hermansdalen, Bunes and Horseid. The most difficult part of the island to reach is the area south and west of Krokvann. Ropes are necessary to enter this area with safety, and the present writers have only mapped around the edge.

The field work has been conducted with the aim of mapping the major lithologies on the island, determining the overall structure and finally to collect samples for detailed petrographical and geochemical studies. Particular emphasis has been placed on the anorthosite body south of Å in order to compare this with the anorthosite described from Flakstadøy (Romey 1970) and Langøy (Heier 1960).

Previous work.

The earliest record of geological work on Moskenesøy is in general publications on the Lofoten—Vesterålen rock province (Helland 1897, Kolderup 1898). Subsequently there has been little or no published work on the rocks of Moskenesøy until the geochronological study of Heier and Compston (1969) which included some rocks from this

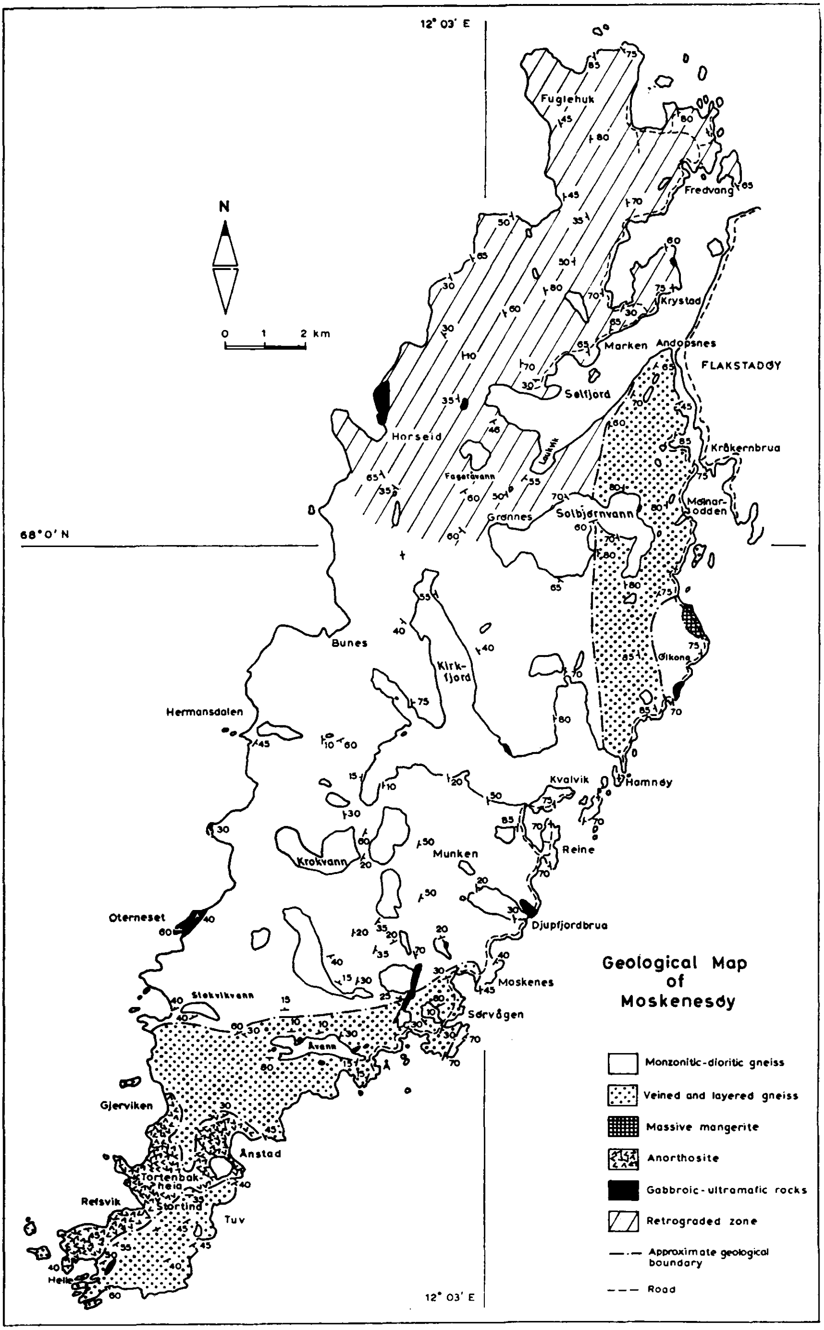

Fig. 1. Geological map of Moskenesøy.

island; also a recent study of secondary garnet formation in the Lofoten—Vesterålen province incorporated samples from Moskenesøy (Griffin and Heier 1969).

Geological outline.

Monzonitic augen gneiss is the dominant rock type on the island. It is sometimes interlayered with a biotite-rich dioritic gneiss, and also may grade into more leucocratic quartz-bearing monzonitic gneiss variants, ferromagnesian spotted variants or grey, more mafic, variants. North of Solbjørnvann this monzonitic sequence is frequently strongly retrograded, producing a variety of rock types, including strongly banded gneisses and also conspicuous leucocratic gneisses. Some distinctive intrusions of coarse-grained mangerite and medium-grained banded mangerite are evident in the eastern part of the island, north of Hamnøy. In this area, and south of Sørvågen a complex sequence of veined and layered gneisses occurs, frequently containing monzonitic layers. This sequence is intruded by a dome-like anorthosite body, in the core of an anticline south of Å. South of the anorthosite the gneiss sequence is strongly layered and contains graphite and magnetite-quartz layers.

Small gabbro-ultramafic intrusions with textures varying from granulitic to coarse-grained, sub-ophitic to poikilitic occur scattered throughout the island. Finally, late-stage dolerite and pegmatite dykes are commonly found.

The island of Mosken consists entirely of retrograded monzonitic gneiss with only slight variations. Pegmatite dykes are also present.

Petrography.

Monzonitic and dioritic gneiss sequence.

This rock group crops out over most of Moskenesøy except south of Å and between Hamnøy and Andopsnes. It consists mainly of interbedded brown monzonitic gneiss and dioritic gneiss (subordinate) with minor grey, or quartz-bearing and more leucocratic, or ferromagnesian spotted varieties. The brown monzonitic gneiss is characterized by elongate porphyroblasts of mesoperthite giving the rock an augen gneiss texture. Some examples show evidence of extensive retrograde metamorphism (see p. 63).

(i) Augen gneiss (1, 38A).*)

The rock is foliated and porphyroblastic, containing single large crystals or aggregates of mesoperthite reaching 2—3 cms. These are elongate, defining the foliation. The groundmass is 1—3 mm and consists mainly of mesoperthite and plagioclase ($\sim An_{30}$) with subordinate biotite and clinopyroxene and minor orthopyroxene, opaque minerals, garnet, amphibole and accessory apatite and zircon. The rock shows strong evidence of deformation (curved twin lamellae in plagioclase and «kink bands» in biotite). Plagioclase may be rimmed partially by mesoperthite. Clinopyroxene is dusty and surrounded by amphibole coronas. Biotite flakes are often rimmed by aggregates of minute garnet, amphibole, opaque (haematite?) and quartz crystals. Minor recrystallization of biotite occurs. Garnet coronas are best developed around opaque minerals (titano-magnetite) and where biotite and magnetite are associated. Orthopyroxene is usually altered to serpophite or has amphibole coronas.

(ii) Massive, porphyroblastic monzonitic gneiss (170).

In mineralogy this rock is essentially identical to the augen gneiss described above. Texturally it differs, showing little evidence of deformation, and preserving an essentially granular igneous texture. Similar secondary garnet and amphibole formation is present. From field and petrographic study this rock cannot be distinguished from the massive, porphyritic intrusive mangerites found elsewhere in Lofoten—Vesterålen (Heier, 1960; Romey, 1971; Griffin, 1971). However, chemically it is distinct from these mangerites and similar to the augen gneiss (see p. 65) and so is regarded as part of the monzonitic-dioritic gneiss sequence. No contact between this massive rock and the augen gneiss sequence could be mapped in the field.

(iii) Grey, monzonitic gneiss (181).

This rock differs from the other monzonitic gneisses in colour, and also the presence of ferromagnesian minerals conspicuously enclosed in coarse aggregates (> 2 cm across) of mesoperthite. The mesoperthite shows coarse exsolution textures (composition of plagioclase blebs

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*) Sample numbers refer to the Lofoten collection at the Mineralogisk-Geologisk Museum, Oslo. The same numbers are used in Table 1 and the locality map accompanying the collection.

~An_{35}). Apart from these features the rock is similar to the other monzonitic gneisses, (i) and (ii), in mineralogy, corona development and chemistry.

(iv) Ferromagnesian spotted monzonitic gneiss (200).

Best examples of this monzonitic gneiss variation occur on the western side of Moskenesøy, particularly at Hermansdalen and Bunes. It is foliated with characteristic elongate pyroxene aggregates reaching 1 cm size giving the «spotted» appearance. Mesoperthite porphyroblasts may be present and the rock grades into a typical augen gneiss with increasing abundance of the porphyroblasts. Other examples are transitional towards medium, even-grained leucocratic monzonitic gneiss as the content of the ferromagnesian «spots» decreases.

The spotted gneiss is brown and coarse-grained, consisting chiefly of plagioclase (~An_{30}) and some antiperthite with subordinate perthite, quartz, orthopyroxene, clinopyroxene and primary amphibole and accessory biotite, opaque minerals and apatite. Quartz occurs both as large crystals and myrmekitic intergrowths with plagioclase. Poorly developed secondary amphibole coronas around pyroxenes and unidentified coronas around opaque minerals are also present. Noteworthy features of this rock are the lack of biotite and the presence of intricate feldspar overgrowth patterns around large feldspar crystals.

(v) Quartz-bearing leucocratic monzonitic gneiss (194).

Outcrops of this gneiss occur mainly between Krokvann and Munken. It is medium-coarse-grained and consists chiefly of mesoperthite and up to 25 % quartz, with minor plagioclase, amphibole, orthopyroxene, magnetite, corona garnet and biotite and accessory apatite and zircon. In thin section strikingly regular rod perthite is visible, as well as peculiar vermiform intergrowth of quartz and biotite. Quartz is frequently poikiloblastic, containing idioblastic apatite.

(vi) Dioritic gneiss (38, 43, 151, 196, 98).

The dioritic gneiss grades into a basic gneiss. It is readily distinguishable from the augen gneiss because of greater abundance of ferromagnesian minerals (up to 40 %), dark grey colour and medium grain size (up to 3 mms) with no feldspar porphyroblasts. It shows similar evidence of deformation as the augen gneiss (viz. «kink» bands in biotite, bent twin lamellae in plagioclase and some granulation along the margins of crystals). It consists chiefly of plagioclase ($\sim An_{40}$) and some antiperthite with subordinate clinopyroxene, biotite, orthopyroxene and opaque minerals. Garnet, amphibole, quartz, secondary biotite and haematite occur as well developed coronas associated with primary biotite and magnetite, or as discrete secondary aggregates. Orthopyroxene in contact with plagioclase exhibits successive rims of clinopyroxene, garnet(?), quartz and biotite (38) or clinopyroxene, quartz, amphibole (43). Accessory minerals include apatite and zircon. Some specimens contain common primary hornblende and plagioclase with abundant minute inclusions (43, 98, 193).

(vii) Mosken monzonitic gneiss (354, 355).

The Mosken gneiss is a foliated, coarse-grained, grey rock consisting mainly of plagioclase ($\sim An_{35}$) with subordinate perthite, clinopyroxene, orthopyroxene, amphiboles, biotite, opaque minerals, garnet and chlorite with minor quartz and apatite. Retrograde secondary mineral formation is pronounced, particularly finely crystallized biotite-hornblende-garnet-quartz-opaque mineral clusters. Pyroxene is extensively uralitized — clinopyroxene to hornblende and orthopyroxene to anthophyllite. Secondary garnet crystals reach 2 mm in size and are associated with idioblastic biotite and xenoblastic quartz. Quartz rarely occurs in myrmekite with plagioclase.

The 7 rock types above have been described as representative examples of the major rocks to be found within the monzonitic-dioritic gneiss sequence on Moskenesøy, but it should be noted that many minor variations, transitional between these types, occur, e.g. a quartz-bearing medium-grained monzonitic gneiss (351) with ferromagnesian mineral content approaching that of normal augen gneiss (15—20 %) rather than a content typical of the quartz-bearing leucocratic gneiss (v). Also specimen 356 is an example of a medium-grained gneiss with ferromagnesian content intermediate between augen gneiss and dioritic gneiss. Ferromagnesian minerals are clinopyroxene, orthopyroxene, biotite, amphibole and magnetite with secondary garnet, amphibole, haematite, biotite well developed in coronas or areas of recrystallization. Rare coronas around orthopyroxene adjacent to plagioclase consist of succeeding rims of clinopyroxene, quartz and garnet.

Veined and layered gneiss sequence.

This sequence crops out in a strip about 2—4 km wide, extending from Hamnøy north to Andopsnes, and also at the southern end of the island, south of a line from Stokvikvann to Sørvågen. It consists of a considerable variety of gneisses, dominated by a dark grey, fine-medium-grained gneiss with irregular veins of coarser-grained «granitic» material. In general layering is not conspicuous north of Hamnøy, but small outcrops of thinly layered (0.5—1.5 cms) gneiss occasionally are evident. South of Tuv layering is prominent but veining is rare; the layers are from 0.1—10 m thick. This well-layered sequence includes metasedimentary quartz-magnetite bands and a layer of graphite-bearing gneiss at Helle.

The contact between this sequence and the monzonitic-dioritic gneiss sequence is sharp at and north of Hamnøy but was not so obvious south of Sørvågen where it could best be delineated by absence of feldspar «augen» in the layered gneiss sequence, though distinction between the dioritic gneiss and even-grained monzonitic gneiss and the layered gneiss is difficult. It is likely that these two sequences form part of a single basement complex derived by metamorphism of a sedimentary and volcanic(?) sequence with varying lithologies and unit thicknesses. Even-grained banded mangerite (this term is preferred since no gneissic texture is evident) occurs within the veined and layered gneiss sequence. West of Mølnarodden a monzonitic gneiss with scattered augen and grading into dioritic gneiss is also present within the sequence as a regular layer about 100—150 m wide. These features point to the lack of clear separation between the two sequences in terms of the detailed petrology of their individual members, although they do form two mappable units (Fig. 1).

A further noteworthy feature is that the veined and layered gneiss sequence contains some bands with an amphibolite facies mineral assemblage and showing no evidence of any history in the granulite facies. This may reflect higher activity of water in certain layers at the time of the granulite facies metamorphism, so that these layers never attained granulite facies mineralogy, or alternatively it may indicate that after the granulite facies metamorphism, certain layers were more permeable to fluids and more readily underwent retrograde metamorphism to an entirely amphibolite facies assemblage, while nearby less permeable layers only show incipient retrograde effects (cf. Griffin and Heier 1969). Shearing may also play a role in this varied retrogression.

(i) Banded mangerite (148B, 85).

This rock is brown, medium-grained and leucocratic, with a saccharoidal texture. It consists mainly of perthite with subordinate quartz and plagioclase (~An_{30}), minor clinopyroxene, biotite, magnetite, amphibole, garnet and accessory apatite and zircon. Minor zones of mylonitisation occur and the quartz shows undulose extinction. Coronas of amphibole around clinopyroxene are evident, as well as garnet-secondary biotite coronas associated with the magnetite and primary biotite. A more mafic mangerite (83B) also occurs within the veined and layered gneiss sequence. This contains less than 5 % quartz but has a higher proportion of clinopyroxene, orthopyroxene and magnetite (with associated coronas) than 148B and 85.

(ii) Basic granulite (135 and 148A).

The basic granulites are dark grey, medium-grained with a granoblastic texture. They consist mainly of antiperthite (~An_{30}) with subordinate clinopyroxene, biotite, orthopyroxene and minor quartz, magnetite and apatite. Garnet, amphibole, biotite and haematite coronas are well developed. Minor myrmekitic quartz is evident. In 135 green amphibole replacing clinopyroxene occurs in a distinct band cutting the rock.

(iii) Amphibolite (83A).

It is banded and coarse grained consisting chiefly of xenoblastic plagioclase (~An_{30}) and microcline with subordinate blue-green amphibole and minor quartz, sphene, epidote and biotite and accessory zircon and apatite. Amphibole occurs both as crystal aggregates and also in a distinct band with poikiloblastic texture, enclosing small quartz crystals. No opaque minerals were observed. The amphibole-quartz association may represent replacement of pyroxene, otherwise there is no evidence of this rock ever having been in granulite facies.

(iv) Layered gneiss (276A, 304A).

The layered gneiss sequence south of Tuv is dominated by medium grained, brown, granoblastic dioritic granulite consisting mainly of plagioclase antiperthite ($\sim An_{30-35}$) with subordinate hypersthene and minor clinopyroxene, interstitial orthoclase, magnetite and apatite and accessory biotite, garnet, Mg-spinel, hercynite and muscovite. These accessory minerals occur in coronas. Pegmatitic segregations (304) are conspicuous in the gneiss sequence, particularly near the anorthosite. These have similar chemistry and mineralogy as the normal grainsize rock, except for greater content of apatite. More silicic varieties in the layered gneiss sequence (261) contain quartz (up to 20 %, or even higher, in the quartz-magnetite bands), and may show a corona development. Where feldspar occurs in contact with quartz or clinopyroxene it shows distinct exsolution-free rims. Noteworthy features of these granulites include paucity of biotite, amphibole, and K-feldspar, the lack of well developed coronas and the abundance of apatite. Uncommon mafic layers (276B) in the sequence contain up to 15 % amphibole (mafic minerals total 65 % of the rock) and the plagioclase is about An_{50}. Scapolite may also be present.

Massive mangerite (H-107/66).

A small intrusive mass of this rock type occurs about 3.5 kms south of Mølnarodden. It is bounded by strongly sheared monzonitic and dioritic gneisses. The mangerite is dark brown, coarse grained and granular. Mesoperthite is the dominant constituent. Subordinate plagioclase ($\sim An_{20}$), clinopyroxene, orthopyroxene, myrmekitic quartz, opaque minerals with accessory apatite and garnet (in well developed coronas — Griffin and Heier 1969) are also present.

Anorthosite (267B, 294A, 293, 300C).

The anorthosite crops out south of Å and extends from Ånstad across the island to Refsvik, north to Gjerviken and south to Helle. It intrudes the veined and layered gneiss sequence as a dome-like body in the core of an anticline, with the north contact dipping at 30—40°NE to NW and the southern contact dipping SE at 30—50°. Part of the southern contact is a near-vertical fault from Stortind, SW for about 1 km. At Helle the lower part of the contact in the cliffs NE of the anchorage is a 20 cm wide sheared and mylonitized zone. Near this zone the anorthosite has a slightly cataclastic texture, but over most of the intrusion a coarse grained sub-ophitic texture is typical. The anorthosite is purple-grey with a grainsize of 1—10 cm and it consists of > 90 % plagioclase (varying from An_{35}—An_{50}), some of which is antiperthitic. Subordinate orthopyroxene, clinopyroxene and magnetite also occur. Minor interstitial quartz is present in some specimens (300C). The feldspar may be patchily sericitized and rare epidote and calcite may also develop. Orthopyroxene contains red-brown ribbon-like inclusions of uncertain composition. Clinopyroxene frequently occurs around the margins of the orthopyroxene crystals. Amphibole coronas are evident around both pyroxenes. Garnet and biotite coronas are associated with the magnetite. Foliation is rare but in some places irregular bands of magnetite crystals are evident, parallel to a weak foliation and generally conformable with the contact with the gneiss. Pyroxene may be altered to hornblende and chlorite and the feldspar saussuritized in zones subjected to hydrothermal activity.

The anorthosite is intruded by a 1—2 m wide gabbro dyke near Helle (see p. 59). The dyke is fine grained (1—3 mms) at the margins and coarse grained towards the centre (5—10 mms). Gneiss inclusions(?) (267C, 300B) accompanied by much shearing and brecciation occur at Helle and in the contact zone at South Ånstad (see p. 59).

Pegmatite dykes up to 1 m wide intrude the anorthosite at Helle and Ånstad. Extensive alteration of anorthosite occurs along the margins of these dykes. In the cliffs at the back of Gjerviken dark, irregular dolerite(?) dykes appear to intrude the anorthosite.

On Tortenbakheia and north of Ånstad the contact between the anorthosite and gneiss consists of an anorthosite-gneiss mixed rock zone about 10 metres wide with parallel foliation or banding in both rock types. As mentioned before, on a broad scale the anorthosite/gneiss contact is conformable with the general structure, but in detail the gneiss near the anorthosite contact shows considerable variation in strike and dip, with interleaving with anorthosite and irregular intrusion of both rock types by pegmatitic feldspar-rich pods.

The gneiss (294B) interleaved with anorthosite (294A) in the contact zone appears to be more mafic in composition (e.g. 294B — about 50 % plagioclase An_{45} and 50 % orthopyroxene, clinopyroxene, amphibole and accessory biotite, magnetite and garnet coronas). Preliminary rare earth element determinations indicate that a 'low melting' salic fraction may have been removed from this rock.

The pegmatitic feldspar-rich pods have only been observed in the rocks immediately surrounding the anorthosite. This strongly suggests that their formation is connected to the anorthosite intrusion and they possibly reflect the mobilization and partial melting of the gneiss in the immediate contact zone. Distinct, monzonitic dykes (see p. 61) and veins well exposed at Å may also be products of melting of the gneiss by the intrusion of a hot anorthositic mass. The pegmatitic pods have a grainsize reaching 15 cms and consist chiefly of antiperthitic plagioclase ($\sim An_{25}$) with subordinate magnetite (sometimes reaching 20 % of the rock and having well developed garnet-Mg-spinel symplectitic coronas or more rarely clinopyroxene coronas), clinopyroxene, orthopyroxene and apatite. The abundance of apatite is noteworthy. Specimens 305A, 305G are typical of samples taken in the contact zone of the anorthosite and the gneiss. They show great variation in grainsize but little variation in mineralogy or composition (p. 66).

Gabbroic and associated ultramafic rocks.

These rocks are present as distinct masses ranging from a few metres to about 1 km in size. They intrude the monzonite-dioritic gneiss sequence, the veined and layered gneiss sequence and possibly the anorthosite(?). The main bodies occur just west of Sørvågen, 1½ km west of Å, ¼ km north-east of Helle, at Djupfjordbrua, Ølkona, Horseid and Erteneset (as well as several other localities, see Fig. 1). There is no observable field link between the major gabbro-ultramafic bodies and the anorthosite. Monzonitic veins, dykes and segrerations (see p. 61) cut the mafic rocks (this is well exposed north of Horseid and at Åvann), and probably represent partial melting and mobilization in the country rock gneisses at the time of intrusion of a hot gabbroic magma. Similar segregations and veins may be caused by the anorthosite intrusion (see p. 58).

The cross-cutting relationships to the country rocks and the general association of gabbros and ultramafic rocks distinguish this group from the more basic varieties of the dioritic gneiss sequence, but where field exposure is poor, it may be impossible to distinguish medium grained varieties of the two rock types on hand specimen and thin-section examination (e.g. specimens 18A, 69B with 40—60 % plagioclase ($\sim An_{40}$), in addition to clinopyroxene, orthopyroxene, amphibole, biotite and opaque minerals). Similarly specimen 267A may represent an inclusion of gneiss within the anorthosite (or a small mafic intrusion within the anorthosite mass). The latter interpretation is favoured because of the coarse grainsize in the centre of the dyke, low plagioclase content (<15 %; ~An_{55}), abundant orthopyroxene, clinopyroxene and amphibole and accessory biotite, magnetite and chlorite, and lack of apatite. However more leucocratic varieties such as specimens 267C, 300B with about 60 % plagioclase (~An_{40}) medium grainsize and distinct foliation in hand specimen probably represent gneiss inclusions. No apatite was observed in these specimens.

(i) Djupfjord gabbro.

The Djupfjord gabbro type (37) is well exposed at the northern end of Djupfjordbrua. It is a dark grey, granular medium grained gabbro, distinguishable from the nearby dioritic gneiss by the lack of biotite and gneissic foliation. It consists of about 50 % plagioclase (~An_{50}) with subordinate pale green clinopyroxene and orthopyroxene and minor biotite, magnetite, amphiboles, garnet, and apatite. Biotite may be primary, or secondary in corona formation associated with the garnet and an opaque mineral. Amphibole coronas are poorly developed around some pyroxene aggregates. There appear to be two generations of pyroxene — (a) large crystals of poikilitic clinopyroxene, containing probable exsolved orthopyroxene and magnetite (b) smaller (~1 mm) crystals, mainly in granoblastic-like aggregates but also as rims around crystals of type (a). The large pyroxene crystals probably represent primary igneous crystallization while the small crystals formed as a result of recrystallization during metamorphism.

A specimen (52B) collected from near the contact with the gneiss sequence is medium grained and is ultramafic, containing less than 5 % plagioclase. It is composed of hornblende, orthopyroxene, clinopyroxene and minor opaque minerals, biotite and garnet. The plagioclase contains abundant inclusions and well developed garnet idioblasts formed where plagioclase is in contact with pyroxene. Garnet coronas are also associated with the opaque minerals and plagioclase, while amphibole coronas are common around clinopyroxene. Most of the amphibole appears to be primary. In one area of the slide a recrystallized fine grained vein(?) of garnet (in flower-like aggregates), biotite, amphibole, quartz and clinopyroxene occurs. This appears to extend into the augen gneiss country rock (52A) where it consists of plagioclase, biotite, amphibole and subordinate garnet, quartz and opaque mineral. This vein may represent a small zone where the fluid promoting the secondary retrograde metamorphism (see p. 69) was able to penetrate both rock types and effect their recrystallization.

(ii) Ølkona spotted gabbro (145A, B, C).

The Ølkona gabbro is coarse grained, dark grey with a marked spotted appearance due to concentrations of hornblende in 4—8 cm diameter aggregates intergrown with plagioclase. It has a hypidiomorphic, gabbroic texture and consists of varying proportions of plagioclase ($\sim An_{55}$), hornblende, clinopyroxene and orthopyroxene with accessory opaque minerals, biotite, garnet coronas and apatite. In Specimen 145B pyroxene has been entirely replaced by hornblende. The feldspar is dusty near the hornblende. Specimen 145C is a leucocratic version of the gabbro containing 60—70 % plagioclase, subordinate clinopyroxene and orthopyroxene and only minor amphibole. Mylonite zones are conspicuous.

(iii) Other intrusions.

The most conspicuous intrusions are dark brown weathering ultramafic bodies near Sørvågen, Åvann and Helle (see Fig. 1). These are dense, coarse-grained, hypidiomorphic rocks typically with no plagioclase, e.g. specimen 109 consists of > 50 % orthopyroxene, subordinate olivine and minor amphibole, magnetite, phlogopite, clinopyroxene and irregular serpentinite veins. Orthopyroxene is poikilitic and encloses magnetite and olivine crystals. Amphibole is pale brown and is formed by alteration of orthopyroxene. It is best termed an olivine orthopyroxenite. Towards the edge of the intrusions the brown (dark green when fresh) olivine orthopyroxenite changes to a green colour, with an increase in the content of green amphibole and an increasing proportion of plagioclase and clinopyroxene so that gradation into a gabbroic composition is achieved in the contact zone, e.g. specimen 107 contains about 20 % interstitial plagioclase, clinopyroxene and amphibole with minor orthopyroxene, magnetite and biotite. No olivine was identified. Other variations include orthopyroxene hornblendites (163) containing mainly hornblende and orthopyroxene with minor plagioclase, clinopyroxene, biotite, apatite and magnetite. Much of the amphibole appears primary though some evidently replaces the rare clinopyroxene. The plagioclase contains abundant inclusions and incipient coronas are evident near where biotite occurs. The rock is medium-grained and has a relict igneous texture. It occurs as a small lens 15 m long and 5 m wide within the augen gneiss near Reine.

At Ertneset a gabbroic-ultramafic intrusion occurs which shows all gradations from leucocratic, foliated gabbro (353B) to gabbro (346) with sharp contacts against ultramafic varieties. Also spotted gabbro is present where amphibole occurs instead of clinopyroxene. Gneiss inclusions occur in this body (e.g. 348, fine-grained, foliated and containing up to 20 % biotite and abundant garnet coronas).

Monzonitic dykes and veins (5A).

This late-stage rock occurs as veins and dykes up to 2 m wide, cutting the veined and layered gneiss sequence south of Å. This is the most widespread occurrence of the rock, i.e. between the anorthosite contact and Å, but it has also been observed cutting the gabbro-ultramafic intrusions and the nearby country rocks (e.g. Åvann and Horseid) and it only rarely occurs intruding the monzonitic-dioritic gneiss, apparently not closely linked with any gabbro body, e.g. at Djupfjord. It is medium- to coarse-grained consisting of >80 % K-feldspar (sometimes perthitic) and subordinate clinopyroxene, and magnetite and in some cases, ilmenite and accessory apatite occur. Poorly developed coronas of uncertain mineralogy are present around some opaque phases. Zones of mylonitization also occur. As discussed earlier, these veins and dykes may represent mobilized melts in the veined and layered gneiss sequence and the monzonitic-dioritic gneiss sequence. This is discussed further on p. 67 where the detailed chemistry is considered.

Dolerites.

Dark grey fine- to medium-grained dolerites up to 9 m thick are widespread intrusions on Moskenesøy. They do not appear to follow any regular trend and usually cannot be traced for more than a few hundred metres. They post-date the gabbro-ultramafic intrusions but pre-date the pegmatite dykes. In many localities, e.g. Kvalvik, Reine, they intrude zones where the gneiss country rock is strongly sheared and mylonitized. The shear planes have the same dip and strike as the dolerite.

The dolerite (160, 126) has a sub-ophitic texture and shows varying degrees of retrograde metamorphism tending to obscure this primary texture. Thus specimen 126 consists mainly of lath-like plagioclase, with subordinate dusty clinopyroxene and minor apatite, opaque minerals, amphibole and garnet, biotite (~5 %) in coronas, representing minor, but clearcut retrograde metamorphism. K-feldspar and zoned plagioclase fills intergranular spaces between the lath-like plagioclase. Specimen 160, however, shows extensive retrograde metamorphism and 15—20 % garnet is present, lath-like feldspar is inclusion filled, less abundant and is corroded by well crystallized idioblastic garnet aggregates. Relict clinopyroxene is minor but fine-grained, pale green aggregates probably represent recrystallized clinopyroxene. Minor biotite and magnetite are also present, characteristically in aggregates or in irregular veins. These two rocks (160, 126) probably represent similar bulk compositions subjected to different degrees of retrograde secondary metamorphism — the same metamorphism which produced the garnet coronas in the rocks of the gneiss sequence and the mangerite and anorthosite intrusions.

Pegmatites.

Large, conspicuous, white pegmatite dykes up to 3 m wide occur extensively along the shore platform between Å and Sørvågen and also extend through the cliffs of this area, and southwards to Tuv. Smaller dykes occur scattered more sparsely throughout the island and on Mosken. They intrude monzonitic-dioritic gneiss, veined and layered gneiss, anorthosite, gabbro, monzonitic veins and dolerite, and reflect the latest intrusive event of the island. The dykes are coarsegrained (up to 10 cm) and contain mainly microcline, plagioclase, quartz and subordinate biotite, muscovite and minor magnetite, ilmenite, tourmaline and garnet in some localities. The country rock bordering the pegmatites usually shows marked penetration and alteration by fluids associated with the pegmatitic intrusion. At Sørvågen and Moskenes large garnet crystals have formed in the gneiss bordering the pegmatite. At Ånstad and Djupfjord zones of pegmatitic breccias accompany the pegmatite dykes. The pegmatites have been mined at Moskenes for decorative stone.

Retrograded rocks of Moskenesøy.

North of a line drawn from Kirkfjord to Grønnes to Andopsnes extensive but irregular zones of retrograded gneisses occur within the monzonitic and dioritic gneiss sequence. The best farmland on Moskenesøy and the smoothest topography with general lack of outcrop is typically associated with large retrograde zones. With onset of retrogression the monzonitic gneiss changes from brown to grey to white with accompanying increasing degree of recrystallization. Some partially retrograded and recrystallized grey monzonitic gneisses occur as far south as Hermansdalen (202A). This rock is a quartz-bearing monzonitic gneiss in which the crystals show shearing and granulation along the margins, perthite appears to be altering to microcline, and the ferromagnesian minerals are fine-grained aggregates of amphibole, biotite, opaques and possible minute crystals of epidote. Quartz occurs in distinct stringers and has undulose extinction. Accessory apatite and rare zircon also occurs.

Typical retrograded monzonitic augen gneiss (e.g. 249) is pale grey, medium-grained and granoblastic. It consists mainly of xenoblastic plagioclase characteristically with cores containing abundant inclusions (epidote, white mica and amphibole) but with clear edges. Aggregates of ferromagnesian minerals consist of hornblende (with associated quartz) biotite, sphene and epidote. Minor non-maximum microcline is also present. Accessory magnetite and apatite also occur.

Near Marken on the road to Selfjord a quarry exposes a grey, porphyroblastic and migmatitic gneiss (359A) in contact with a grey, partly retrograded monzonitic augen gneiss (359B). The contact between the 2 rock types appears transitional on the weathered surface but in the quarry face it is sharp, with the foliation of the augen gneiss running abruptly into the contact and the bands of the migmatitic gneiss bending parallel to the contact, although there is also intricate folding of the 0.1—10 cm thick migmatitic bands near the contact.

The migmatitic gneiss consists mainly of plagioclase ($\sim An_{30}$) with subordinate biotite, epidote, hornblende, microcline, quartz and accessory apatite. The augen gneiss is also composed mainly of plagioclase (some antiperthitic) with subordinate perthite, clinopyroxene, biotite, magnetite and accessory garnet (coronas), apatite and zircon. Secondary amphibole and quartz coronas around biotite and clinopyroxene are common. Also sliver-like aggregates of magnetite, biotite and quartz surrounded by a corona of granoblastic amphibole are present. The augen gneiss is the dominant rock type of the area and it is likely that the migmatitic gneiss is a local mobilization of the augen gneiss due to penetration of fluids during the secondary retrograde metamorphic event.

The retrograde metamorphism has also resulted in some small zones of conspicuous leucocratic gneisses (e.g. 246) (possibly retrograded leucocratic quartz monzonitic gneiss) e.g. just north of Krystad and along the ridge between Laukviken and Fageråvann. It consists of microcline, and quartz with subordinate plagioclase, zoisite, haematite, white mica (phengitic?) and accessory apatite. It has a saccharoidal fabric (typical of the completely retrograded rocks) and a medium-grained granoblastic texture.

In some localities the retrograde metamorphism is accompanied by shearing and in a single outcrop a grey, partly retrograded augen gneiss changes gradually, by increased shearing and 'streaking out' of the feldspar augen, into a thinly banded rock. It consists mainly of antiperthite and perthite (with rims of plagioclase) and subordinate quartz, hornblende, biotite, haematite and garnet (all forming characteristic coronite aggregates) and accessory zircon and apatite. Rare clinopyroxene is present. It has dark green amphibole rims and appears to be replaced by biotite and quartz within the amphibole rim.

Near Fuglehuk a completely retrograded basic rock occurs. It was probably initially part of one of the gabbroic-ultramafic intrusive masses. It is dark green, medium-grained and consists almost completely of pale green amphibole with minor saussuritized plagioclase, chlorite, biotite, opaque minerals and rare, relict clinopyroxene.

Structure.

The structure of Moskenesøy is dominated in the south by an anticline trending approximately ENE and plunging to the NE. The anorthosite is intruded into the core of this fold. The structure is well defined in the layered gneiss sequence bordering the anorthosite, but north of Moskenes the general trends swing to nearly N-S and the rocks are isoclinally folded, though some exposures indicate at least two generations of folding and show fold patterns deviating markedly from the general trend. The overall N-S trend is particularly dominant north of Reine; some trends oblique to this may be attributed to zones of shearing and retrogression.

The contacts between the major rock types are conformable, but the gabbro/country rock contacts are sharply crosscutting. In general the pegmatite dykes trend approximately NE-SW and dip steeply to the NW, while the dolerite dykes have a variety of trends.

Chemistry.

The major element chemistry, C.I.P.W. norms and some trace element chemistry of the major rock types, grouped according to the petrographical descriptions given in an earlier section, are presented in Table 1. Rather than discuss the chemistry of the Moskenesøy rocks alone, it is of greater interest to incorporate chemical data for the rest of the Lofoten Islands, using data from Heier and Thoresen (1971), since the islands form part of a single high-grade petrologic province.

The most noteworthy features of the chemistry are (1) The monzonitic augen gneiss — dioritic gneiss sequence of Moskenesøy is chemically distinct from the massive mangerites of Vestvågøy, Flakstadøy and Moskenesøy. This is of particular interest because in some localities the monzonitic gneiss (e.g. specimen 170) could not be distinguished in the field from the massive porphyritic mangerite intrusive rocks (as discussed on p. 51). The monzonitic gneiss is more variable in composition than the intrusive mangerites, but generally contains higher Ca, Mg, Fe and lower Si and K. In general the K/Rb ratio is >600 in the massive mangerites and < 600 in the monzonitic gneiss sequence. This reflects the pattern of increasing K/Rb with increasing K pointed out by Heier and Thoresen (1971).

(2) The various textural varieties of the monzonitic gneisses (e.g. H-109, 1, 170, 181, 200) have similar overall chemistry, though the transition between the more mafic dioritic gneisses and the monzonitic gneisses is reflected in the analysis of specimen 1.

(3) Two analyses of strongly retrograded rocks show their similar major and minor element chemistry to slightly retrograded members of the gneiss sequence (thus specimen 249 is similar to a typical monzonitic gneiss while 246 is similar, except for higher K content, to a quartz-bearing leucocratic member of the sequence). The high-K specimen 246 only has a K/Rb ratio of 280 and is an exception to the general trend of K/Rb increasing with K content as mentioned above.

(4) The banded leucocratic mangerite (148B) from the veined and layered gneiss sequence is intermediate in chemistry between a leucocratic monzonitic gneiss and a massive mangerite.

(5) The dioritic gneiss (38) is similar in major element chemistry to the Djupfjord gabbro (37).

(6) Specimen 300C was chosen as a typical anorthosite and the thin section showed >95 % plagioclase. However the analysis obtained

is typical of an anorthositic gabbro rather than a true anorthosite. Thus a non-representative, more mafic portion of the complex was analyzed. The K/Rb ratio of this anorthositic gabbro is significantly higher than that found in the basic rocks from the small gabbro intrusions and supports the field interpretation that there is no direct link between the two rock types.

(7) Specimens 305A, 305G were collected from the anorthosite/gneisscontact. Specimen 305A was coarse grained and was believed to represent the anorthositic pegmatitic fraction commonly found in the contact zone while specimen 305G was finer grained and in contact with 305A. It was believed to represent the gneiss intruded by specimen 305A. The analyses and the CIPW norms show that both specimens are anorthositic with high normative plagioclase and extremely low Rb contents and high K/Rb ratios. This points to the close mixing of the gneiss/anorthosite at the contact and the difficulty of separating the two rocks in this zone on field evidence alone.

(8) The layered gneiss, represented by specimens 261 and 304A, is of dioritic or quartz dioritic composition, though there must be considerable variation in composition from layer to layer, indicated by the marked changes in mineralogy (p. 56). Specimen 304A is from within a few metres of the anorthosite/gneiss contact zone but specimen 261 is several hundred metres distant. The low Rb and high Sr content and the high K/Rb ratio are particularly noteworthy and comparable with the values found in the anorthosite and anorthosite/gneiss contact zone.

(9) Specimen 304 is a coarse grained pegmatitic rock chosen as an example of the proposed melt developed in the contact zone. The high Fe, Ti and P contents relative to the anorthosite and the layered gneiss reflect the high opaque mineral and apatite content of this rock, though the Rb, Sr and Zr contents and the K/Rb ratio are not significantly different from the values obtained from the anorthosite and gneiss.

(10) The mafic-ultramafic rocks fall into a group on their own when the major and especially their trace element chemistry is examined. In particular the K/Rb ratio is significantly higher than that typical for the monzonitic-dioritic gneiss sequence but is markedly lower than found for the anorthosite and the layered gneiss.

(11) The late-stage intrusive dolerite has the chemistry of a rather iron-rich alkali basalt. It is notably high in Ti and P. It has significantly higher Rb and lower Sr and K/Rb ratio than the mafic-ultramafic intrusions.

(12) Finally, attention is drawn to monzonitic chemistry of specimen 5A and the low Rb and very high K/Rb ratio for this rock. These values support the hypothesis (p. 58) that these latestage dykes and veins formed by partial melting of the low-Rb dioritic→quartz dioritic layered gneiss possibly linked with the anorthosite formation and emplacement.

Origin of the anorthosite.

The structural position of the anorthosite, the intermixing of gneiss and anorthosite in the contact zone, the presence of gneiss inclusions in the anorthosite and the strong suggestion of partial melting of the gneiss in the immediate contact zone all suggest that either (1) the anorthosite intruded as a hot body into its present position, probably as an intrusive semi-solid crystal mush, or (2) the anorthosite formed as a crystalline residuum resulting from partial melting of the dominantly quartz dioritic layered gneiss sequence in the core of an anticline. In general the low melting fraction separated completely from the residuum during formation and only traces of this are left directly associated with the anorthosite and gneiss sequence.

The lack of any well defined gabbroic margin precludes the direct origin of the anorthosite from a basic magma by flotation of plagioclase crystals as envisaged by Romey for the layered norite-troctolite-anorthosite complex of Flakstadøy. Romey (1970) described strong evidence for crystal accumulation, but such features were not observed in the Moskenesøy anorthosite. It is possible that the latter anorthosite represents the anorthositic fraction (from a differentiated basic complex) that was subsequently separated from the more mafic fraction during deformation and intruded as a semi-solid hot mass. This cannot be proved or disproved on the evidence available. However there is no field indication of an associated large volume of ultramafics necessary as the complementary fractionate. The small mafic-ultramafic bodies are interpreted, on field and geochemical observations, as being unrelated to the anorthosite. High Bouger anomalies under Moskenesøy (138 milligals) decreasing regularly north-westwards to between 40 and 80 milligals under Langøy, together with seismic data have been interpreted as resulting from a shallower Moho-discontinuity under Moskenesøy compared with Langøy (Sellevoll 1967). However geophysical methods cannot distinguish between anomalies produced by (1) a shallow Moho or by (2) the presence at the base of the crust of a large ultramafic residuum complementary to the anorthosite observed at higher levels.

It is significant that the composition of the layered gneiss surrounding the anorthosite is dominantly diorite-quartz diorite, a suitable parent composition for giving rise to an anorthositic-gabbroic anorthositic residuum by anatexis at deep levels in the earth's crust (Green 1969a, 1969b). Also the low Rb and the very high K/Rb ratio, even when compared with other granulite facies rocks, suggests that a major partial melting event may have taken place. However the required complementary low melting salic liquid fraction cannot be identified in the area. The dykes and veins of monzonite are of suitable composition but are relatively minor in volume. Rare earth element determinations for the major rocks of Moskenesøy may clarify this (cf. Green et al 1969), but it is quite likely that any such complementary salic magma intruded to higher levels.

Thus it is impossible at present to decide whether the Moskenesøy anorthosite was derived initially from a parent basaltic magma or formed as a residuum by partial melting of a sequence of dioritic-quartz dioritic composition at deep crustal levels. The weight of geochemical evidence supports the latter interpretation.

Conclusions.

It is clear from their petrography and chemistry that the rocks of Moskenesøy form part of the Lofoten—Vesterålen high grade metamorphic province. The geochronological work of Heier and Compston (1969) on the rocks of this province, combined with the studies on secondary garnet formation by Griffin and Heier (1969) lead to the following conclusions.

The oldest rocks of Moskenesøy are the metasedimentary and metavolcanic veined and layered gneisses and monzonitic-dioritic gneisses. These rocks were subjected to granulite facies metamorphism possibly as early as 2800 m.y. ago. Prior to, or at the same time as this metamorphism, the gneisses were intruded by massive mangerites. There is one small exposure of mangerite of this type on Moskenesøy. Emplacement of the anorthosite, ultramafic-gabbroic bodies and finally the dolerite dykes took place. The dolerites intruded either during or subsequent to a time of shearing. The last event to occur involved the intrusion of a series of pegmatite dykes, especially on South Moskenesøy.

The advent of an oxidising fluid into the above rocks at 1700—1800 m.y. ago caused updating of these rocks and the formation of the secondary garnet and the completely retrograded gneisses. It is interesting to speculate that the introduction of the oxidising fluid and the intrusion of the pegmatite dykes are different expressions of the same event. The extensive and frequently total retrogression of the rocks of North Moskenesøy, the abundant evidence of widespread shearing and the general lack of pegmatite dykes are features of North Moskenesøy. In contrast, on South Moskenesøy there are common large pegmatite dykes, frequently following well defined, though narrow, shear zones and there is generally only minor retrogression of the country rocks (usually secondary garnet formation). An explanation of these features is that where shearing was widespread on North Moskenesøy the fluids were able to permeate and spread out through the country rocks on a large scale, but where the shearing was narrowly defined, as on South Moskenesøy, the fluids were confined and formed pegmatitic dykes in the shear zones and only had small scale retrogressive effects on the country rocks. Intermediate stages between these two extremes are exposed in mid-Moskenesøy where thin pegmatite veins (1—5 cms) in shear zones are bordered by zones of retrogression several metres thick in the country rocks.

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References.

ANDERSON, A. T., & MORIN, M. 1969: Two types of massif anorthosites and their implications regarding the thermal history of the crust. *The origin of anorthosite and related rocks* (Y. W. Isachsen, ed). *New York State Museum and Science Service Mem. 18, 57—69.*

GREEN, T. H. 1969a: Experimental fractional crystallization of quartz diorite and its application to the problem of anorthosite origin. *The Origin of anorthosite and related rocks* (Y. W. Isachsen, ed.). *New York State Museum and Science Service Mem. 18,* 23—29.

GREEN, T. H. 1969b: High pressure experimental studies on the origin of anorthosite, *Canadian Jour. Earth Sci. 6,* 427—440.

GREEN, T. H., BRUNFELT, A. O., & HEIER, K. S. 1969: Rare earth element distribution in anorthosites and associated high grade metamorphic rocks, Lofoten—Vesteraalen, Norway. *Earth and Planetary Sci. Letters, 7,* 93—98.

GRIFFIN, W. L. 1971: Geology of Austvågøy. *(in prep.)*

GRIFFIN, W. L. & HEIER, K. S. 1969: Parageneses of garnet in granulite facies rocks, Lofoten—Vesteraalen, Norway. *Contr. Mineral and Petrol. 23,* 89—116.

HEIER, K. S. 1960: Petrology and geochemistry of high-grade metamorphic and igneous rocks on Langøy, Northern Norway. *Norges Geol. Unders. 207,* 246 pp.

HEIER, K. S. & COMPSTON, W. 1969: Interpretation of Rb-Sr age patterns in high-grade metamorphic rocks, North Norway. *Norsk Geol. Tidsskr. 49,* 257—283.

HEIER, K. S. & THORESEN, K. 1971: Geochemistry of high grade metamorphic rocks, Lofoten—Vesterålen, North Norway. Geochim. et Cosmochim. Acta 35, 89—99.

HELLAND, A. 1897: Lofoten og Vesterålen. *Norges Geol. Unders. 23,* 545 pp.

KOLDERUP, C. F. 1898: Lofotens og Vesterålens gabbrobergarter. *Bergens Museums Aarbog,* 1—56.

ROMEY, W. D. 1971: Basic igneous complex, mangerite and high grade gneisses of Flakstadøy, Lofoten, Northern Norway: I. Field relations and speculations on origin. *Norsk Geol. Tidsskr.* in press.

SELLEVOLL, M. A. 1967: Seismic measurements in Norway 1965, Lofoten—Vesterålen region. In 'Site selection for a seismic array station and crustal studies in Norway 1965'; Final scientific report (A. Sørnes & M. A. Sellevoll). *Advanced Research Project Agency No. 612—1, 61—76.*

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Table 1. Analyses of rocks from Moskenesøy.

	Monzonitic gneiss								
	1	H-109	170	181	200	249	354	194	246
SiO_2	52.54	54.05	56.88	55.84	59.74	54.80	58.30	70.15	69.97
TiO_2	1.24	0.95	0.97	0.89	0.87	0.96	0.56	0.33	0.23
Al_2O_3	18.38	19.04	19.16	20.12	16.99	19.18	17.74	16.16	14.90
Fe_2O_3		3.85							
FeO	9.92*	3.90	7.39*	6.80*	7.68*	7.34*	5.86*	2.51*	2.12*
MnO	0.17	0.13	0.14	0.13	0.10	0.14	0.13	0.05	0.05
MgO	3.73	3.03	3.16	3.10	2.70	2.58	4.17	0.30	0.20
CaO	6.07	5.53	5.99	5.70	5.07	5.68	6.44	2.33	0.56
Na_2O	4.53	5.10	4.66	4.83	4.26	5.26	3.10	3.94	2.96
K_2O	3.14	3.12	2.69	3.15	3.20	2.68	2.92	4.03	6.98
P_2O_5	0.69	0.46	0.51	0.46	0.45	0.56	0.19	0.18	0.07
Sum	100.41	99.16	101.55	101.02	101.06	99.18	99.41	99.98	98.04
Rb ppm	69		43	59	60	87	56	105	249
Sr ppm	983		950	1051	620	1013	749	676	282
Zr ppm	409		301	342	384	332	236	199	220
K/Rb	378		520	443	442	256	432	319	232
Rb/Sr	0.0702		0.0453	0.0561	0.0967	0.0859	0.0749	0.155	0.883

* Total iron expressed as FeO.

Na_2O determined by flame photometer, all other elements by x-ray fluorescence, Mineralogisk-Geologisk Museum. Analysis numbers with prefix «H» from Heier (unpublished results).

C.I.P.W. Norms

	1	H-109	170	181	200	249	354	194	246
q	—	—	—	—	4.22	—	6.09	25.01	23.12
or	18.55	18.43	15.89	18.61	18.91	15.83	17.25	23.81	41.24
ab	32.10	42,15	39.41	40.85	36.03	42.51	26.22	33.32	25.03
ne	3.37	0.53	—	—	—	1.07	—	—	—
an	20.55	19.85	23.43	23.92	17.79	20.82	25.87	10.38	2.32
c	—	—	—	—	—	—	—	1.51	1.63
di	4.26	3.67	2.48	1.12	3.73	3.12	3.99	—	—
hyp	—	—	12.86	0.28	17.68	—	18.48	4.90	4.10
ol	17.63	6.07	4.45	13.47	—	12.70	—	—	
mt	—	5.58	—	—	—	—	—	—	
il	2.35	1.80	1.84	1.69	1.65	1.82	1.06	0.63	0.44
ap	1.60	1.07	1.18	1.07	1.04	1.30	0.44	0.42	0.16

Because Fe^{2+}/Fe^{3+} was not determined in many of the analyses all Fe has been taken as Fe^{2+} in the norm calculation. Thus no magnetite is calculated and also the norms show higher normative olivine and nepheline and lower hypersthene than would be the real case. In spite of this shortcoming it is apparent that several of the monzonitic and dioritic gneisses are olivine-normative (e.g. H-109 where Fe^{2+}/Fe^{3+} is known) but probably none would in fact be strongly nepheline-normative.

	Monzonitic gneiss	Dioritic gneisses		Veined and Layered gneisses			Layered gneisses (associated with the anorthosite)		
	148B	H-110	38	148A	H-106	H-108	261	304A	304
SiO_2	68.33	50.48	49.89	53.18	49.13	48.48	62.54	56.58	51.62
TiO_2	0.33	0.75	1.05	0.88	0.80	0.68	0.48	0.22	1.07
Al_2O_3	16.75	18.21	18.41	15.46	19.34	19.30	18.03	18.58	18.69
Fe_2O_3		7.36			6.43	5.58			
FeO	2.80*	2.65	10.29*	8.45*	4.05	4.40	5.13*	6.47*	11.21*
MnO	0.04	0.16	0.16	0.14	0.17	0.17	0.07	0.16	0.13
MgO	0.17	6.14	6.68	7.52	5.30	6.25	1.20	4.84	2.95
CaO	2.93	8.60	9.06	6.52	8.86	9.52	4.74	6.56	7.45
Na_2O	3.94	4.20	3.72	3.36	3.75	3.55	5.39	4.46	4.70
K_2O	3.92	1.30	1.34	3.91	1.52	0.99	2.13	1.19	1.20
P_2O_5	0.15	0.24	0.43	0.39	0.36	0.17	0.37	0.44	1.74
Sum	99.36	100.09	101.03	99.81	99.71	99.09	100.08	99.50	100.76
Rb ppm	58		24	112			2	4	2
Sr ppm	485		1152	875			792	1083	1116
Zr ppm	330		285	250			164	197	204
K/Rb	561		464	290			8837	2469	4979
Rb/Sr	0.120		0.0208	0.128			0.00252	0.00369	0.00179

* Total iron expressed as FeO.

	Monzonitic gneiss	Dioritic gneisses		Veined and Layered gneisses			Layered gneisses (associated with the anorthosite)		
	148B	H-110	38	148A	H-106	H-108	261	304A	304
q	22.20	—	—	—	—	—	8.69	1.24	—
or	23.16	7.68	7.92	23.10	8.98	5.85	12.58	7.03	7.09
ab	33.32	35.52	25.68	25.14	31.72	30.02	45.59	37.72	39.75
ne	—	—	3.13	1.78	—	—	—	—	—
an	13.55	27.00	29.58	15.56	31.70	33.81	18.72	27.17	25.58
c	1.06	—	—	—	—	—	—	—	0.29
di	—	10.96	10.40	11.67	7.77	9.73	2.03	2.06	—
hyp	5.09	0.99	—	—	1.43	0.73	10.70	22.84	8.57
ol	—	6.46	21.33	19.99	6.54	9.17	—	—	13.42
mt	—	6.89	—	—	9.32	8.09	—	—	—
hm	—	2.61	—	—	—	—	—	—	—
ilm	0.63	1.42	1.99	1.67	1.52	1.29	0.91	0.42	2.03
ap	0.35	0.56	1.00	0.90	0.83	0.39	0.86	1.02	4.03

	Mangerite Moskenesøy		Anorthositic rocks			Basic intrusives			
	5A	H-107	305G	305A	300C	37	109	145A	160
SiO_2	57.26	61.31	58.41	56.93	55.22	51.64	49.80	49.50	47.81
TiO_2	0.87	0.86	0.12	0.19	0.21	0.55	0.15	0.52	2.96
Al_2O_3	17.06	16.67	22.58	21.30	18.01	15.95	3.88	16.25	15.60
Fe_2O_3		1.17							
FeO	9.43*	5.10	3.11*	3.21*	8.03*	8.94*	13.13*	8.51*	14.93*
MnO	0.14	0.22	0.07	0.08	0.21	0.16	0.26	0.15	0.24
MgO	1.38	0.73	2.01	2.08	7.53	8.95	31.89	11.25	7.19
CaO	4.00	2.41	6.60	7.62	6.10	10.89	2.31	12.01	9.21
Na_2O	4.75	5.10	5.25	5.01	3.79	2.50	0.30	1.94	2.78
K_2O	4.47	6.26	1.50	1.41	0.59	1.13	0.07	0.45	1.12
P_2O_5	0.63	0.17	0.10	0.10	0.10	0.23	0.08	0.25	0.76
Sum	99.99	100.00	99.75	97.93	99.79	100.94	101.87	100.83	102.60
Rb ppm	21	40	5	4	1	38	1	5	19
Sr ppm	473	44	1281	1235	888	713	75	1242	347
Zr ppm	101		225	218	157	157	34	269	194
K/Rb	1770	1313	2489	2925	4895	247	581	747	490
Rb/Sr	0.0445	0.910	0.00390	0.00324	0.00113	0.0534	0.0133	0.00401	0.0548

* Total iron expressed as Fe0.

	Mangerite Moskenesøy		Anorthositic rocks			Basic intrusives			
	5A	H-107	305G	305A	300C	37	109	145A	160
q	—	0.03	2.73	1.89	0.20	—	—	—	—
or	26.41	36.99	8.86	8.33	3.49	6.68	0.41	2.66	6.62
ab	40.17	43.13	44.40	42.37	32.05	21.14	2.54	16.41	23.51
an	12.04	4.11	32.08	31.47	29.60	28.97	9.03	34.30	26.78
c	—	—	0.57	—	0.29	—		—	—
di	3.20	5.81	—	4.70	—	19.26	1.52	19.17	11.62
hyp	6.04	6.20	10.65	8.57	33.53	8.85	49.50	8.13	2.70
ol	9.02	—	—	—	—	14.47	38.40	18.60	23.98
mt	—	1.70	—	—	—	—	—		—
ilm	1.65	1.63	0.23	0.36	0.40	1.04	0.28	0.99	5.62
ap	1.46	0.39	0.23	0.23	0.23	0.53	0.19	0.58	1.76