The Geology of the Gjersvik Area, Nord-Trøndelag, Central Norway

OLE LUTRO

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The Gjersvik area consist of low-grade metamorphic rocks overlain in the west by the higher grade Helgeland Nappe Complex. The low-grade sequence is divided into three groups, the Gjersvik, the Limingen and the Røyrvik Groups. The Gjersvik and Limingen Groups constitute a redefined Gjersvik Nappe, thrusted above the Røyrvik Group. The stratigraphy within the Gjersvik Nappe is inverted. The greenstones and felsic rocks in the Gjersvik Group are of tholeiitic affinity and are thought to represent part of a Lower or Middle Ordovician island arc complex which was affected by sea floor weathering after deposition. Parorogenic movements, possibly in Middle Ordovician time, led to erosion of the Gjersvik Group and the formation of a polymict conglomerate marking the basal unit of the Limingen Group. This group consists mainly of calcareous metasediments of shallow water origin and is probably of Middle to Upper Ordovician age. The Røyrvik Group consists of phyllites, often bituminous, associated with quartzites and some greenschists. The group has an uncertain age and stratigraphical position. The Helgeland Nappe Complex in the map area is composed of metasedimentary gneisses and schists intruded by a tonalite.

The Helgeland Nappe Complex appears to have been subjected to a folding and metamorphism which is not recorded in the rocks in the rest of the area; the age of this metamorphism, which reached amphibolite facies, is unknown. The main folding and metamorphism which affected all the rocks in the area probably occurred towards the end of Silurian time. This deformation is divided into five different episodes of which the first two are the main ones. The regional schistosity was formed during the first episode, and late in this episode the thrusting took place. In the western part of the area upper greenschist facies conditions were reached during the first phase of folding, whereas lower greenschist facies conditions prevailed in the eastern part. The later phases of folding took place under waning metamorphism with some retrogression of the metamorphic mineralogy. The intrusion of the tonalite occurred either at a late stage during or after the second phase of Silurian folding.

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Introduction

The Gjersvik area is situated in Nord-Trøndelag in central Norway, north and northwest of the lake Limingen (Fig. 1). Geologically, the eastern and greater part of the investigated area belongs to the Grong region of low-metamorphic rocks which was extensively mapped by the late state geologist Steinar Foslie in the 1920's and 1930's. The rocks in the western part of the area belong to the high-metamorphic sequences of the Helgeland Nappe Complex (Ramberg 1967, Gustavson 1973). The geology of the Gjersvik area has previously been described by Foslie & Strand (1956).

Remapping of the Grong region has been carried out by several workers during the last few years and is still going on. This account is based on the

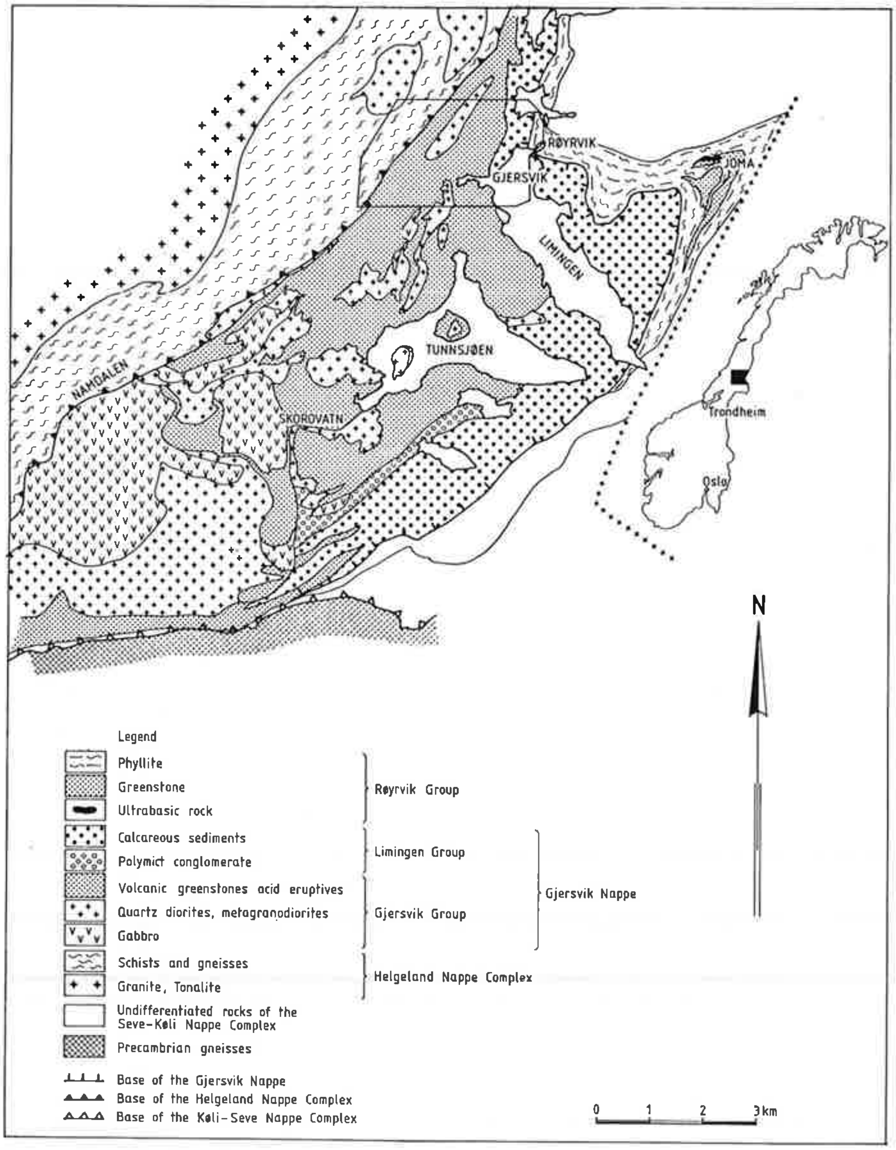


Fig. 1. Simplified geological map of the Grong region, based on maps by Foslie (1957, 1958 a, b, c) and Halls et al. (1977). The Gjersvik area is outlined.

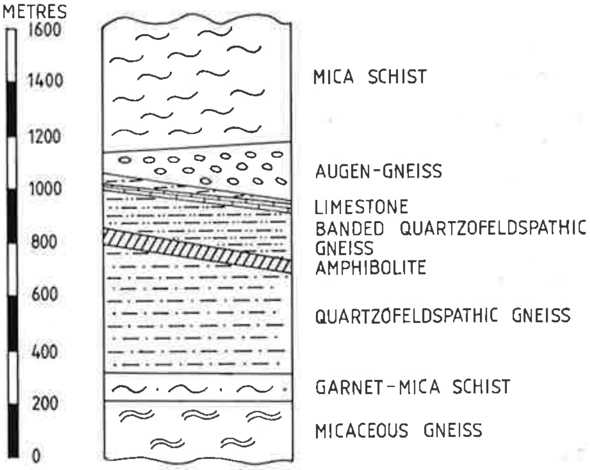
author's part of the remapping (Plate 1), covering an area of about 160 m^2, and is a shortened version of a cand. real. thesis submitted at the University of Bergen (Lutro 1977).

Lithological descriptions

THE HELGELAND NAPPE COMPLEX

The western part of the Gjersvik area is composed of rocks of high metamorphic grade. The main lithologies are gneisses and schists with minor

Fig. 2. The tectonostratigraphic succession of the Helgeland Nappe Complex within the Gjersvik area. The ornament used is the same as in Plate 1.



amphibolites, limestones and quartzites. Intruded into these rocks is a body of tonalite and smaller lenses of altered peridotites are also found. The rocks have been metamorphosed in lower to middle almandine amphibolite facies and subjected to polyphase deformation. The rocks are described by Foslie & Strand as high metamorphic Cambro-Silurian sediments and gneisses belonging to a thrust unit overlying the eastern low-metamorphic rocks of the area. This thrust unit has been called the Helgeland Nappe by Ramberg (1967) and the Helgeland Nappe Complex by Gustavson (1973).

The rocks within this part of the Helgeland Nappe Complex have been divided into a tectono-stratigraphic succession (Fig. 2). Whether or not this represents a true stratigraphic sequence is difficult to tell since no primary sedimentary structures are found.

In the following account, lithological descriptions are purposely brief. Fuller descriptions of the rock-types are contained in Lutro (1977).

MICACEOUS GNEISS

This rock-type occupies the core of a large F_2 fold, the Kjeråklumpen Antiform, in the western part of Steinfjellet and is probably structurally the lowest rock unit in this part of the Helgeland Nappe Complex. It is a greyish fine-grained and schistose rock, with a weak gneissic banding developed. It consists mainly of quartz, plagioclase, muscovite and biotite.

Near the western margin a thin limestone horizon 1 to 2 m thick occurs within the gneiss. This limestone is sometimes altered to a medium-grained heteroblastic calc-silicate rock consisting of tremolite with some plagioclase, diopside and epidote.

QUARTZO-FELDSPATHIC GNEISS

This rock-type is found on both limbs of the Kjeråklumpen Antiform in two separate zones which join up north of Kjæråen. The gneiss in the eastern outcrop is up to 500 m thick in the northern part but thins out southwards, The gneiss of the western zone extends outside the present map-area. The gneiss is a greyish-white rock with a well developed schistosity and a gneissic banding. It has a very uniform composition and consists of quartz, albite and microcline with a minor amount of biotite. It is heteroblastic with grains of albite and microcline up to 5 mm in size.

AMPHIBOLITE

The quartzo-feldspathic gneiss to the east is in contact with an up to 70 m thick, dark-coloured, fine to medium-grained schistose amphibolite consisting mainly of hornblende and oligoclase. The rock contains many coarse-grained lenses and veins composed mainly of oligoclase. These are mostly oriented parallel to the pervasive schistosity in the rock.

BANDED QUARTZO–FELDSPATHIC GNEISS

East of the amphibolite occurs a rather inhomogeneous rock unit consisting of a quartzo-feldspathic gneiss with bands of amphibolite and zones and lenses of limestone and augen-gneiss. This unit is about 200 m thick.

The banded quartzo-feldspathic gneiss is rather similar to the quartzo-feldspathic gneiss except that it contains bands of amphibolite up to about 10 cm in thickness. These bands lie parallel to the schistosity. There are also many zones of limestone with thicknesses up to 10 metres. This is a fine- or medium-grained rock; in addition to calcite it contains minor amounts of diopside, tremolite and phlogopite.

AUGEN-GNEISS

Augen-gneiss occurs mainly in the northern part of the map area. North-northeast of Kjeråtjørnin it has a thickness of about 200 metres. It wedges out southwards, where it occurs as thinner zones within the banded quartzo-feldspathic gneiss. This is a schistose and at times banded rock with bands consisting of quartz and plagioclase which alternate with darker biotite-rich layers. The banding and schistosity are parallel and wrap around augen of oligoclase up to 3 cm across.

LIMESTONE

Most of the limestone within this part of the Helgeland Nappe Complex occurs in the easternmost part of the complex near to the contact to the Gjersvik Group. The number of individual bands of limestone and thicknesses are extremely variable. These features have been described in some detail by Foslie & Strand (1956) and Lutro (1977).

The limestone is usually steel-grey to almost black in colour, but can locally be brownish-grey. Sometimes it displays a fine banding consisting of white bands of recrystallized calcite, 1–2 mm thick. The rock, which is fine- to medium-grained, consists of calcite with minor tremolite and phlogopite.

Layers of other lithologies such as mica schist, quartzitic rocks, gneisses and amphibolite are found within the limestone. These layers are often deformed and broken up into round, lensoid or rather angular fragments ranging in size from a few millimetres to several metres. The regional schistosity swings around these fragments.

MICA SCHIST

Between the easternmost limestone and the Gjersvik Group a thin zone of mica schist up to 30 m thick is present. Most of the mica schist, however, outcrops in between the eastern limestones, the augen-gneiss and the banded quartzo–feldspathic gneiss. The mica-schist is thought to constitute the core of a major synform, the Sierkesjohke Synform.

The schist is usually a fine- to medium-grained greyish rock which locally contains frequent augen of plagioclase as well as several generations of pegmatitic veins and lenses. In the area around Ohtje Stöörje the pegmatitic veins strongly dominate over the host mica schist.

In the mica schist an up to 50 m-thick quartzite horizon runs south-southwestwards from lake 789 and gradually thins out. This is a fine-grained light-coloured rock containing bands or thin zones of dark amphibolite and mica schist.

TONALITE

A massif of tonalite is intruded into the mica schist and quartzo–feldspathic gneiss in the north-west corner of the map-area. It is a light-coloured medium-grained rock consisting of quartz, oligoclase, biotite, sphene and epidote. The oligoclase occurs in lath-shaped grains up to 0,5 cm in length.

SERPENTINITE

In the mica schist several small lenticular serpentinite bodies occur, these having a typical brownish colour on weathered surfaces. The largest of these serpentinites, about 75 m long and 10 m wide is found just north of Kjæråtjørnin. The rock consists of relics of olivine surrounded by serpentine minerals, magnesite and opaque minerals.

Origin of the Helgeland Nappe Complex

The occurrence of sedimentary rocks such as limestones and quartzites within the gneisses and schists points to a sedimentary origin for most of the layered rocks within this part of the Helgeland Nappe Complex. The only exception is the amphibolite which might conceivably be igneous. The contact zones between the different rock units, with the exception of the tonalite, do not show any features such as xenoliths and apophyses indicating igneous contacts. Nor do they show signs of a stronger deformation than that affecting the bulk of the rock pile. The contact relationships would thus indicate that the present lithological sequence might represent a metamorphosed sedimentary succession.

The gneisses, except for micaceous gneiss, are feldspar-rich, mica-poor rocks and have a composition pointing to an origin as arkosic sediments, whereas the schists most probably represent metamorphosed pelites and the micaceous gneiss a pelitic feldspathic sandstone. The original sedimentary succession then might have consisted of arkosic sandstones, pelitic feldspathic sandstone, pelites, limestones and quartzites with possibly a mafic volcanic rock now represented by the amphibolite.

The combination of arkosic sandstones, pelitic feldspathic sandstones, quartzites and limestones suggests that these rocks were deposited in a near-coastal environment with only a short transport of the clastic debris which might have come from a granitic terrain.

The assumed original lithologies have similarities with rocks deposited in late Precambrian times in Scandinavia, when arkoses, quartzites pelites and limestones, with minor volcanic rocks, were deposited in fault-controlled basins (Bjørlykke et al. 1976). Later in this account it is argued, on tectonic and metamorphic grounds, that the rocks of the Helgeland Nappe Complex within the map-area might have a Cambrian or older age.

THE GJERSVIK GROUP

The central part of the map-area is made up of metavolcanic, meta-intrusive and minor metasedimentary rocks (Plate 1). These have been metamorphosed in lower middle greenschist facies and have been subjected to several phases of deformation. These rocks have previously been called the Gjersvik Nappe (Oftedahl 1956, Foslie & Strand 1956) and the Skorovass Greenstone (Oftedahl 1974), but have been redefined as a group, the Gjersvik Group (Halls et al. 1977, Lutro 1977).

The rocks which constitute the Gjersvik Group are divided informally into three formations (Lutro 1977):

The Bjørkvatnet Formation	(youngest)
The Bjørkvassklumpen Formation	
The Kleiva Formation	(oldest)

The Kleiva Formation

The main lithology of this formation is a banded amphibolite intercalated within which are a variety of meta-igneous rocks ranging from metagabbro in the southern outcrop to metadiorite and some metagranodiorite in the northern area.

The banded amphibolite is a schistose rock in which the banding is produced by darker actinolite, biotite and epidote-rich layers which alternate with lighter, more plagioclase-rich bands, the plagioclase often occurring as porphyroclasts. The banding is on the millimetre scale. The rock is progressively finer grained and markedly more schistose towards the contact with the Helgeland Nappe Complex where it is represented by an actinolite–epidote–chlorite schist.

Metagabbro occurs mainly in a 200 to 250 m-thick and 4 km-long body in the southern part of the formation outcrop. In addition, smaller lensoid bodies 10 to 50 m in length are found north of the main body. The rock is generally medium- to coarse-grained, massive to weakly foliated and consists of actinolite, epidote and strongly saussuritized plagioclase. It contains numerous gabbroic pegmatitic veins with plagioclase and actinolite laths up to 5 cm in size.

Within the metagabbro, lenses of serpentinite up to 50 m in length and 10 m across are present; these are often grouped in trains. Monomineralic zones of actinolite are also found.

Metadiorite is found east of Kjæråtjørnin and further to the north-north-east where it forms a large part of the northern outcrop of the formation. It is a greyish rock and varies from massive to strongly foliated and banded. The main minerals are partly altered andesine, actinolite and epidote. Quartz and garnet are found in minor amounts.

Metagranodiorite is present in thin (0,5–20 m wide) but rather extensive (1–2 km) zones. It is porphyritic with plagioclase megacrysts lying in a very fine-grained often schistose groundmass of quartz, plagioclase, sericite and epidote.

In addition to the serpentinites within the metagabbro, serpentinite bodies up to 100 m in length occur within the banded amphibolite. These contain relics of olivine which is strongly altered to serpentine minerals. The serpentinites are often strongly schistose along their margins but have massive central portions.

The Bjørkvassklumpen Formation

East of and structurally below the Kleiva Formation is a formation consisting of fine-grained actinolite schists and some felsic rocks, the Bjørkvassklumpen Formation.

The actinolite schist is a very fine-grained dark schistose rock consisting mainly of actinolite, albite and epidote with some quartz, chlorite and biotite. In its eastern part this rock is often banded. The rock contains lens-shaped aggregates of epidote and these are enveloped by the banding and the schistosity.

The felsic rocks are metamorphosed fine- to coarse-grained granodiorites occurring in rather thin but extensive zones (0,5–30 m wide and up to 3 km long) and containing porphyroclasts of albite in a very fine-grained and schistose groundmass. The coarse-grained metagranodiorite occurring south-west of Bjørkvatnet is less deformed than the other more elongate bodies.

The Bjørkvatnet Formation

This formation constitutes the eastern part of the Gjersvik Group and is considered to be the youngest unit of the group. The formation consists of an approximately 3 km-thick sequence of metavolcanic and meta-intrusive rocks. The sequence is inverted with the rocks younging towards the east. Fig. 3 shows schematically the succession within the formation.

The dominating rock-types within the formation are massive to variably schistose volcanic greenstones which were deposited either as pillow lavas or as massive flows. In the area around and just north of Bjørkvatnet and on Annlifjellet, pillow lavas are well developed in two different horizons. In addition, pillow structure has been observed in lavas in other localities.

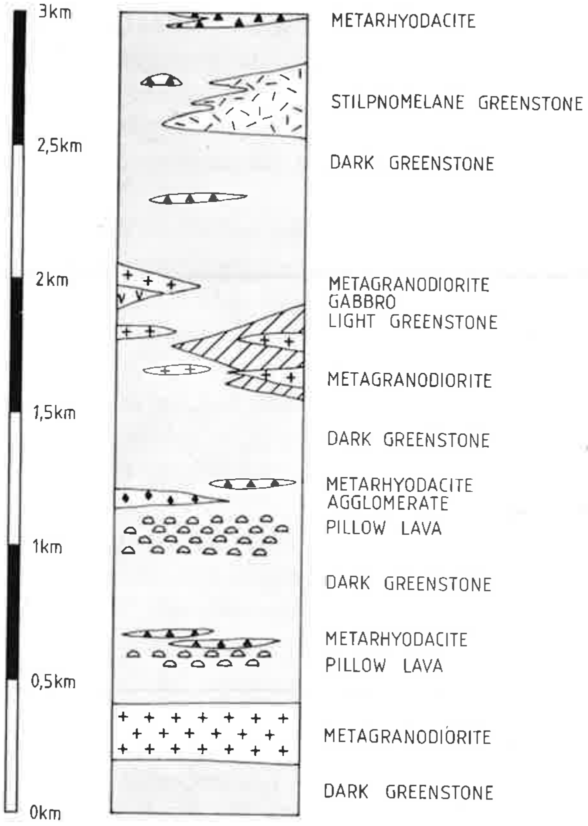


Fig. 3. Schematic stratigraphic column of the Bjørkvatnet Formation.

The pillows are usually 0,5 to 1 m across and rather round to somewhat flattened in cross section. The chilled margin is often marked by a 0,5 to 2 cm-thick zone rich in either epidote or dark chlorite. The interiors of the pillows are usually massive and contain few vesicles, but on Annlifjellet parts of the pillows consist of round masses of epidote. These were formed either by replacement or by the filling up of pillows emptied during extrusion with epidote and some quartz.

The pillow lavas indicate extrusion into water, usually in a submarine environment (MacDonald 1968, Wilson 1960). The pillows contain few vesicles and this is generally taken to indicate either that the lavas was gas-deficient or that it was extruded in relatively deep water (Moore 1965, Jones 1969). The shape of individual pillows is usually helpful in determining the way up in the lava sequence (Shrock 1948). Using this criterion the pillows in the area show the lava pile to be inverted as depicted in Fig. 4.

The greenstones are most commonly seen without pillow structures. The thickness of individual flows is not readily determinable, but near Gjersvik exposures are found where subparallel epidote-rich zones occur, 1 to 3 cm wide. These are rather similar to the chilled margins of the pillow lavas and may represent the chilled bottom or top of individual lava flows. The thickness of the individual flows would then be up to about 2 metres. This is similar to the

Fig. 4. Pillow lava in the Bjørkvatnet Formation. From a locality on Annlifjellet. The pillow form shows that the lava pile is inverted.

flow thicknesses described by Furnes (1974) from Solund, West Norway, where both pillow lavas and massive lava flows are developed.

The basaltic lavas in the Gjersvik area probably had variable properties through time which led to the formation of both pillow lavas and massive lavas in a submarine environment. The formation of massive lavas in submarine environments is considered to occur (G. P. L. Walker pers. comm. in Furnes 1974) when the lavas have a high rate of extrusion and a low viscosity. Another possibility is that some of the lavas were extruded subaerially, although pillow lavas and sedimentary pyrite–magnetite ('vasskis') horizons indicate a prevailing submarine environment, perhaps of moderate depth.

Three different types of greenstones have been mapped out; a dark greenstone, a light greenstone and a stilpnomelane-bearing greenstone. The dark greenstone is the most extensive and pillow structures are observed only in this type. It is a fine-grained, massive to slightly schistose rock, and is composed mainly of albite, actinolite, epidote and chlorite. Relics of igneous texture are found including lath-shaped, albite phenocrysts up to 1 mm long. Veins and lenses consisting of epidote with some quartz or calcite are widespread in this rock-type and are found both in massive lavas and in pillow lavas.

The light greenstone which is a fine-grained, massive to schistose rock occurs in a 50 to 100 m-thick and 30 km-long zone just east of Tjiermejaevrieh. It contains the same minerals as the dark greenstone, but the paler coloration is caused by the presence of a much lighter iron-poor actinolite.

The stilpnomelane greenstone is very similar in appearance to the dark greenstone, but the presence of stilpnomelane has produced an even darker colour.

This lava variety is found mainly on Litlfjellet and south of Gjeitbergvika intercalated with the ordinary dark greenstone.

Felsic extrusive rocks are found as rather thin but extensive zones in the Bjørkvatnet Formation. They are rhyodacitic in composition and have previously been called keratophyres (Oftedahl 1956) and trondhjemites (Foslie & Strand 1956). Associated with some of these metarhyodacites are felsic agglomerates. The metarhyodacite is a very fine-grained to dense porphyritic rock, white to bluish in colour. The phenocrysts are euhedral to subhedral albite grains 1 to 1,5 mm across, set in a very fine-grained groundmass of quartz and albite with subordinate epidote, chlorite and sericite. A few roundish quartz phenocrysts have also been observed.

South of Bjørkvatnet a metarhyodacite is gradational into a felsic agglomerate in which fragments lie in a metarhyodacitic groundmass. Another agglomerate is found just north-northeast of this in a 1 km-long and 5 to 10 m-thick zone. In addition, scattered smaller outcrops of agglomerate occur throughout the area. The fragments in these agglomerates are usually angular to subangular and largely composed of felsic rocks with some darker greenstone blocks and some pumice-like material. The fragments are up to about 30 cm across.

The metarhyodacites most probably represent recrystallized felsic tuffs. The close association with agglomerate and the very thin but extensive nature of the metarhyodacite units, points to a pyroclastic origin rather than an origin as a felsic lava which is very viscous and produces dome-like structures (MacDonald 1972). The very similar quartz keratophyres in the Trondheim region are also assumed to be of a tuffaceous origin (Chaloupsky & Fediuk 1967, Roberts 1967, Oftedahl 1968). The occurrence of pumice-like material within the agglomerates might indicate that some parts of the formation were deposited subaerially.

Three different types of intrusive rock occur within the Bjørkvatnet Formation: fine-grained porphyritic metagranodiorite, coarse-grained metagranodiorite and metagabbro.

The fine-grained porphyritic metagranodiorite occurs as intrusions varying in size from small bodies 10–20 m in length and a few metres thick to larger bodies several km long and up to 10 m thick. The rock is greyish and massive to weakly schistose. Phenocrysts of quartz up to 3 mm across lie in a groundmass consisting of quartz and albite with some sericite, epidote and chlorite.

The coarse-grained metagranodiorite is found as comparatively large bodies. South of Bjørkvatnet one occurs in a synform as a folded sheet, and a sill or funnel-shaped body is found north-northeast of Orrvatnet and can be followed in the same direction for 10 km in an up to 100 m-thick body.

The metagranodiorite is a light grey rock containing 1 cm-sized quartz grains and some smaller highly sericitized feldspars (plagioclase and some K-feldspar) with minor amounts of sphene, biotite, chlorite, calcite and ore minerals.

Near the top of the succession along the shores of Limingen chlorite schists and iron-ore-rich quartzites of epiclastic origin are found. These occur in zones of less than 5 m thickness. Apart from the agglomerates and metarhyodacites pyroclastic rocks are scarce and the few greenschist horizons observed in the area might represent tectonically deformed greenstones, as has been demonstrated by Halls et al. (1977) for greenschists in the Skorovatn area south of Gjersvik.

A zone of very schistose and often banded rocks runs from Gjersvika along Langtjønna and Store Kroktjønna towards Saksvatnet. The zone is about 50 to 100 metres thick. The rocks within this shear-zone include strongly schistose and very fine-grained greenstones and felsic rocks, and banded rocks of both felsic and mafic composition. In the banded mafic rocks epidote lenses up to about 15 cm across are enveloped by the foliation. The well-developed metamorphic foliation and banding and the existence of porphyroclasts of minerals found in undeformed greenstones and felsic rocks suggest that these rocks represent strongly deformed greenstones and felsic rocks rather than pyroclastic rocks.

Ore occurrences within the Bjørkvatnet Formation

One fairly large and several smaller ore deposits are found in the formation. The minor deposits are largely thin but extensive zones composed of pyrite with magnetite (Annlifjellet, Halvvegesberget, Sæterlifjellet) or pyrrhotite (Tjiermajaevrieh). They are often associated with metarhyodacite and display banding, pyrite interbanded with magnetite and pyrrhotite.

The large occurrence is the Gjersvik ore-body situated just 500 metres east of Gjersvik. The ore-body lies in an asymmetrical synformal structure plunging southwards, with the eastern limb more steeply dipping than the western.

The hanging wall is composed of metarhyodacite which in the eastern part just above the ore-body occurs as fragments in a matrix of fine-grained pyrite. This zone of stockwork ore is about 4 m thick. The ore, which has a thickness up to a metre or so, is made up of pyrite with minor amounts of pyrrhotite, chalcopyrite and sphalerite. According to Oftedahl (1958) the ore is formed by exhalative sedimentary processes. The reserves were calculated by Foslie (1926) to be c. 1,4 mill. tons. The foot-wall consists of dark greenstone with an andesitic composition.

The pillow lavas found in the lava sequence indicate that at least large parts of the Bjørkvatnet Formation are inverted. In addition, the contact between the Bjørkvatnet Formation and the Limingen Group is also inverted. An inversion in the Gjersvik area would lead to the following stratigraphy for the ore deposit:

Greenstone, andesitic	top
Ore deposit, massive ore	
Stockwork ore	
Metarhyodacite	
Greenstone, undifferentiated	bottom

This is a succession similar to that found in Kuroko-type ore deposits (Lamberg

& Sato 1974) where an acid lava contains a zone of stockwork ore grading upwards into a massive ore. The massive ore and the stockwork ore were formed in connection with degassing late in the eruptive cycle (Horikoshi 1969). The sulphides were precipitated when the gas came in contact with seawater and they accumulated on and around the lava in the manner suggested by Oftedahl (1958).

As noted earlier, the metarhyodacites are considered to be of tuffaceous origin but the hanging wall of the Gjersvik ore deposit may provide an exception to this rule. The fold to which this hanging-wall is related is difficult to follow northwards and the reason for this might be that the 'fold' represents an inverted felsic lava dome, to which in fact it bears a resemblance. Dome-shaped acid lavas and Kuroko-type ore deposits usually have limited areal extension, and Kuroko-type deposits seldom attain dimensions beyond 500x500x 100 m (Lambert & Sato 1974). This may explain the absence of a continuation of the ore deposit on the south side of Geitbergvika.

Origin of the Gjersvik Group

The banded schists and amphibolites of the Bjørkvassklumpen and the Kleiva Formation most probably represent deformed lavas and tuffs of mainly mafic composition and were thus rather similar to the mafic rocks of the Bjørkvatnet Formation. The group as a whole is therefore considered to represent a mafic lava sequence with some felsic lavas and tuffs into which gabbro, diorite, granodiorite and local peridotites were intruded.

The pillow lavas found in the Bjørkvatnet Formation indicate an oceanic environment of deposition and they might have been formed at considerable depth. The pyroclastic felsic rocks and the massive mafic lavas do, however, indicate a subaerial environment during the building up of the lava-pile, whereas the Kuroko-type deposits indicate a moderate water depth, max. 500 m (Lambert & Sato 1974). It thus seems that the water depth varied considerably during the build-up of the lava-pile. This change in depth and mode of deposition of the lavas can be explained in the context of an island arc which has already been suggested by Gale & Robert (1974) and Hall et al. (1977). The range in rock composition found in the Gjersvik Group is similar to that found in island arcs (Gill 1970).

The origin of the Gjersvik Group is further treated in a later section on geochemistry.

THE LIMINGEN GROUP

In the eastern part of the area a succession of metasedimentary rocks (Fig. 5) lies structurally below the Gjersvik Group. Based on structural evidence and on the occurrence of a conglomerate in Finnbursvika containing pebbles derived from Gjervik Group lithologies, this sequence — the Limingen Group — is clearly younger than the Gjersvik Group. The rocks of the Limingen Group are only slightly metamorphosed and show preserved primary sedimentary structures even though they have been deformed by several phases of folding.

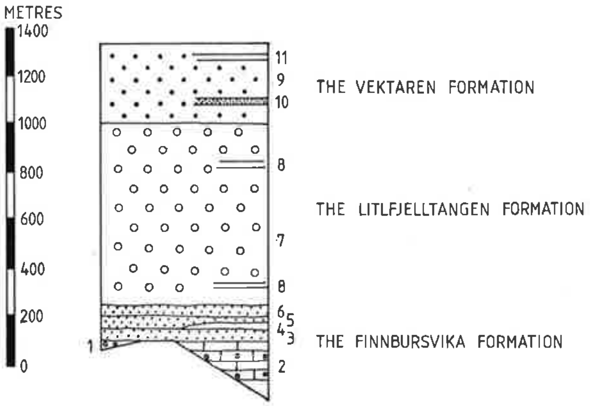


Fig. 5. Schematic stratigraphic column av the Limingen Group. Because of the influence of folding in thickening or thinning lithological units, the thicknesses given are approximations. The numbers corresponds to the numbers allotted to the different members in the description.

The Limingen Group is divided informally into three formations (Plate 1), each of which is subdivided into two or more members, as follows (in descending stratigraphical order):

Psammite	(11)	The Vektaren Formation
Greenstone	(10)	
Phyllitic psammite	(9)	
Psammite	(8)	The Litlfjelltangen Formation
Conglomeratic calcareous psammite	(7)	
Calcareous psammite	(6)	The Finnbursvika Formation
Metasiltstone	(5)	
Greenstone	(4)	
Metagreywacke-schist	(3)	
Dolomite–limestone conglomerat	(2)	
Conglomerate/calcareous schist	(1)	

The Finnbursvika Formation

Conglomerate/Calcareous schist

At Finnbursvika a polymict conglomerate marks the basal parts of the Finnbursvika Formation. This conglomerate is divided into two units by a strongly calcareous schist. The total thickness is about 20 metres. The conglomerate contains pebbles of gabbro, greenstone and felsic rocks and has a rather low pebble/matrix ratio. The pebbles, which lie in a schistose sericite- and chlorite-rich matrix, are rather elongate in shape and attains lengths of up to 20 cm. The pebble lithologies are identical to the rocks found in the structurally overlying Gjersvik Group. The conglomerate is most probably a northern extension of the rather thick conglomerate unit south-east of Skorovatn, shown on Foslie's (1958) map Trones where the pebbles are clearly derived from the Gjersvik Group (Halls et al. 1977).

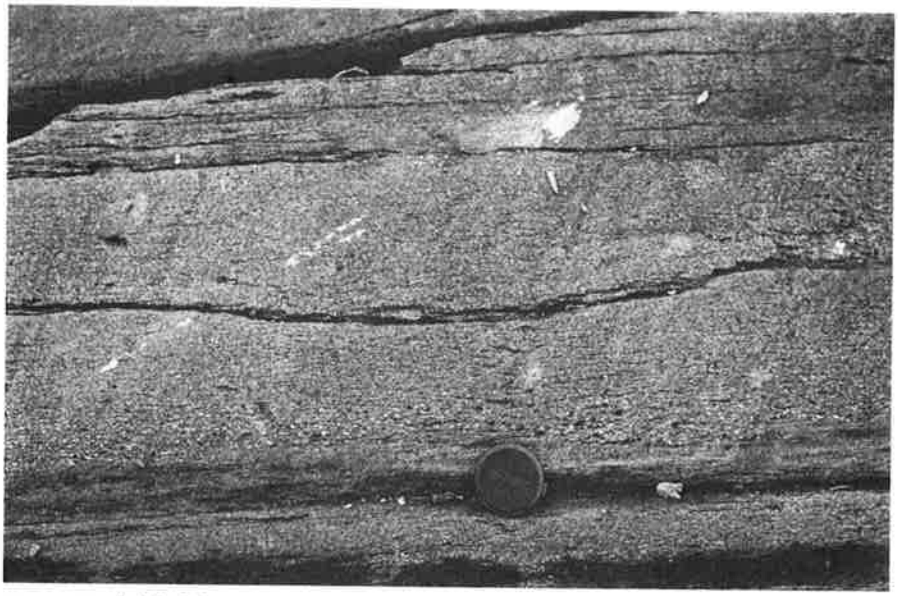
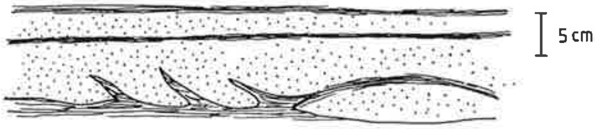


Fig. 6. Graded bedding showing right way up in the metagreywacke/schist member of the Finnbursvika Formation. The locality is 1.3 km east of Gjersvik along the shore of Limingen.

Fig. 7. Flame structure in the metagreywacke/schist member of the Finnbursvika Formation. Locality along the shore of Limingen, about 1.3 km east of Gjersvik.



Dolomite/limestone conglomerate

About 500 m north of Vestertjørna a foliated dark limestone is the lowest member of the Limingen Group. Further north this lithology changes gradually into a reddish– brown rock composed of limestone and dolomite set in a calcite matrix. In addition some quartzite pebbles are found. The fragments of carbonate are up to 50 cm across and are generally angular to subangular in shape although they are locally elongated and round. In the area from Saksvatn to Vektaren this rock has an apparent thickness of about 1 km. It is uncertain, however, whether this large thickness is a primary feature or partly due to tectonic repetition.

Metagreywacke/schist

North of Geitbergvika a metagreywacke and schist association lies in contact with the Gjersvik Group. This overlies the dolomite–limestone conglomerate. This member is about 50 m thick and is made up of units consisting of metagreywacke grading upwards into metasiltstone or schist. Each unit is up to 30 cm thick. In addition to graded bedding (Fig. 6), ripple-drift lamination is observed in some of the metasiltstones and in one place flame structures of pelite are observed penetrating an overlying metagreywacke layer (Fig. 7).

The metagreywacke consists mainly of fragments of quartz and plagioclase with minor microcline and fine-grained pelite. The grain-size is 0,5 cm or less. The matrix is composed of fine-grained sericite, chlorite, quartz, plagioclase, calcite and epidote. The upper part of each unit is a fine-grained schist with a composition like that of the matrix in the metagreywacke.

Graded bedding, which is common in the metagreywake, is usually considered to be formed by turbidity currents (Kuenen & Migliorini 1959, Dzulynski & Walton 1965) and ripple-drift cross-lamination is common in turbidites (Walker 1967). Load casts and related flame structures are also found in turbidites. A characteristic feature of many turbidites is the lateral extent of even the thinnest layers (Dzulynski & Walton 1967), but this is difficult to observe within the present area because of poor exposure. However, the alternating greywacke and schist lithology carries several of the structures usually found in rocks deposited by turbidity currents and is thought to have originated by the agency of such currents.

Greenstone

Northeast of Vestertjørna a greenstone unit occurs within the metagreywacke/schist member. This is about 100 m thick and 1,5 km in lateral extent, and is composed of fine-grained, massive to schistose greenstone. In its massive portions the rock displays sub-ophitic texture with lath-shaped albite, indicating an origin as a basaltic lava.

Metasiltstone

Stratigraphically above the metagreywacke/schist is a calcareous metasiltstone about 40 m in thickness. This is a greenish-grey, thin-banded foliated rock. This banding is caused by alternating quartz–feldspar–calcite bands and darker chlorite–sericite-rich layers. Each of the bands has a thickness of about 1 mm.

Calcareous psammite

The metasiltstone is stratigraphically overlain by a 40 m-thick calcareous psammite. The rock consists of sandy layers up to 5 cm thick separated by thinner sericite–chlorite-rich layers. The sandy layers may contain as much as 50% calcite, in addition to quartz and plagioclase.

The Litlfjelltangen Formation

Conglomeratic calcareous psammite

The basal member of this formation is a calcareous psammite containing scattered pebbles and thicker conglomeratic layers. It is a banded schistose rock with light brownish-weathering sandy layers alternating with finer-grained greenish–grey layers. This layering seldom exceeds 2 or 3 cm in thickness. The sandy layers consinst of quartz and calcite with some plagioclase, sericite and chlorite; calcite may constitute up to 60% of the mode in some cases. The fine-grained greenish–grey layers consist mainly of sericite and chlorite.

The banding represents an original layering in the rock, as can be shown by the presence of a variety of sedimentary structures (see p. 69). Deformation has, however, very often transposed this layering into a tectonic banding parallel to the main schistosity.

The conglomerate layers are up to 5 m thick but they quite often thin out rapidly laterally. The conglomerates are polymict with a rather low pebble/matrix ratio and individual pebbles are seldom in contact. The pebbles are round to ellipsoidal in shape, often with fractures normal or oblique to their long axes. They are up to 40 cm in length though usually around 5–10 cm. Quartzite, granite and granitic gneiss are common lithologies of the pebbles; more rarely there are clasts of black tourmaline-rich quartzite, felsic volcanic rocks and dolomite. The pebbles of quartzite and granitic gneiss carry a foliation which is frequently oriented at an angle to the schistosity in the host rock, indicating an earlier deformation and metamorphism in the provenance area. A possible explanation is that the foliate pebbles were derived from a Precambrian terrain or from an area deformed during an early Caledonian event.

Psammite

This lithology is found within the conglomeratic psammite in two 10 to 20 m-thick zones. It consists of metasandstone beds alternating with thinner darker, fine-grained sericite–chlorite-rich layers. Primary sedimentary structures such as cross-bedding and channelling indicate that these layers represent original bedding.

Primary structures within the Litlfjelltangen Formation

In a rather restricted area around Litlfjelltangen primary sedimentary structures (Fig. 8) are well displayed along a lake-shore section. These structures are quite different from those found in the Finnbursvika Formation.

Horizontal layering. Parallel layers which were probably once deposited as horizontal beds are common at Litlfjelltangen. The individual layers have a thickness of about 0,5 to 1 cm but seem to wedge out fairly rapidly. This might represent a discontinuous horizontal layering (Picard & High 1973). This lens-shaped layering could also, however, have been produced by tectonic deformation, but the comparatively underformed nature of the other sedimentary structures within the Litlfjelltangen Formation makes a sedimentary origin more likely. The many occurrences of scattered pebbles within these layers indicate a deposition under conditions corresponding to the lower part of the upper flow regime wherein pebbles over 2–3 cm in size may be moved (Harms & Fahnestock 1965). Layering of this type is formed where swift currents prevail such as on tidal flats and within fluvial environments producing channel fillings (Picard & High 1973).

Cross-bedding. Apart from the horizontal layering cross-bedding is the most common sedimentary structure at Litlfjelltangen. The cross-bedding can be divided into two types; one type with concave cross-beds (Fig. 8a&b), and

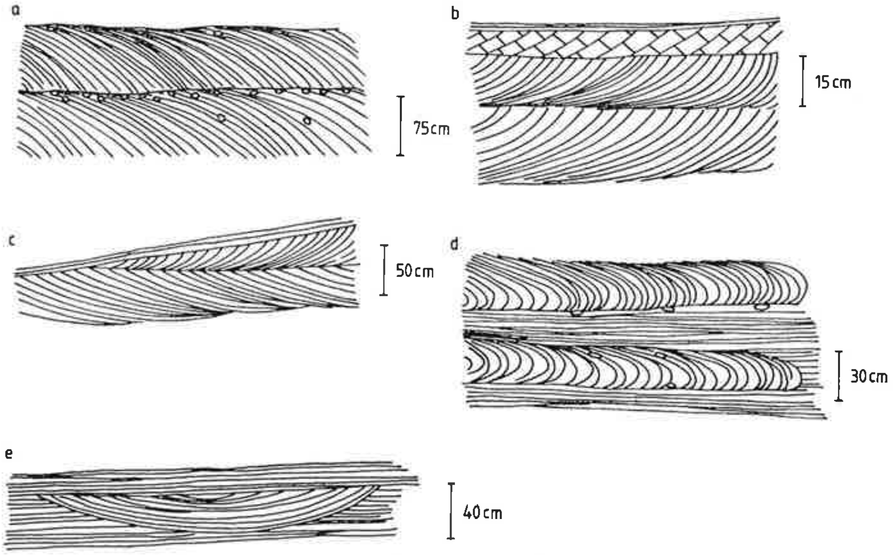


Fig. 8. Sketches drawn from photographs showing different sedimentary structures found in the Litlfjelltangen Formation. *a,* Inverted cross-bedding with pebbles concentrated along the bottom of the bed. *b*, Cross-bedding slightly overfolded, overlain by climbing ripples and parallel layering. *c*, Tangential sets of cross-bedding. *d*, Inverted intraformational recumbent folds. *e*, Channel.

another type with tangential foresets (Reineck & Singh 1973) with a low angle between deposition surface and foresets. Sets of cross-beds (McKee & Weir 1953) have thickness varying from about 10 to 50 cm where individual cross-beds are 1 to 2 cm thick. The concave sets have a relatively constant thicknesses whereas the tangential sets are more wedge-shaped (Fig. 8c). Pebbles are often concentrated along the bottom of concave sets (Fig. 8a).

Sections showing the three-dimensional shape of the cross-bedding were not observed, but sections showing throughs are found above or beneath cross-bedded sets suggesting that they might be through cross-beds (McKee & Weir 1953). Trough cross-bedding is found within sediments from many different environments and is very common in fluviatile and shallow-water deposits (Picard & High 1973, Reinech & Singh 1973), whereas low-angle tangential cross-bedding is found in beach, shallow-water lacustrine and fluviatile deposits.

Intraformational recumbent folds. These structures (Fig. 8d) represent deformed cross-bedding and the folding of the foresets is thought to be caused by sediment-loaded currents flowing over unconsolidated cross-beds and dragging these with them (McKee et al. 1962). Another explanation favoured by Allen & Banks (1972) is that they form when flows pass across sandy layers made highly unstable by earthquakes. Both mechanisms could have been operating in the present case. Structures found above folded cross-beds indicate heavy sediment-loaded flows and the area was most probably tectonically unstable during the time of sedimentation because of continued volcanism in neighbouring regions.

Intraformational folds of this type have been described from fluvial environments (Reinech & Singh 1973), and another type from deep-water sediments in the western Trondheim Region (Roberts 1972).

Climbing ripples. This structure occurs in sets from about 5 cm up to 50 cm thick. They are found above cross-bedded units and are themselves overlain by parallell beds (Fig. 3b). They are formed when large amounts of silt and sand are deposited under weak hydrodynamic conditions (McKee 1966).

Climping ripples are common in fluvial environments such as river floodplains, in areas of overbank flows and in deltas (McKee 1966). They are associated with trough cross-bedding and intraformational recumbent folds. In addition, climbing ripples have been reported from turbidite deposits (Walker 1967).

Isolated ripples. In a few places ripples have been found developed only within single layers and over shorter distances (up to 1 metre), and climbing ripples are developed only within four or five layers. These ripples were formed when insufficient material was supplied to form continuous layers of ripples (Reinech & Singh 1973).

Channels. On the point north-east of Litlfjelltangen channels are found cutting parallel layering (Fig. 8c). These vary from 20 cm to 2 m in width and are up to 40 cm deep. The channels are only observed in sections approximately normal to the flow direction and these show that the layering is parallel to the channel walls; layering parallel to the flow direction has not been observed. Some of the channels consist of coarser-grained material than that in the surrounding sediments.

Channels are formed when water flows over unconsolidated sediment surfaces (Reinech & Singh 1973); those with layering parallel to their walls are formed in drowned channels, in river channels or by submarine flows.

The Vektaren Formation

Phyllitic psammite

This is a banded and schistose rock-type with a thickness of about 160 m occurring to the east of the Litlfjelltangen Formation. The banding consists of sandstone beds alternating with thinner sericite and chlorite layers. Within this unit there is a thin conglomerate with scattered pebbles of granite, felsic volcanics, epidote-rich rocks and mafic rocks. The pebbles are flattened or elongated and have a maximum length of 30 cm. This conglomerate has a thickness of up to 4 m.

Psammite

Near the contact to the Røyrvik Group a less well banded and more homogeneous psammite about 10 m thick occurs within the phyllite psammite. This is a schistose greyish rock which contains biotite porphyroblasts in addition to matrix quartz, plagioclase and some calcite, sericite and chlorite.

Greenstone

East of Vektarklumpen a greenstone horizon about 10 m thick and 500 m in length lies conformably within the Vektaren Formation. It contains relics of a subophitic texture, but otherwise the rock is recrystallized and contains actinolite porphyroblasts. The relict igneous texture points to an origin either as a diabase sill or as a mafic lava flow.

Origin of the Limingen Group

The conglomerate in Finnbursvika is assumed to have been derived by erosion of Gjersvik Group lithologies. The dolomite-limestone conglomerate might represent the remains of a carbonate reef formed on the continental side of the island arc possibly represented by the Gjersvik Group volcanics.

The metagreywacke/schist member above the conglomerate is considered to have been deposited by turbidity currents and thus represents a deeper marine environment than that ascribed to the deposition of the conglomerates. However, the rather restricted thickness of the turbidites indicates a comparatively local and not very deep sedimentary basin as the overlaying sediments are representative of shallow-water deposits.

The sedimentary structures found in the rocks of the Litlfjelltangen area are common within present-day alluvial deposits. A characteristic feature of the Litlfjelltangen Formation is the presence of wedge-shaped conglomerate horizons; these represent the most coarse-grained deposits in the formation. In modern alluvial deposits these are found as channel lags, point bars or channel dunes (Allen 1965, Picard & High 1973) and represent substratum deposits (Allen 1965). Such deposits display sedimentary structures such as trough cross-bedding and horizontal layering (Allen 1965, Picard & High 1973), and upward fining is common within conglomerates. The wedging out of conglomerate layers indicates a shifting of depositional site and is typically found in braided rivers. Low-angle cross-bedding is also common within bottom-stratum deposits (Picard & High 1973).

The other primary structures observed around Litlfjelltangen are found in top-stratum deposits. Climbing ripples are common in flood-plain deposits (McKee 1957) and in levee sediments (Coleman 1969, Reinech & Singh 1973), while intraformational folds are formed within flood-plain deposits (McKee 1957).

The primary structures thus indicate the occurrence of a combination of top-stratum and bottom-stratum deposits within the Litlfjelltangen Formation. The relationship between the different types of structures is not known well enough to specify the type of alluvial environment in which these rocks were deposited, but alluvial fan deposits can be excluded as they are characterized by a predominance of unsorted conglomerates (Bluck 1967). It seems more likely that we are dealing with some form of river deposits, perhaps those of braided rivers as the conglomeratic layers wedge out rapidly.

The sediments within the Litlfjelltangen Formation are also rather calcareous with some sandy layers occasionally containing more than 50% calcite. This carbonate could not have been transported over a long distance since carbonate disintegrates rapidly under transport (Blatt et al. 1972). The source must therefore have lain nearer to the area of deposition than the source for the rest of the clast material. This is quite rounded and thus must have been transported over a comparatively long distance. One possibility is that these sediments represent a late phase in the filling of the marginal basin which was earlier filled with debris from an island arc and associated reef and partly by turbidity currents. The clastic non-carbonate material from the continental side of the basin could then have mixed with the carbonate-rich flows along the axis of the basin, the carbonate possiby originating from the erosion of a carbonate platform or reef.

THE RØYRVIK GROUP

The easternmost part of the map-area is underlain by rocks belonging to the Røyrvik Group. These lie structurally beneath the Limingen Group. A tectonic contact between the two groups has been favoured in recent years (Oftedahl 1974, Kollung pers. comm. 1975, Halls et al. 1977).

Within the map-area the Røyrvik Group is dominated by phyllites and quartz schists but volcanic greenstones, quartz keratophyres and serpentinites are important constituent lithologies in other parts of the region. The Joma orebody is located in one of the greenstone units.

Phyllite

A dark bituminuous phyllite is the main rock-type within the group. This consists of fine-grained sericite, quartz, some calcite and small opaque grains (graphite) which give the rock its dark coloration. Within the rock quartz veins, segregations and lenses are common, more especially towards the contact with the Limingen Group.

This phyllite alternates with other non-bituminous phyllites. Two types are found; one which is grey and sericite- and calcite-rich, and another which is bluish-grey and more quartz-rich and contains some sphene. These varieties of phyllite often display a strongly crenulated main schistosity.

Quartz schist

This lithology occurs as lenticular zones in the bituminous phyllite. It is a fine-grained, banded and schistose rock varying in colour from light to dark bluish-black, and is often strongly deformed by small-scale folds. It consists mainly of quartz in bands separated by thin films of sericite, chlorite and biotite. This quartz schist is rather abundant in the Røyrvik Group and in the Gåsvatnet area (see Foslie's (1958) map Tunnsjøen) is considered to represent ribbon chert (Reinsbakken pers. comm. 1978).

Greenschist
At Røset an up to 15 m-thick, schistose, light green rock-type transected by veins of calcite and quartz occurs in the phyllite. It consists of very fine-grained albite with actinolite, epidote, chlorite and biotite. The rock may have originated as an extrusive, but volcanic textures or structures have not been found and a sedimentary origin as a tuffitic sediment is quite possible.

Origin of the Røyrvik Group
The metasediments of the Røyrvik Group represent lithologies deposited in an environment quite different from that of the Limingen Group. The fine-grained nature of the bituminous phyllites and the cherty appearance of the quartz schist indicates that these sediments were formed in a very quiet environment where fine-grained materials are deposited and where non-detrital sediments are formed. This might have been a deep ocean basin far away from any continent or island arc.

Structural geology

INTRODUCTION

The rocks of the Gjersvik area have suffered five major and minor phases of Caledonian deformation. These phases are given the notation D_1 to D_5, where D_1 is the earliest and D_5 the latest. Folds associated with these phases are denoted F, planar structures S and lineations (other than fold axes) L with the same subscript as the phases of deformation. Original primary layering is abbreviated S_L. In addition to these deformations, an earlier phase of folding and metamorphism has been recognized in the rocks of the Helgeland Nappe Complex. This is here designated D_0.

STRUCTURAL EVOLUTION

D_0 episode
Structures ascribed to this deformation phase are, as noted above, restricted to lithologies of the Helgeland Nappe Complex. The structures of this very early episode were mostly obliterated during later deformation, but an early schistosity consisting of muscovite is occasionally observed in thin-sections of the mica schists of this nappe. This schistosity is seen to have been transposed or folded into the regional schistosity. This early S_0 schistosity is also found preserved within pre-D_1 garnets in the garnet–mica schist where it cuts across relics of a S_L lamination represented by curved dust trails. This indicates that the S_0 schistosity was formed during a metamorphic episode and not during sedimentation or diagenesis (Hobbs et al. 1976).

Mesoscopically, D_0 appears to be represented by some small intraformational isoclinal folds in quartzite layers. The S_1 schistosity wraps around these flattened folds which have greatly thickened hinges and attenuated limbs.

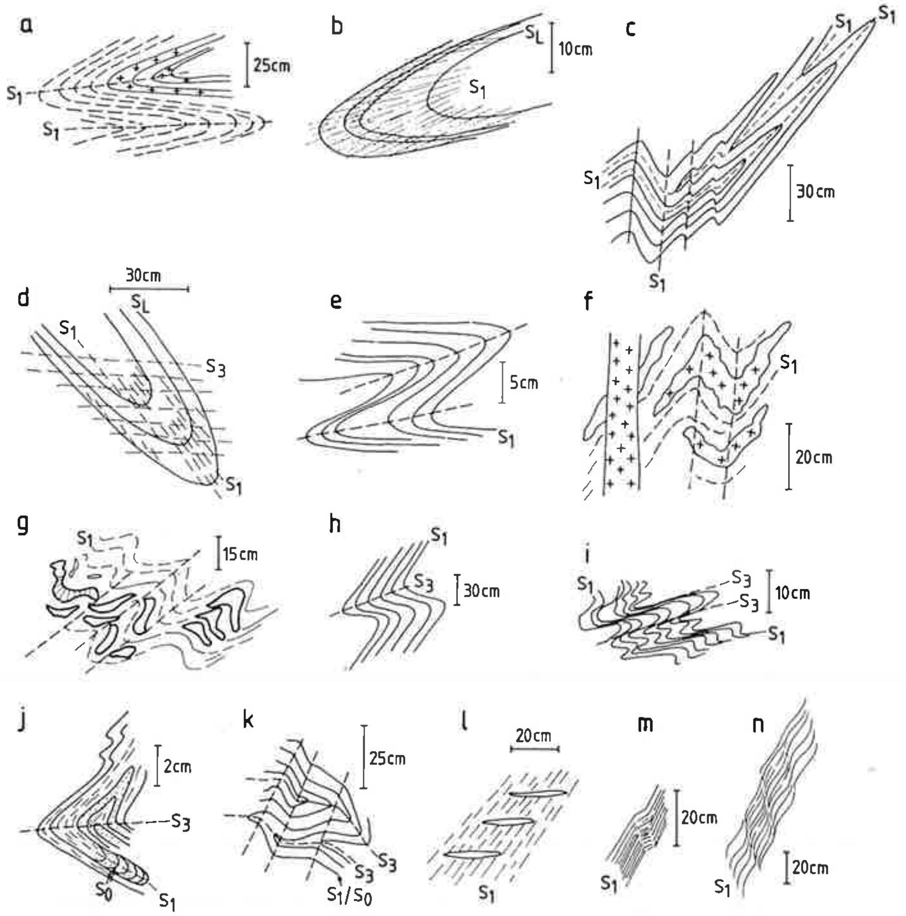


Fig. 9. Sketches of fold profiles. *a*, F$_1$ fold deforming granitic veins and banding in mica schist in the Helgeland Nappe Complex. *b*, F$_1$ fold in conglomeratic calcareous psammite in the Limingen Group. *c*, F$_1$ fold in the Helgeland Nappe Complex refolded by F$_2$ folds. *d*, F$_1$ fold in conglomeratic calcareous psammite in the Limingen Group transected by S$_3$ crenulation cleavage. *e*, F$_2$ fold in banded amphibolite in the Kleiva Formation. *f*, F$_2$ folds folding the S$_1$ schistosity and deformed granodioritic veins; a granodiorite vein lies parallel to the axial plane of the F$_2$ fold. *g*, F$_2$ folds in the conglomerate in phyllitic psammite in the Vektaren Formation. *h*, F$_3$ folds in the Litlfjelltangen Formation in conglomeratic calcareous psammite. *i*, F$_3$ folds in the main shear-zone in the Bjørkvatnet Formation. *j*, F$_3$ fold refolding F$_1$ in calcareous psammite in the Litlfjelltangen Formation. *k*, F$_3$ folds refolded by F$_4$ folds in phyllitic psammite in the Vektaren Formation. *l*, Tension gashes in quartzo-feldspathic gneiss in the Helgeland Nappe Complex. *m*, Kinking in mica schist in the Helgeland Nappe Complex. *n*, Crenulation cleavage in garnet–mica schist in the Helgeland Nappe Complex.

D$_1$ episode

This is the first deformation event which is common to all the tectonostratigraphic units in the area. Minor folds of this generation are tight to isoclinal and near similar in style (Fig. 9a, b), and frequently show evidence of late-D$_1$ flattening. The folds have a penetrative axial plane schistosity, S$_1$, which constitutes the regional schistosity of the area. This schistosity has a nearly constant

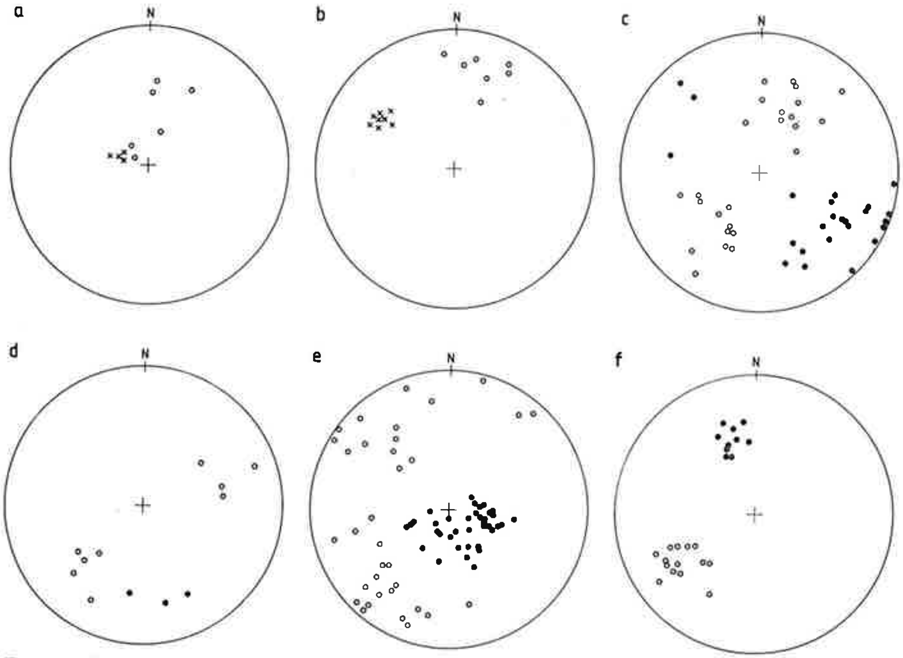


Fig. 10. Stereographic projections of structural data (Wulff net, lower hemisphere) *a*, F_1 folding in the Helgeland Nappe Complex; crosses — L_1 lineation; circles – F_1 fold axes. *b*, F_1 folding in the Limingen Group; crosses — pebble orientation, L_{1b}; filled circles — intersection lineation (S_1 v S_L) L_{1a}; circles — F_1 fold axes constructed by intersection of S_L and S_1. *c*, F_2 folds in the Helgeland Nappe Complex; circles — fold axes; filled circles — poles to axial planes. *d*, F_2 folds in the Limingen and Røyrvik Groups and in the Bjørkvatnet Formation; circles — fold axes; filled circles — poles to axial planes. *e*, F_3 folds in the Limingen Group; circles — fold axes; filled circles — poles to axial planes. *f*, F_4 folding in the Limingen Group; circles — fold axes and lineation; filled circles — poles to axial planes.

N–S to NNE–SSW strike with a westerly dip increasing from 30° in the east to 50° to 80° in the west in the Røyrvik, Limingen and Gjersvik Groups to subvertical in the Helgeland Nappe Complex. Exceptions occur only where it is deformed by later folds.

In the Helgeland Nappe Complex measurable F_1 fold axes show a variation from a NNE trend with a plunge of about 30° to an approximate E–W trend with a plunge of 75° to vertical (Fig. 10a). This variation can be seen within a single exposure and is not due to refolding, thus indicating that the F_1 folding in the Helgeland Nappe Complex is markedly non-sylindrical.

The few F_1 folds observed in the Kleiva Formation lithologies have a westerly axial trend with a plunge varying with the dip of the S_1 schistosity.

The axes of F_1 folds in the Limingen Group generally have a N–S trend with plunges of 10° to 30° to the north (Fig. 10b). This axial trend is largely constructed using the intersection of S_1 with layering as F_1 folds are relatively few in the formations of this group.

In the Røyrvik Group the D_1 episode is generally represented by the S_1 schistosity. Definite folds of D_1 age have not been observed in the phyllites of the map-area.

A lineation of D_1 age, L_1, is observed in the Helgeland Nappe Complex and in the Kleiva Formation. This lineation is formed by elongate mineral aggregates lying in the S_1 schistosity and plunges at 70° to 90° towards the west (Fig. 10a). A weaker mineral lineation with the same orientation is also present in the Bjørkvassklumpen Formation.

Two different L_1 lineations are represented in the Limingen Group. One, L_{1a}, is an intersection lineation of S_1 and S_L and is marked by a weak colour banding on S_1. This has a gentle N to NNE plunge and is parallel to the F_1 fold axial trend. The other lineation, L_{1b}, is defined by the orientation of pebbles in the Litlfjelltangen Formation. These pebbles are elongate and many show fracturing either normal or oblique to their long axis. Pebble long axes are approximately normal to the F_1 fold axial trend (Fig. 10b). The initial orientation of the pebbles was probably produced during an early phase of buckling, with some rotation and subsequent fracturing associated with a later episode of flattening (Ramsay & Sturt 1970). The component of flattening is also indicated by boudined quartz and calcite veins lying parallel to S_1.

Major folds of F_1 age have not been observed in the area, but the inversion of large parts or the whole of the Gjersvik Group is considered to have taken place during this deformation episode. A D_1 age for the inversion is also indicated by the S_L/S_1 angular relationship (Hills 1963) in the adjacent Limingen Group. The alternation between normal and inverted layering indicates that F_1 folds with a wavelength of about 20 m are present in the metagreywacke/schist member of the Finnbursvika Formation and from 100 to 200 m in the Litlfjelltangen Formation.

D_2 *episode*

The structures of this episode are assumed to be later than D_1 on the basis of refolding of F_1 folds and the S_1 schistosity (Fig. 9c). The minor F_2 folds are mainly open to close similar-type folds but in the Helgeland Nappe Complex they may be tight to isoclinal. A weak crenulation cleavage associated with F_2 is developed in the metagreywacke/schist member in the Finnbursvika Formation: otherwise no S_2 axial plane cleavage is found. The axial planes of minor F_2 folds generally dip steeply towards NW with the fold axes plunging either N to NE or S to SW at angles varying from 0° til 40° (Fig. 10c, d).

Minor F_2 folds occur mainly within the Helgeland Nappe Complex, in the eastern part of the Limingen Group (Fig. 9g) and in the Røyrvik Group. In the western part of the Helgeland Nappe Complex the minor F_2 folds are congruent to a major F_2 antiform, the Kjæråklumpen Antiform. This fold has an axial trace trending NNE–SSW. Moving east from the antiform, a point is reached within the mica schist unit where the minor F_2 folds become symmetrical and then, east of this, revert to being asymmetrical but with an opposite vergence. This changing vergence indicates the presence of a major synform, the axial trend of which is located along the zone of symmetrical minor folds. These zones trends NNE–SSW just east of Kjeråtjørnin and the fold is named the Sierkesjokke Synform. An important additional effect of the D_2 deformation in this area was to steepen the attitude of the basal thrust of the Helgeland Nappe Complex, the thrusting itself being an early event (p. 79).

In the Kleiva Formation a few minor F_2 folds are observed (Fig. 9e) and these are similar in style to the F_2 folds in the overlying nappe with a vergence indicating the presence of a synform to the west. In the Bjørkvassklumpen and the Bjørkvatnet Formations only very few F_2 folds have been observed. In the Bjørkvatnet Formation some major F_2 folds are deforming metagranodiorite, metagabbro and greenstone horizons in very open structures with steeply dipping NNE–SSW axial planes. Minor F_2 folds are not especially common within the Limingen and the Røyrvik Groups. These sequences, however, are situated on the western limb of a major F_2 antiform (Foslie & Strand 1956) which is one of several major F_2 folds occurring east of Limingen and folding the regional S_1 schistosity. These folds have steeply dipping NE–SW to NNE–SSW oriented axial planes with SW-plunging axes.

The tonalite in the Helgeland Nappe Complex most probably was intruded late during or after the D_2 episode as it cuts the western limb of the Kjæråklumpen Antiform.

D_3 episode

The minor folds of this episode are recognised on superposition evidence (Fig. 9j), coupled with the fact that a relatively pronounced S_3 crenulation cleavage transects earlier structures (Fig. 9d). F_3 folds are found only in the eastern part of the area within and to the east of the Bjørkvatnet Formation. They occur only as minor structures within the map-area and are asymmetric close to tight folds of near similar type (Fig. 9h, j), overturned down-dip and with rather flat-lying axial planes (Fig. 10e). Associated with the folding is an axial plane crenulation cleavage, S_3, which is best seen in mica- and chlorite-rich lithologies.

The F_3 folds are non-cylindrical and arcuate hinges are seen in many outcrops. Within a single outcrop, depending on the lithology, axial plunge variation of up to 90° may be observed. This non-cylindrism is not caused by fold imposition on earlier folds or by refolding by later structures but is an inherent property of the F_3 folding.

F_3 folds are most common in the Limingen Group where wavelengths are up to about 1 m, amplitudes from 30 to 40 cm. Within the Bjørkvatnet Formation they are most prominently developed as small-scale shear folds folding the foliation in the shearzone (Fig. 9i), but S_3 is found in the more schistose greenstones throughout the formation. In the Røyrvik Group F_3 folds are most frequently seen in the quartz schist whereas the S_3 crenulation cleavage is developed in the phyllites.

These flat-lying folds are very similar in character to the post-schistosity gravitational collapse folds described by Roberts (1967b, 1971b) and produced experimentally by Ramberg (1967) and are most probably of the same age and origin. They were formed when the main compressive stresses operating during the D_1 and D_2 build-up of the nappe pile were relaxed (Roberts et al. 1970). According to Roberts the F_3 folds die out when the regional schistosity and lithological banding steepens across the Trondheim region. This may be the reason for the absence of F_3 folds in the western part of the area as S_1 steepens to a sub-vertical attitude in that direction.

D_4 episode

In the Limingen and the Røyrvik Groups a crenulation is often developed on micaceous S_1 surfaces thus defining a L_4 lineation which plunges at about 20 to 30° towards SSW. This lineation is sometimes associated with small-scale folding with open to closed folds (Fig. 9k) having axial planes with a SSW–NNE strike and dips of 60 to 80° towards SSE (Fig. 10f). This minor F_4 folding deforms F_3 folds and S_3 cleavage in the Limingen Group. This L_4 crenulation has also been observed in a few places in the Bjørkvatnet and the Bjørkvassklumpen Formations.

D_5 episode

In the Helgeland Nappe Complex three different late minor structures may possibly be related to a common E–W compressive stress. In the mica schist a kinking with NNW–SSE oriented axial planes and near-vertical axes is seen: the kinks have a dextral sense of rotation when viewed down-plunge (Fig. 10 m). The quartzo–feldspathic gneiss carries NNE–SSW oriented en échelon tension gashes with an E–W strike and vertical dip (Fig. 10 l). In garnet–mica schist a late vertical NNW–SSE oriented crenulation cleavage is fairly common (Fig. 10 n).

The crenulation cleavage is thought to have been formed by the NNW–SSE oriented shear stress and the tension gashes by the NNE–SSW oriented shear stresses of the E–W oriented compressive stress. The NNE–SSW oriented shear stress also probably caused differential movements along S_1 which in turn led to the development of kink structures (Ramsay 1967).

On Litlfjelltangen an approximately N–S trending kink banding deforms the L_4 lineation. This kinking shows a similar sense of rotation to that of the kinking in the Helgeland Nappe Complex and might be of the same generation. Late shear zones occurring in the Kleiva Formation and which show a NNE–SSW strike may also have formed during D_5.

THRUSTING

The Helgeland Nappe Complex

This nappe complex is well established further to the north in the southern part of Helgeland (Strand 1955, 1960), Gustavson 1973). Within the present area the tectonic nature of the contact between the Gjersvik Group and the nappe complex is not well displayed. Mylonites are developed further to the north in the Helgeland area (Gustavson 1973) but are not found in the Gjersvik area. This might be explained by the mineralogy of the rocks occurring along the contact. These are calcite–amphibole–biotite– and quartz-rich lithologies and these minerals either easily recrystallize during cataclasis or are deformed by recrystallization (Higgins 1971). The breaking up of the different rock-types found as layers in the limestone along the contact does indicate, however, that strong tectonic movements have taken place in this zone. This feature has also been described from areas further to the north (Gustavson 1973). There are, in addition, important tectonic and metamorphic differences between the Helgeland Nappe Complex and the underlying rocks indicating that the contact is tectonic: a pre-D_1 deformational and metamorphic event reaching almandine–amphibolite facies is recognizable in the nappe but not in the underlying Gjersvik Group rocks.

The thursting which brought the Helgeland Nappe Complex into contact with the Gjersvik Group most probably took place during D_1 as F_1 structures both in the nappe complex and in the Kleiva Formation have similar orientations. In both units a westerly oriented L_1 lineation is present indicating nappe translation in an E–W direction, most probably from the west. The influence of thrusting on F_1 folds in the nappe complex and in the adjacent Kleiva Formation is indicated by the difference in their orientations as compared with the F_1 folds in the Limingen Group which have a roughly northerly trend. This early thrusting is not observed in the Helgeland area where the thrusting is considered to be a late tectonic event (Gustavson & Grønhaug 1960). This might indicate that the thrusting of the Helgeland Nappe Complex took place during more than one episode.

The Gjersvik Nappe

The Gjersvik Nappe, as originally named by Foslie & Strand (1956) and Oftedahl (1956), comprised only rocks of the Gjersvik Group, the thrust contact being placed at the Gjersvik/Limingen Group boundary. In recent years regional and detailed mapping in the Grong–Limingen region has indicated that the boundary between the Gjersvik and the Limingen Groups is of a primary nature, and that the two groups together constitute a nappe that early in the deformational history was thrust above the Røyrvik Group (Oftedahl 1974, Kollung pers comm. 1975, Halls et al. 1977). The Limingen Group has therefore now been included in a redefined Gjersvik Nappe (Halls et al. 1977). This thrusting probably took place during the later stages of D_1 as the contact is folded by F_2 folds. The nature of the contact between the Limingen and the Røyrvik Groups is not readily seen in the Gjersvik area.

The shear-zone in the Bjørkvatnet formation

This shearzone most probably developed during the later stages of D_1. The massive and competent nature of the greenstones might have caused the strain to have been concentrated along this shear surface producing fine-grained rocks within the zone. The rocks on either side of the zone are similar and the amount of displacement is probably not very great.

FAULTING

The latest event in the deformational history is that of minor faulting. The largest displacement is found south–west of Bjørkvatnet where a sinistral movement of up to 500 m has occurred along a low-angle reverse fault of approximately 3 km strike extent. The strike of the rocks north of Geitbergvika indicates that they should continue on Geitbergtangen, and not in Finbursvika. In all probability there is an E–W trending fault beneath the bay which offsets the southern block some 200 m to the east. Other faults in the area trend either NW–SE or NE–SW but these show only minor displacements.

SUMMARY

Six deformation episodes have been distinguished in the map area together with a late brittle phase of faulting. Traces of the earliest episode, D_0, are found only in the Helgeland Nappe Complex. F_1 and F_2 folds are developed throughout the area and represent the main macroscopic folding which has governed the distribution of the different rock units. During D_1 the Helgeland Nappe Complex and the Gjersvik Nappe were thrust into position: basal thrusts were steepened or even folded during D_2. The later F_3 folds, which were most probably formed as gravity collapse structures, are found only in the eastern part of the area. F_4 and F_5 are comparatively local structures and of only minor importance.

The folding history in the eastern low-metamorphic part of the area is very similar to the structural evolution in the Trondheim region. The main folding in the Trondheim region took place in Middle to Upper Silurian time (Roberts 1971a, Wilson et al. 1973) and it is more than likely that the principal Caledonian deformation and metamorphism in the Gjersvik area is of a similar age. This is also suggested by a Pb isotope model age of 420 ± 70 m.y. on galena from Lille Tromsdalen (in the Gjersvik Group south of the present area) (Moorbath & Vokes 1963).

The Helgeland Nappe Complex seems to have had a longer structural history than the rest of the area, with an early F_0 phase found only in this nappe complex. The F_1 and younger structures in this nappe are of the same age as those in the eastern part of the area. Both F_1 and F_2 are very similar to the folds described by Myrland (1972) from another part of the Helgeland Nappe Complex, and the F_2 folds are of late Silurian age or older as they are found in xenoliths in the Bindal granite which is dated as 424 ± 26 m.y. B.P. (Priem et al. 1975). The age of the S_0 schistosity is uncertain; it could well be Silurian, but it might possibly represent an early Caledonian event, perhaps late Cambrian–early Ordovician, which has been reported both from Western Norway (Kvale 1960, Skjerlie 1969, Sturt & Thon 1977) and from Finnmark (Sturt et al. 1967, 1975, Sturt & Roberts 1978, Zwaan & Roberts 1978). Yet another possibility is that the D_0 is of Precambrian age.

Metamorphism

INTRODUCTION

The metamorphism of the rocks in the Gjersvik area will be described in relation to the different deformational episodes. On the basis of textures, mineral growth and deformation the minerals and the fabrics to which they are related are dated as pre, syn or post the respective deformational episodes.

METAMORPHIC SEQUENCE

Syn-D_0 metamorphism

The minerals which formed in this early phase in the rocks of the Helgeland Nappe Complex are muscovite and sericite defining the early S_0 schistosity, and biotite and elongate quartz which are found as inclusions in post-D_0, pre-D_1 garnets.

Post-D_0, pre-D_1 metamorphism

Minerals dating to this phase were deformed during later structural episodes shown by strain effects such as undulose extinction, and have the S_1 schistosity wrapping around them. In rare instances they contain a relict S_0 schistosity which makes an angle with S_1. However, the pre-D_1 minerals in the Helgeland Nappe Complex rarely show inclusions and in such cases they could as well be syn-D_0 as post-D_0.

Plagioclase, commonly oligoclase, is usually found as strained crystals in the Helgeland Nappe Complex rocks with the S_1 schistosity wrapping around them, and thus was formed pre-D_1. Garnets were also formed as pre-D_1 minerals, but these garnets sometimes continued to grow into and through the D_1 episode and developed crystal faces cutting the S_1 schistosity.

In some rocks in the Helgeland Nappe Complex porphyroclasts and lath-shaped aggregates of muscovite are found. The actual shape of the porphyroclastic aggregates was clearly produced during D_1, but the growth of the granoblastic polygonal muscovite is later. The aggregates of muscovite probably represent pseudomorphed pre-D_1 minerals, probably K-feldspar or an Al-silicate which readily alters to muscovite. The lath-shaped aggregates in particular have a shape pointing to an origin as kyanite. This mineral has been described from the Helgeland Nappe Complex just north of this area (Gustavson & Grønhaug 1960) and it is therefore possible that kyanite may have grown in the pre-D_1 phase in this part of the nappe complex.

Another pre-D_1 mineral is diopside which occurs in the calc–silicate rock and in limestone. Tremolite is also a pre-D_1 mineral in limestone. Coarse-grained veins of quartz, plagioclase, muscovite and garnet in gneisses and mica schist, plagioclase veins in amphibolite and quartz, and plagioclase and K-feldspar veins in quartzo–feldspathic gneiss were deformed, folded or boudined during D_1 and were therefore emplaced prior to the F_1 folding (Fig. 9f).

The volcanic rocks in the Bjørkvatnet Formation were partly or wholly altered to a greenschist facies mineralogy before the D_1 deformation as both albite, actinolite and epidote are deformed by D_1 structures. This alteration is not related to any tectonic deformational episode and could have been caused either by burial metamorphism (Smith 1968) or by sea-floor metamorphism (Cann 1969). A feature favouring sea-floor metamorphism is the high Na and low Ca contents in the analyses of these volcanic greenstones as Na is known to be introduced and Ca depleted during this type of alteration (Miyashiro 1973). The Ca was most probably bound in the form of epidote in veins, and nodules in the greenstone. The pre-tectonic alteration is also indicated by the occurrence of epidote pebbles in conglomerates composed of material derived from the Gjersvik Group (Halls et al. 1977). Halls and co-workers have also ascribed the formation of this type of epidote to in-situ sea-floor metamorphism.

Deformed pre-F_1 epidote and albite is also found in the Bjørkvassklumpen Formation but not in the Kleiva Formation. This would appear to indicate that the sea-floor metamorphism affected the Bjørkvassklumpen Formation but not the Kleiva Formation. Alternatively, such alteration may have taken place in the Kleiva Formation, but all traces were then susequently eradicated by the strong D_1 deformation related to emplacement of the Helgeland Nappe Complex.

Syn-D_1 metamorphism

Minerals formed syntectonically are generally characterized by crystallization in S-planes where elongate minerals are usually oriented parallel to fold axes. These are normally free of deformational textures (Spry 1969). Some minerals such as plagioclase and garnet may develop S- or spiral-shaped inclusion fabrics indicating rotation during growth (Spry 1969).

The regional schistosity is a syn-D_1 structure which in the Helgeland Nappe Complex is defined mainly by parallel-oriented muscovite, biotite and amphibole, but also in appropriate lithologies by elongate plagioclase and quartz. In the Kleiva and Bjørkvassklumpen Formations the S_1 schistosity is defined by biotite and actinolite and some epidote and albite, whereas actinolite and chlorite are the main S_1 minerals in the Bjørkvatnet Formation.

Stilpnomelane, which is a common mineral in parts of the Bjørkvatnet Formation, is also considered to be of syn-D_1 growth as it is cross-cut by post-D_1 biotite. In the Limingen and Røyrvik Groups sericite and chlorite with occasional biotite are syn-D_1 minerals in the metasediments, and epidote, actinolite, albite and chlorite are the S_1 minerals in the volcanic rocks.

In the Helgeland Nappe Complex garnet and plagioclase both grow over S_1 yet at the same time the external S_1 schistosity wraps around them. These minerals have probably formed after the formation of the schistosity but before the stage of flattening which dates to late-D_1 time.

The thin-banded amphibolitic rocks found in the Kleiva and Bjørkvassklumpen Formations are thought to have acquired their pronounced banding during the D_1 tectono-metamorphic episode : as noted earlier, D_1 strain was also more intense in the stratigraphically lower parts of the Gjersvik Group towards the basal thrust of the Helgeland Nappe Complex. It is also well known that mafic rocks are often transformed into banded rocks during deformation and metamorphism (Waters & Campbell 1935, Turner 1941, Printz & Poldervaart 1964, Sclar 1965). The banding and schistosity in these amphibolites wraps around albite and epidote porphyroclasts and lenses of epidote, indicating the tectonic nature of the rocks.

Post-D_1, pre-D_2 metamorphism

Minerals growing across a shistosity where the schistosity continues right through without being deflected are considered to have grown after the schistosity. In the Helgeland Nappe Complex quartz, albite and garnet continued to grow post-D_1, their outer parts thus overgrowing S_1 and in the case of garnets developing good crystal faces. In limestones tremolite grew across S_1 and in amphibolites both in the Nappe Complex and in the Kleiva Formation actinolite shows the same relationship.

Biotite and muscovite have also grown over S_1 in the Helgeland Nappe Complex, while biotite is post-D_1 but pre-D_2 in the Gjersvik and Limingen Groups. In some limestones calcite recrystallized post-D_1 developing a granoblastic polygonal texture. Likewise, quartz in porphyroblastic aggregates in the Nappe Complex and in quartz schists in the Røyrvik Group is considered to be a post-D_1 growth as it often shows a granoblastic polygonal texture, but is somewhat strained due to later episodes of deformation.

In the chlorite schist in the Bjørkvatnet Formation porphyroblasts of actinolite cross-cutting the S_1 schistosity are deformed by S_3. In phyllites in the Røyrvik Group sphene containing inclusions of the S_1 fabric shows the same relationship. These two minerals probably grew post-D_1, pre-D_2, but might have been later.

Granodioritic veins cutting S_1 occur in the Helgeland Nappe Complex. These are folded by F_2 folds and thus were intruded in the post-D_1, pre-D_2 phase.

Syn-D_2 metamorphism

Only minor mineral growth took place during this phase. In the S_2 crenulation cleavage in the Finnbursvika Formation of the Limingen Group calcite crystallized. In the Helgeland Nappe Complex coarse-grained veins up to 15 m in thickness consisting of quartz, albite, muscovite and garnet are found parallel or subparallel to the axial planes of F_2 folds (Fig. 9f): these are especially common in the northern part of the area. Other mineral growth syn-D_2 has not been recognized in the nappe complex.

Syn-D_3 metamorphism

In a few places in the eastern part of the area chlorite and sericite have recrystallized in the S_3 crenulation cleavage. Thin calcite and quartz veins are developed parallel to S_3 in the Limingen Group and similarly aligned quartz veins are formed in the quartz schists of the Røyrvik Group.

Post-D_3 metamorphism

In the eastern part of the Røyrvik Group in the map area a local muscovite porphyroblastesis has been found, where muscovite grows over the S_3 crenulation cleavage. Elsewhere, the post-D_3 metamorphism was entirely retrograde but the restricted development of the late structures, D_4 and D_5, makes the actual timing of the retrograde reactions difficult to pinpoint.

In the Helgeland Nappe Complex both garnet and biotite are altered to chlorite, and feldspars are saussuritized. In the Kleiva Formation retrograde effects are easily seen in the late, D_5, shear-zones where actinolite is altered to

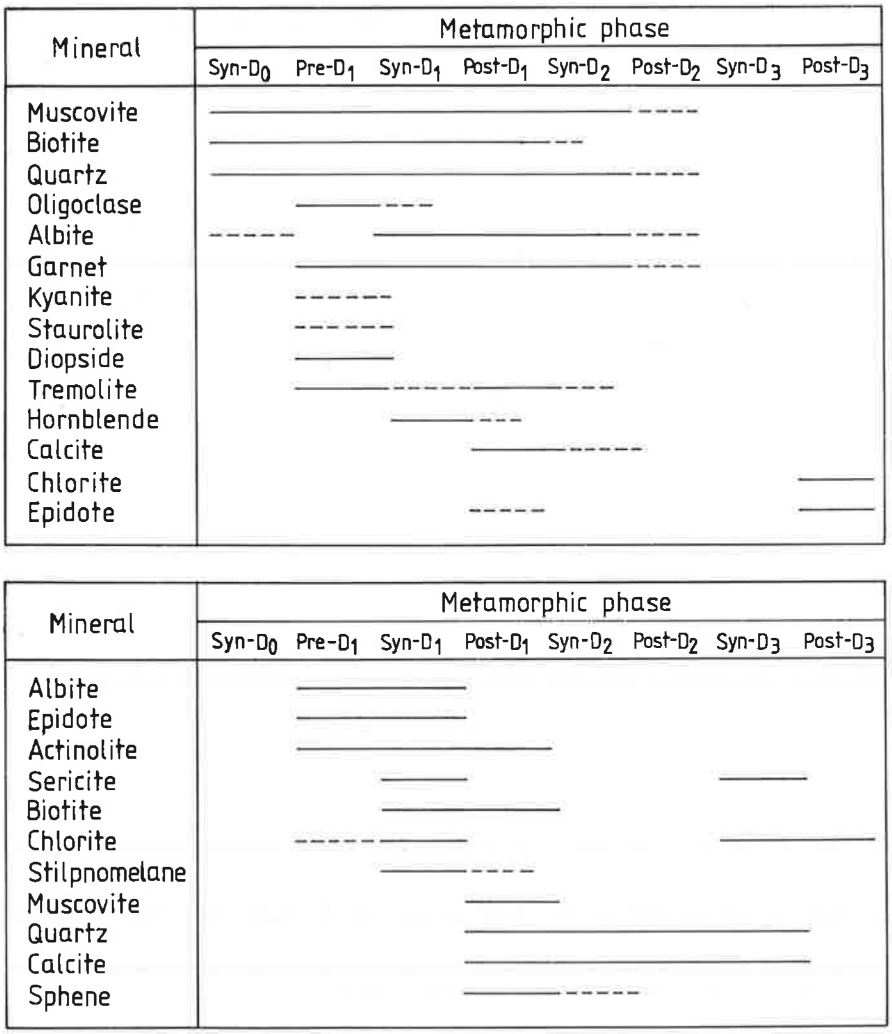


Fig. 11. The relationship between mineral growth and metamorphic phases in: (a) The Helgeland Nappe Complex; (b) The Gjersvik, Limingen and Røyrvik Groups. Broken line where mineral growth is uncertain.

chlorite and plagioclase to epidote. Elsewhere in the formation biotite and the few garnets are partly altered to chlorite. In the Bjørkvatnet Formation and in the Limingen and Røyrvik Groups biotite and actinolite are altered to chlorite.

DISCUSSION

The timing and grade of the metamorphic peak in the area is somewhat difficult to place exactly. In the Helgeland Nappe Complex garnet, oligoclase, diopside and possibly staurolite which is described by Foslie & Strand (1956) are all pre-D_1 minerals indicating that the metamorphic condition at that time reached up into almandine-amphibolite facies, B 2. 1 (Winkler 1967). Kyanite and staurolite are described from the nappe complex further north (Gustavson

& Grønhaug 1960) indicating that some of the muscovite aggregates might be pseudomorphed kyanite. In the area around Majavatn, Nissen (1965) found that local variation between B 2. 1 and B 2. 2 facies existed. This might indicate that the part of the nappe complex discussed in this account only passed through B 2. 1 and that the pseudomorphs could be after K-feldspar rather than kyanite.

The pre-D_1 metamorphism in the Helgeland Nappe Complex thus reached the lower or middle almandine-amphibolite facies and this is the highest grade found in the map area. This grade was most probably achieved in post-D_0 time as the syn-D_0 minerals found are muscovite, quartz and biotite.

The syn-D_1 minerals garnet, albite, epidote and muscovite indicate that the highest part of the greenschist facies, B 1. 3, was reached during the D_1 episode in the Helgeland Nappe Complex and in the Kleiva Formation. Eastwards from the Kleiva Formation the syn-D_1 metamorphism decreases and is in the lower greenschist facies in the Bjørkvatnet Formation where stilpnomelane indicates B 1. 1 (Winkler 1967). This grade of metamorphism also existed in the Limingen and Røyrvik Groups during D_1.

Within this eastern low-metamorphic area biotite grew post-D_1 across syn-D_1 stilpnomelane indicating that the metamorphism had increased to B 1. 2, and stilpnomelane is stable in this sub-facies (Miyashiro 1973b). This post-D_1 grade is also found in the Kleiva and Bjørkvassklumpen Formations; at the same time garnet continued to grow in the Helgeland Nappe Complex rocks indicating B 1. 3 conditions. These conditions persisted well into D_2 time in the Nappe Complex indicated by the occurrence of garnet-bearing syn-D_2 veins. Elsewhere retrograde metamorphism took over during D_2 and later tectonic episodes with the exception of local pophyroblastesis.

In summary, it is clear that the rocks within the Helgeland Nappe Complex have had a longer metamorphic history than the other rocks in the area (Fig. 11). The metamorphism was of higher grade and the peak of metamorphism occurred earlier in the Nappe Complex than in the remaining part of the area as shown by Fig. 11.

Geochemistry

INTRODUCTION

Thirty-five samples of basaltic greenstone, 21 samples of felsic rocks from the Bjørkvatnet Formation and 2 samples of metadiorite have been analysed for major and trace elements. Fifteen of these analyses are taken from Gale (1974). These and 18 of the others were analysed at NGU while the remainder were analysed at the Geological Institute, University of Bergen.

The analytical methods employed at NGU have been described by Gale (1974) and by Faye & Ødegård (1975). At the Geological Institute in Bergen the main elements except sodium were analysed by X-ray fluorescence using glass beads prepared according to the methods of Padfield & Gray (1791). Twenty international standards and recommended values from Flanagan (1973)

Table 1. Major and trace element chemistry of dark greenstones from the Bjørkvatnet Formation

	D1^2	D2^2	D3^2	D4^2	D5^2	D6^1	D7^1	D8^1	D9^1	D10^2	D11^2	D12^2	D13^1	D14^1
SiO_2	49.80	49.70	50.40	51.20	50.50	50.09	48.83	52.54	56.22	55.80	46.20	45.00	50.85	50.06
TiO_2	1.68	1.33	1.19	1.52	1.42	0.95	0.62	0.63	0.91	1.53	1.01	1.00	1.39	0.90
Al_2O_3	14.90	15.00	14.30	15.20	15.60	15.19	17.53	14.49	14.74	13.70	14.90	15.00	16.34	16.09
Fe_2O_3	14.00	15.50	13.10	14.20	15.60	3.59	2.95	1.78	4.53	14.30	11.60	12.00	3.87	4.15
FeO						7.28	5.52	7.53	5.94				7.52	6.05
MnO	0.28	0.24	0.22	0.30	0.23	0.23	0.18	0.18	0.15	0.24	0.22	0.20	0.18	0.17
MgO	3.50	4.90	3.90	3.30	5.20	3.71	6.59	8.21	3.80	4.80	7.80	9.20	4.88	6.97
CaO	5.30	4.80	6.50	6.60	2.80	5.88	8.39	6.29	3.98	3.40	6.70	9.20	6.66	9.00
Na_2O	6.18	4.92	5.51	5.50	6.61	5.83	5.08	5.34	6.81	3.81	3.24	2.99	5.51	4.18
K_2O	0.09	0.09	0.30	0.08	0.10	0.61	0.13	0.07	0.11	0.27	0.12	0.44	0.14	0.06
H_2O	*4.24	*5.42	*6.10	*2.01	*2.61	3.22	2.87	3.17	1.50	*3.38	*7.38	*3.83	2.06	2.40
CO_2						3.80	1.10	0.35	0.86				0.02	0.10
P_2O_5	0.13	0.06	0.06	0.13	0.06	0.08	0.05	0.06	0.06	0.06	0.06	0.05	0.09	0.12
total	100.10	101.96	101.58	100.04	100.73	100.46	99.84	100.64	99.61	101.29	99.23	98.91	99.51	100.25
Zr	109	66	56	87	61	27	26	27	35	91	44	53		22
Y	36	23	19	35	21	12	9	13	18	25	17	14		22
Nb														3
Sr	55	39	65	106	57	244	248	66	30	145	140	177		222
Rb	2	0	0	0	0	0	0	0	0	0	0	6		2
Ni	6	8	4	6	7	84	27	99		8	142	125		
Cr	16	23	22	16	29	422	74	439		29	516	436		
La						1		2						1
Ce						11	10	15	13					9
Nd						3	4	7	4					3

Analyst: 1) Major elements P. R. Graff, Norges geologiske undersøkelse; trace elements O. Lutro.
2) Major & trace elements by P. R. Graff, Gj. Faye & M. Ødegård, Norges geologiske undersøkelse.
3) Major & trace elements O. Lutro.
* Volatiles calculated as loss-on-ignition.

improved by least squares procedure and matrix correction were used for calibration. Na was determined on pressed powder tablets and ferrous iron by titration with potassium dichromate.

Trace elements were determined by X-ray fluorescence used on pressed powder tablets. Twelve international standards and the recommended values of Flanagan (1973) redefined by least squares procedure were used for calibration. The spectrometer used was a Philips P. W. 1410.

BASALTIC GREENSTONES

Major elements

The mafic volcanic rocks of the Bjørkvatnet Formation have been altered to rocks showing a greenschist facies mineralogy. This alteration took place both pre-tectonically and during later deformation. As noted earlier the pre-tectonic alteration is considered to have been caused by sea-floor metamorphism, whereby the lavas are depleted in Ca and enriched in Na (Miyashiro 1973). The mobility of Ca and Na during alteration has also been reported by other workers (Smith 1968, Cann 1969, Hughes 1973, 1974, Vallance 1974). During alteration the basalts were open to the volatiles H_2O and CO_2 leading to the formation of $CO^{2}_{3}{}^{-}$ – and OH^- – bearing minerals. The analyses of the basaltic

Table 1 continued

	D15^2	D16^2	D17^2	D18^1	D19^1	D20^2	D21^2	D22^2	D23^2	D24^2	D25^3
SiO_2	50.10	50.84	50.51	51.03	43.89	47.00	47.57	55.20	58.40	51.41	55.95
TiO_2	1.37	1.11	1.14	0.80	1.21	0.96	0.74	1.10	1.34	1.17	1.30
Al_2O_3	15.20	16.11	16.12	16.64	17.59	15.80	16.04	14.20	13.60	15.05	14.00
Fe_2O_3	14.90	13.05	13.43	5.60	13.98	10.90	10.33	13.40	11.20	14.45	4.23
FeO				6.04							7.63
MnO	0.25	0.18	0.24	0.18	0.27	0.19	0.18	0.26	0.36	0.23	0.25
MgO	4.70	4.67	4.85	5.35	7.54	7.80	8.21	3.90	2.40	4.89	3.07
CaO	4.30	5.41	5.40	6.56	5.83	10.10	11.06	5.70	3.80	6.49	5.07
Na_2O	6.08	6.13	6.69	4.70	3.14	2.95	2.48	4.99	5.79	4.70	4.16
K_2O	0.26	0.22	0.08	0.43	1.32	0.46	0.34	0.39	0.29	0.12	0.11
H_2O	*1.89	2.62	2.23	2.92	4.96	*4.52	3.23	*2.34	*3.28	2.14	2.80
CO_2		0.27	0.44	0.10	0.96		0.72			0.60	0.60
P_2O_5	0.06	0.14	0.08	0.07	0.14	0.04	0.06	0.05	0.15	0.12	0.37
total	99.11	100.75	101.21	100.42	100.83	100.72	100.96	101.53	100.61	101.37	99.54
Zr	63			41	41	41		42	78	35	46
Y	25			18	15	13		16	39	18	36
Nb										5	6
Sr	60			179		408		191	122	152	187
Rb	1			4		4		4	0	4	3
Ni	12					71		10			
Cr	27					275		27			
La				2						2	3
Ce				18						17	15
Nd				9						7	10

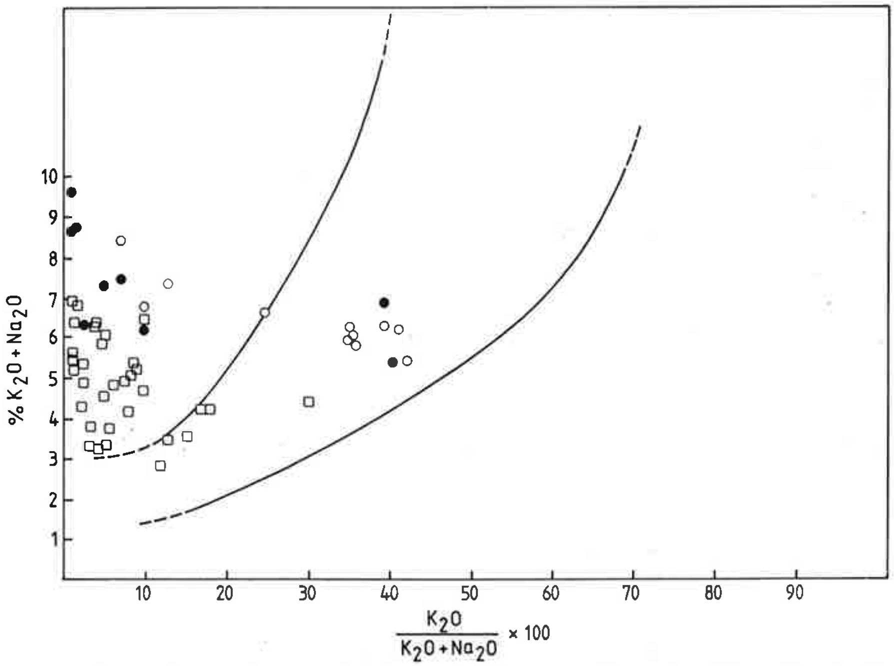


Fig. 12. Plots of greenstones and felsic rocks from the Bjørkvatnet Formation in the 'igneous spectrum' of Hughes (1972); circles — metagranodiorites; filled circles — metarhyodacites; squares — greenstones.

Table 2. Major and trace element chemistry of stilpnomelane greenstones (analyses S1–S6) and light greenstones (L1–L4) from the Bjørkvatnet Formation and of metadiorite (analyses MD1 and MD2) from the Kleiva Formation

	S1[1]	S2[1]	S3[1]	S4[2]	S5[2]	S6[2]	L1[1]	L2[2]	L3[2]	L4[2]	MD1[2]	MD2[2]
SiO_2	49.90	51.22	50.38	51.59	53.75	52.85	50.16	50.60	50.27	48.96	58.47	57.40
TiO_2	1.55	1.16	1.24	0.96	1.14	1.18	0.49	0.40	0.67	0.38	0.63	0.43
Al_2O_3	15.99	14.46	15.02	15.11	14.90	14.95	15.19	15.25	15.55	14.35	17.02	17.07
Fe_2O_3	4.20	6.86	5.53	6.92	5.53	7.12	3.72	1.78	3.64	4.07	10.20	8.47
FeO	8.16	7.56	8.60	6.55	6.88	5.40	5.33	7.53	5.83	5.76		
MnO	0.39	0.28	0.22	0.53	0.22	0.28	0.16	0.13	0.16	0.24	0.22	0.12
MgO	4.31	4.67	4.69	4.24	3.91	3.60	9.24	8.67	8.55	9.61	2.73	4.02
CaO	6.46	6.59	6.77	5.46	4.76	5.08	9.34	9.55	7.52	8.25	7.28	7.87
Na_2O	4.14	3.19	3.67	4.32	4.59	4.52	3.08	3.58	4.65	3.43	3.49	3.17
K_2O	0.50	0.11	0.11	0.21	0.29	0.37	0.17	0.24	0.38	0.70	0.78	1.17
H_2O	3.20	3.70	3.00	3.60	3.30	3.10	3.38	3.17	2.60	2.80	2.10	2.00
CO_2	0.80	0.70	0.10	0.10	0.20	0.20	0.20	0.35	0.20	0.10	0.10	0.10
P_2O_5	0.11	0.11	0.17	0.12	0.18	0.15	0.08	0.06	0.10	0.10	0.23	0.06
total	99.71	100.61	99.50	99.71	99.65	98.80	100.54	101.31	100.12	98.75	102.25	101.88
Zr	42	38	38	39	52	54	38	27	42	24	62	66
Y	22	21	12	12	15	16	17	7	11	7	19	10
Nb		4	4	6	6	5		4	4	2	10	11
Sr	190	181	242	134	152	216	52	106	179	185	324	200
Rb	0	3	4	5	9	6	3	5	7	13	29	46
La		3	3	+	3	2		+	4	+	5	5
Ce		10	9	13	15	15		7	12	7	28	25
Nd		6	5	4	11	10		3	7	5	6	16

Analyst: 1) Major elements, P. R. Graff, Norges geologiske undersøkelse; trace elements O. Lutro.
2) Major and trace elements, O. Lutro.
\+ trace only.

greenstones show high Na_2O and low CaO contents which indicate that these elements were appreciably mobile during alteration. The CaO is thought to have migrated to form the epidote aggregates which are common in the greenstones. The mobility of the alkalies is also indicated by Hughes' (1972) igneous spectrum (Fig. 12) as the greenstone samples plot outside the spectrum on the Na-enriched side. The Fe^{3+}/Fe^{2+} ratio is most probably altered as the Fe_2O_3 contents are higher than the $TiO_2+1,5\%$ limit set by Irvine & Barager (1971) as the highest value in unaltered basalts.

The mobility of elements and change of oxidation ratios makes classification based on norm calculations of little value and variations diagrams using alkalies are of limited use due to the Na-enrichment. The AFM diagram (Fig. 13) does, however, show an iron enrichment trend for the Gjersvik greenstones. This most probably represents an original tholeiitic trend (Kuno 1968) but the secondary Na-enrichment has produced a swing towards an alkaline trend. The very low K_2O content is uncommon in alkaline lavas, in which the K_2O content is usually nearly the same as the Na_2O content (Carmichael et al. 1974).

Plotted on the FeO-FeO/MgO and SiO_2-FeO/MgO diagrams of Miyashiro (1974, 1975) (Figs. 14b & c) the analyses fall in the tholeiitic iron enriched side of the diagrams but do not seem to follow the trend of any spesific island arc. The island arc tholeiitic affinities, however, are indicated by the TiO_2-FeO/MgO plot (Miyashiro 1974), Fig. 13a, which shows a moderate increase in TiO_2 with increasing FeO/MgO.

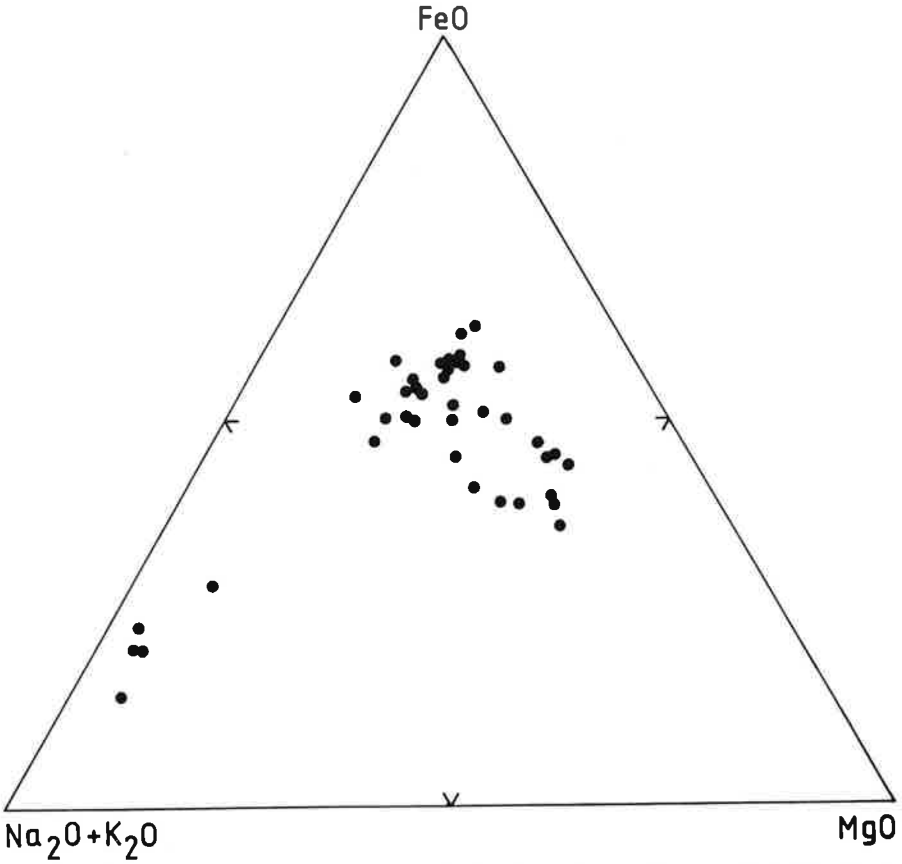


Fig. 13. Plots of greenstones and metarhyodacites from the Bjørkvatnet Formation in an AFM variation diagram.

Trace elements

In recent years incompatible trace elements including rare earths have gained popularity in the effort to try to classify altered basaltic lavas since they have been shown to be more or less immobile during alteration (Frey et al. 1968, Cann 1970, Philpotts et al. 1970, Bickle & Nisbet 1972). The element contents and ratios are also considered to be characteristic of the type of basalt and its tectonic setting (Jakes & Gill 1970, Pearce & Cann 1973, Masuda et al. 1975) and have formed the basis for construction of various discrimination diagrams.

Two such diagrams have been used here — the Ti-Y-Zr and Ti-Zr plots of Pearce & Cann (1973), Fig. 15, — and these show that the Gjersvik greenstones appear to represent altered island arc tholeiitic basalts. The REE pattern, obtained in La, Ce, Nd and Y which proxies for Er (Frey et al. 1968) normalized with standard chondrite values (Fig. 16b), is also similar to patterns obtained from island arc tholeiites by Gast (1968), Jakes & Gill (1970) and Masuda et al. (1975). Another indication of island arc affinities is very low Ni and Cr values (Jakes & White 1972). The geochemical characteristics of the Gjersvik Group basaltic greenstones would therefore point to an origin as

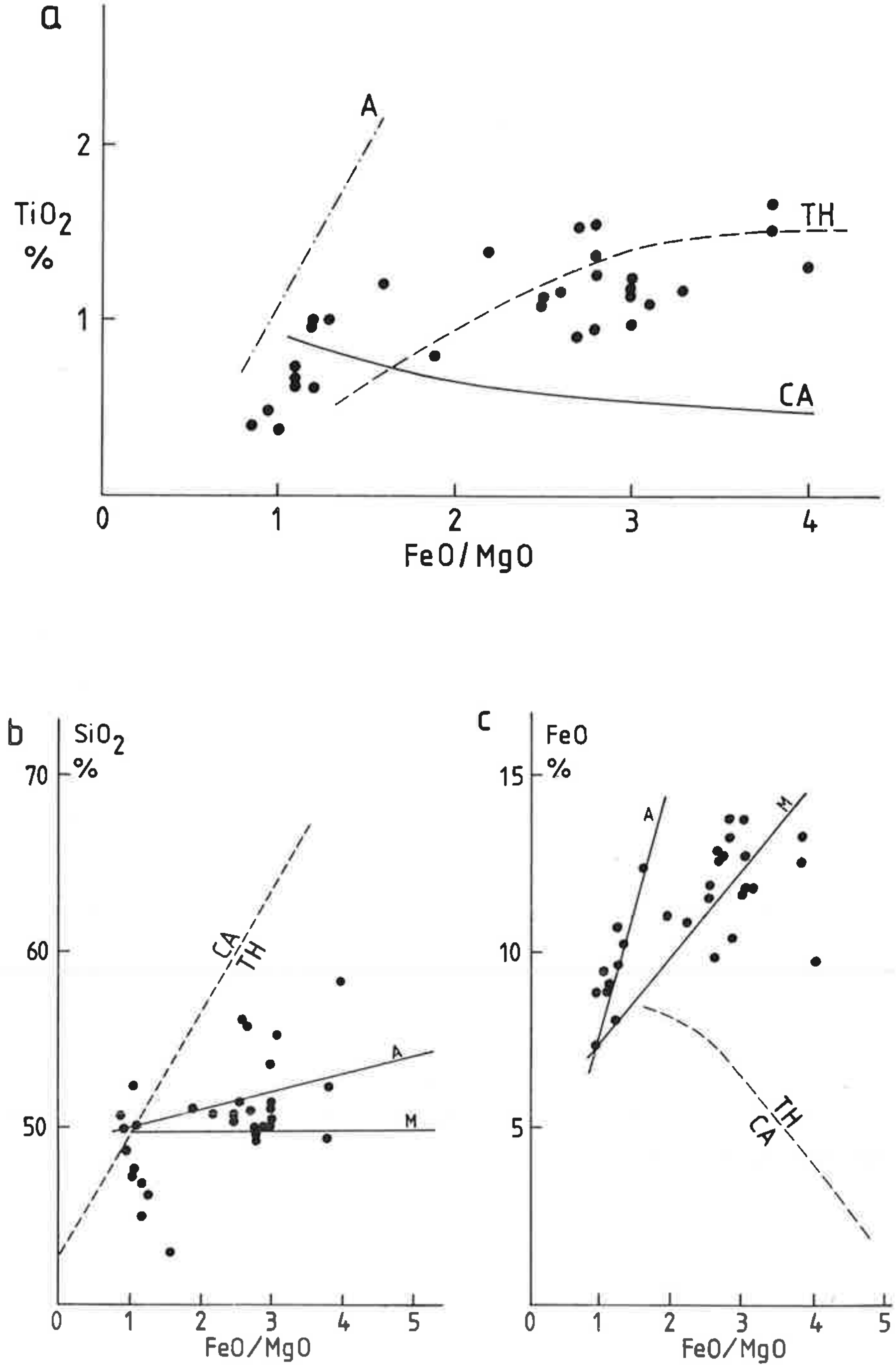


Fig. 14. Plots of greenstones from the Bjørkvatnet Formation in: (a) a TiO_2–FeO/MgO diagram (Miyashiro 1974); (b) SiO_2—FeO/MgO diagram (Miyashiro 1974); (c) FeO/MgO diagram (Miyashiro 1974). In Fig. 13a, A is the ocean floor tholeiitic trend. TH the island arc tholeiitic trend and CA the island arc calc–alkaline trend. In Fig. 13b&c, TH denotes the island arc tholeiitic field and CA the calc–alkaline field; M is the trend of the tholeiitic Macauley island arc.

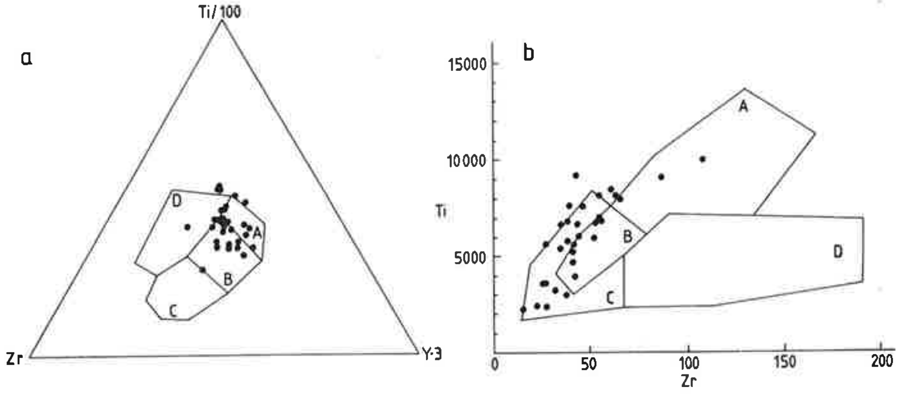


Fig. 15. Plots of basaltic greenstones in the diagrams of Pearce & Cann (1973). *a*, Ti–Zr–Y diagram; field D — within plate basalts; fields A&B — island arc tholeiites; B — ocean floor basalts; C — calc–alkaline basalts. *b*, Ti–Zr diagram; field A&B — ocean floor basalts; field D — calc–alkaline basalts; fields B&C — island arc tholeiites. All values in ppm.

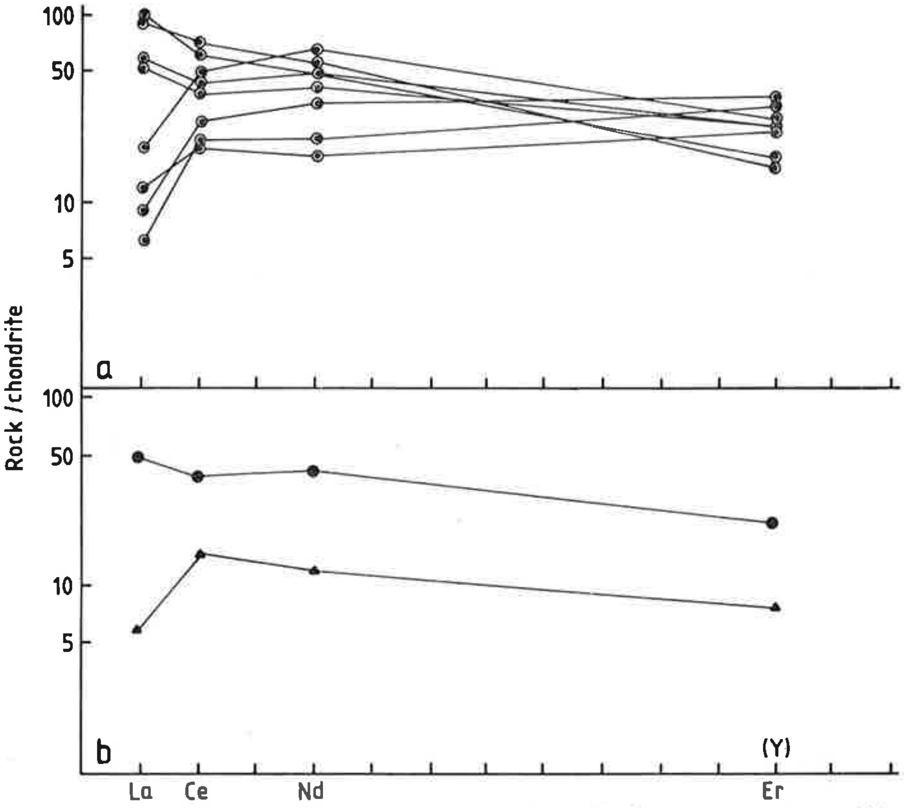


Fig. 16. a, Plots of REE values from metarhyodacites in the Bjørkvatnet Formation. *b*, Plot of the mean of REE values from greenstones within the Bjørkvatnet Formation (triangles) and metagranodiorites (filled circles). The REE values are normalized with chondrite data from Frey et al. (1968).

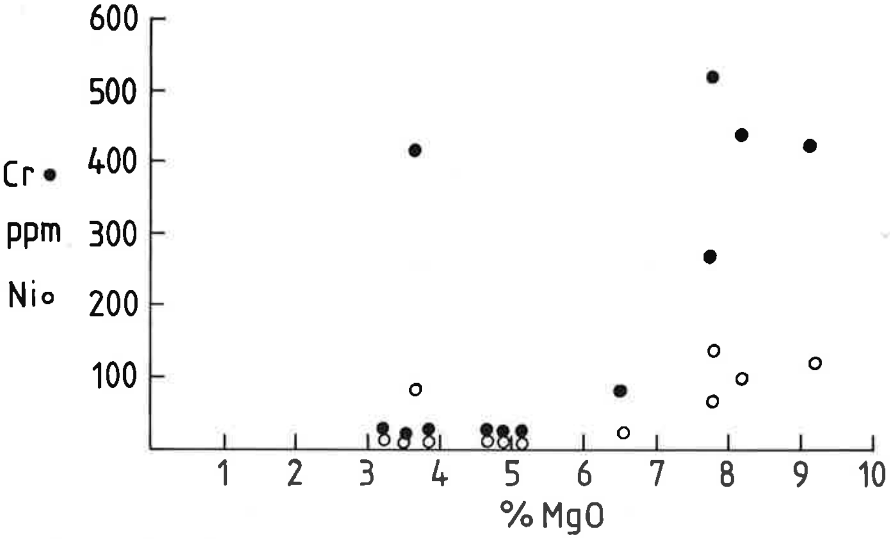


Fig. 17. The relation between MgO content and Cr and Ni contents of some basaltic greenstones from the Bjørkvatnet Formation.

island arc tholeiites. The least iron-enriched basalts are the light greenstones (Table 2, L1 to L4) and some samples of dark greenstone (Table 1, D8, D9, D11, D20) which have FeO/MgO ratios of about 1. This ratio increases to about 4 in stilpnomelane greenstone (Table 2, S1 to S6) and in some samples of dark greenstone (Table 1, D1, D4, D25). Cr and Ni values plotted against MgO show a marked decrease at around 7% MgO (Fig. 17). This sudden fall is suggested here to have been caused by crystallization of Mg-rich olivine and pyroxene in the source magma, thus producing the iron enrichment in the basalts. This also indicates that the Gjersvik Group volcanics represent a differentiated lava sequence.

METARHYODACITE

These rocks (Table 3), which are altered felsic tuffs and lavas, were also subjected to pre-tectonic alteration as they plot outside the igneous spectrum (Hughes 1972), Fig. 12. This indicates that the high Na_2O and low K_2O contents which make these rocks quartz keratophyres (Schermerhorn 1974) are the result of alteration processes. Two of the samples plot inside the igneous spectrum and have Na_2O and K_2O contents which are similar to those of more normal dactic or rhyolitic rocks.

The secondary alteration is also indicated by the REE patterns (Fig. 16a) which show a depletion of the light elements in comparison to the heavy. This is an uncommon pattern in felsic rocks but has been described by Mineev et al. (1963) from altered acidic extrusives. The samples with an unaltered major element chemistry have REE patterns similar to that of dacite in the tholeiitic series (Masuda et al. 1975). The metarhydoacites also have low contents of incompatible elements which compare well with those in island arc tholeiitic dacites (Jakes & White 1972).

Table 3. Major and trace element chemistry of metarhyodacites from the Bjørkvatnet Formation

	MR1[1]	MR2[1]	MR3[1]	MR4[1]	MR5[1]	MR6[2]	MR7[2]	MR8[2]
SiO_2	73.26	77.66	69.65	73.17	72.30	78.93	72.50	75.89
TiO_2	0.10	0.16	0.23	0.31	0.25	0.14	0.32	0.25
Al_2O_3	14.67	12.81	12.61	12.86	13.61	10.16	13.40	11.98
Fe_2O_3	1.01	0.55	2.43	2.78	1.87	2.18	2.97	2.96
FeO	1.21	0.68			0,57			
MnO	0.02	0.02	0.06	0.04	0.05	0.03	0.08	0.03
MgO	0.57	0.55	0.71	0.88	0.29	0.63	0.60	0.50
CaO	0.41	0.59	2.40	0.35	1.94	1.38	0.68	0.24
Na_2O	6.90	6.15	3.26	8.58	4.19	5.57	8.40	9.44
K_2O	0.53	0.16	2.14	0.04	2.52	0.58	0.11	0.01
H_2O	0.92	0.64	1.50	0.73	1.00	0.90	1.10	0.30
CO_2	0.05	0.05	1.30	0.20	1.05	0.25	0.30	0.10
P_2O_5	0.02	0.01	0.07	0.07	0.01	0.02	0.07	0.05
total	99.67	100.03	96.36	100.01	99.65	100.77	100.53	101.75
Zr	253	262	162	201	173	161	190	184
Y	61	68	28	53	34	52	52	57
Sr	110	93	47	41	108	136	88	65
Rb	9	3	47	3	44	12	4	1
Nb	9	9	13	12	13	11	12	13
La	2	3	31	18	33	4	17	10
Ce	18	23	62	38	53	18	32	43
Nd	13	19	34	30	29	11	26	30

Analyst: 1) Major elements P. R. Graff, Norges geologiske undersøkese; trace elements O. Lutro.
2) Major & trace elements, O. Lutro.

METAGRANODIORITE

The metagranodiorites (Table 4) most probably represent intrusive equivalents of the metarhyodacites. They are less altered and plot partly outside and partly inside the igneous spectrum. Those plotting inside have low Na_2O/K_2O ratios similar to the less altered metarhyodacites. The ones plotting outside are similar to the altered metarhyodacites. Alteration is unevenly distributed in individual metagranodiorite bodies, as both altered and unaltered samples are found within the same body.

Trace element abundances are about the same as for the metarhyodacites and thus comparable to those of island arc dacite (Jakes & White 1972). The REE patterns (Fig. 16b) show enrichment of the light elements and are quite similar to the patterns of the less altered metarhyodacite and to tholeiitic dacite (Masuda et al. 1975).

DISCUSSION

It has been shown that the basaltic greenstones of the Bjørkvatnet Formation are most probably representative of altered island arc tholeiites. The metarhyodacites and intrusive equivalents are also similar to felsic island arc rocks and are comparable to dacitic rocks thought to represent differentiates from tholeiitic basalts (Masuda et al. 1975). The chemistry of the rocks in the

Table 4. Major and trace element chemistry of metagranodiorites from the Bjørkvatnet Formation

	MG1^2	MG2^2	MG3^2	MG4^2	MG5^2	MG6^2	MG7^1	MG8^1	MG9^1	MG10^1	MG12^1	MG13^2	MG14^2
SiO_2	73.19	72.81	70.79	69.76	69.52	71.82	71.57	75.18	73.08	73.64	72.36	72.74	72.38
TiO_2	0.35	0.24	0.23	0.35	0.50	0.24	0.39	0.14	0.17	0.25	0.31	0.21	0.26
Al_2O_3	13.07	12.58	12.32	13.20	14.42	12.86	14.10	13.11	13.16	12.06	13.30	12.89	14.00
Fe_2O_3	1.82	2.18	2.11	2.29	3.19	2.44	1.57	1.34	1.97	2.18	1.59	1.30	1.49
FeO							1.12	0.95	1.00	0.87	0.71	1.04	1.26
MnO	0.05	0.13	0.13	0.12	0.08	0.10	0.10	0.07	0.04	0.03	0.12	0.05	0.07
MgO	0.84	0.49	0.80	0.69	1.37	0.30	0.62	0.44	0.42	0.63	0.41	0.58	0.67
CaO	0.99	2.08	2.11	1.74	1.05	2.25	1.30	0.78	0.97	1.91	2.06	2.23	2.38
Na_2O	4.07	3.88	3.76	3.31	7.80	3.09	6.30	6.00	6.78	3.87	5.04	3.78	3.60
K_2O	2.20	2.08	2.09	2.09	0.55	2.28	1.00	0.69	0.39	2.10	1.60	2.45	2.53
H_2O	1.00	1.20	1.50	1.30	1.01	1.63	1.14	0.89	1.58	1.16	1.07	1.10	1.00
CO_2	0.90	1.00	1.30	1.21	0.30	1.28	0.46	0.34	0.72	1.06	1.19	1.10	0.80
P_2O_5	0.08	0.06	0.05	0.09	0.13	0.06	0.05	0.02	0.02	0.03	0.03	0.08	0.05
total	98.56	98.73	97.19	96.15	99.92	98.35	99.72	99.95	100.30	99.79	99.79	99.55	100.49
Zr	181	193	191	175	172	156	176	196	190	180	159	123	122
Y	56	50	47	46	47	31	47	42	47	46	40	32	30
Sr	68	94	87	105	129	100	103	69	82	38	84	169	176
Rb	46	35	34	36	12	37	20	20	8	35	28	65	65
Nb	13	11	12	13	12	12	12	13	11	10	9	8	7
La	15	20	18	15	14	28	16	19	14	11	14		
Ce	36	41	39	38	36	43	32	40	32	31	36		
Nd	30	28	25	25	23	24	26	26	26	23	25		

Analyst: 1) Major elements, P. R. Graff, Norges geologiske undersøkelse; trace elements, Ole Lutro.
2) Major & trace elements, Ole Lutro.

Bjørkvatnet Formation thus seems to confirm the island arc origin of the Gjersvik Group which has been assumed on lithological grounds earlier in the account.

The formation of island arcs is considered to take place above consuming plate margins where oceanic crust is subducted and tholeiitic magma is formed by partial melting of the mantle material lying above the subducted crust (Green 1972, Nicholls & Ringwood 1973, Ringwood 1974). To generate tholeiitic magma a partial melting of 15 to 30% is required (Gast 1968, Green 1972), and the formation of island arc tholeiites is thought (Jakes & White 1972) to require a large degree of melting of peridotite or pyrolite (Green & Ringwood 1967).

The low contents of incompatible elements in the Gjersvik greenstones indicate that a considerable degree of partial melting took place during the formation of the magma (Gast 1968), and the relatively flat REE pattern is in accordance with a partial melting model (Gast 1968, Nicholls & Ringwood 1973). It also precludes the existence of garnet in the source material as this mineral concentrates heavy REE (Gast 1968).

The basaltic greenstones have been shown to represent a differentiated lava sequence displaying iron enrichment. This is assumed to have been caused by crystallization of Mg-rich pyroxene and olivine. Fractionation of olivine and spinel under high pressure leads to the formation of island arc tholeiites (Ringwood 1974). Here the Cr is bound in spinel, not in pyroxene. This fractionation would result in the formation of andesite as the most felsic member.

A low-pressure fractionation of amphibole ± pyroxene from an iron-enriched tholeiitic magma produces a dacitic to rhyodacitic rock with chemical properties similar to those shown by the felsic rocks in the Bjørkvatnet Formation (Nicholls & Ringwood 1973, Ringwood 1974).

Volcanic rocks of intermediate composition are very few in the Bjørkvatnet Formation. Analyses of the slightly deformed metadiorite (Table 2, MD1 & MD2) from the Kleiva Formation show that the rock is similar in composition to tholeiitic andesites (Jakes & White 1972) : the analyses plot within the tholeiitic field in the iron-enrichment diagrams of Miyashiro (1974). The intermediate rocks then might not have reached the surface as lavas but probably solidified at shallow depths.

In summary, the chemistry of the volcanic and intrusive rocks in the Gjersvik Group is strongly indicative of their development in an island arc setting, thus confirming the earlier conclusions of Gale & Roberts (1974) and Halls (et al. 1977). The rocks are considered to belong to an island arc tholeiitic series produced by high-pressure olivine-spinel fractionation and a later low-pressure amphibole ± pyroxene fractionation. As island arc volcanism commences with tholeiitic rocks (Kuno 1968, Sugimura 1968, Jakes & Gill 1970, Jake & White 1972), the Gjersvik volcanics were probably extruded at an early stage. Geographically, these rocks probably originated on the continental-facing inner volcanic zone (Miyashiro 1975) where the light REE are enriched compared to the heavy. As with most recent island arcs the volcanic islands are likely to have originated on oceanic crust (Carmichael et al. 1974, Miyashiro 1974). Magmatic arcs developed close to or upon continental crust are usually dominated by ignimbritic rocks of dacitic to rhyolitic composition, e.g., in the New Zealand and Tonga–Kermadec regions (Carmichael et al. 1974).

Age relations and regional correlation

No fossils have been found within the rocks of the Gjersvik area and no radiometric dating has yet been carried out. The ages are therefore conjectural and must be based on lithological correlation.

The Røyrvik Group can be traced across to the Joma area and further east into the so-called 'phyllite complex' in the Blåsjøen area of Sweden (Nilsson 1964). Sjöstrand (1978) has referred to this sequence of phyllites, greenstones and tuffs as the Brännälven Formation and considers them to be of Cambrian age, a view shared by Juve (1977). These rocks have been correlated with the Remdalen Group (Zachrisson 1969) which is younger than the Ashgillian to Llandoverian Lasterfjäll Group (Zachrisson 1969, Kulling 1972).

Rocks similar to those in the Limingen Group are not found in the neighbouring areas of Sweden, but these lithologies can be traced southwestwards to the Grong culmination and then into the Snåsa–Steinkjer area of the Trondheim region (Roberts 1975) where they are represented by the Upper Hovin

Group and part of the Lower Hovin Group (Peacey 1964, Roberts 1967). Further south these sediments become more flyshoid and are of deeper water origin (Siedlecka 1967, Roberts 1969, 1972). In the Trondheim region there are several thick greenstone units which could possibly correlate with the Gjersvik Group, the main one being the Støren Group. It has been shown, however, that the Støren Group basaltic greenstones are representative of oceanic crust (Gale & Roberts 1974), whereas the Gjersvik Group probably originated as an ensimatic island arc. The Støren Group might therefore conceivably represent the oceanic crust upon which the island arc was formed. The Gjersvik Group will then be younger than the Støren basalts and might be correlated with the Lower Hovin Snåsa greenstones (Roberts 1975). These particular greenstones have been correlated with the Forbordfjell and Jonsvatn greenstones which are of probable Llandeillian age (Roberts 1975). While this is suggestive of a similar age for the Gjersvik Group, the lower boundary is nowhere seen : the initial development of the volcanic arc may therefore date to Llanvirnian time. Another possible correlative of the Gjersvik Group could be that of the greenstones of the Skei Formation on Leka, situated some 80 km west-northwest of Gjersvik (Prestvik 1974). These are now, however, thougt to represent parts of an ophiolite complex (Prestvik & Roaldset 1978).

The conglomerates occurring above the Gjersvik volcanics at the base of the Limingen Group were therefore probably deposited during the same parorogenic episode that produced the Stokkvola Conglomerate which lies stratigraphically above the Forbordfjell greenstone (Roberts 1975). Halls et al. (1977) have, in fact, referred to this major unconformity above the Gjersvik volcanics as the 'Gjersvik disturbance'.

The high-metamorphic rocks of the Helgeland Nappe Complex have generally been considered to be of Cambro-Silurian age and to belong to the so-called 'Nordland facies' (Strand 1960), although the possibility of a Precambrian age for the lowermost gneisses has also been mentioned (Gustavson 1975). According to Gustavson (1975) the bulk of these high-grade rocks might be equivalents of the low-metamorphic rocks in the Trondheim region, in central Västerbotten and on Leka. In the Gjersvik area, however, the rocks of the Helgeland Nappe Complex are believed to be of Cambrian age or older on the basis of the early tectonometamorphic event which is recorded only in this nappe. In the tectonically underlying low-metamorphic Gjersvik, Limingen and Røyrvik Groups in which rocks of supposed Cambrian to Ordovician or early Ordovician to Silurian age occur, the earliest folding and metamorphic crystallization is considered to date to Middle to Upper Silurian time.

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GEOLOGICAL MAP OF THE GJERSVIK AREA

BY OLE LUTRO