THE GEOLOGY OF THE NORTHERN HALF OF THE LYNGEN PENINSULA, TROMS, NORWAY

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The geology of the northern half of the Lyngen peninsula, Troms, Norway, is described. A central gabbro body is bounded to the west by metasediments, to the east by greenstones, and has been tectonically emplaced from the west. Zoned ultramafic rocks of 'Alaskan' type occur within the gabbro.

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Lyngen peninsula is located in the Caledonides of Arctic Norway, some 40 km east of Tromsø. This paper describes the geology of the northern part of the peninsula and enlarges upon the litho-stratigraphic nomenclature advanced by Randall (1971), from his detailed mapping of the southern part of the peninsula.

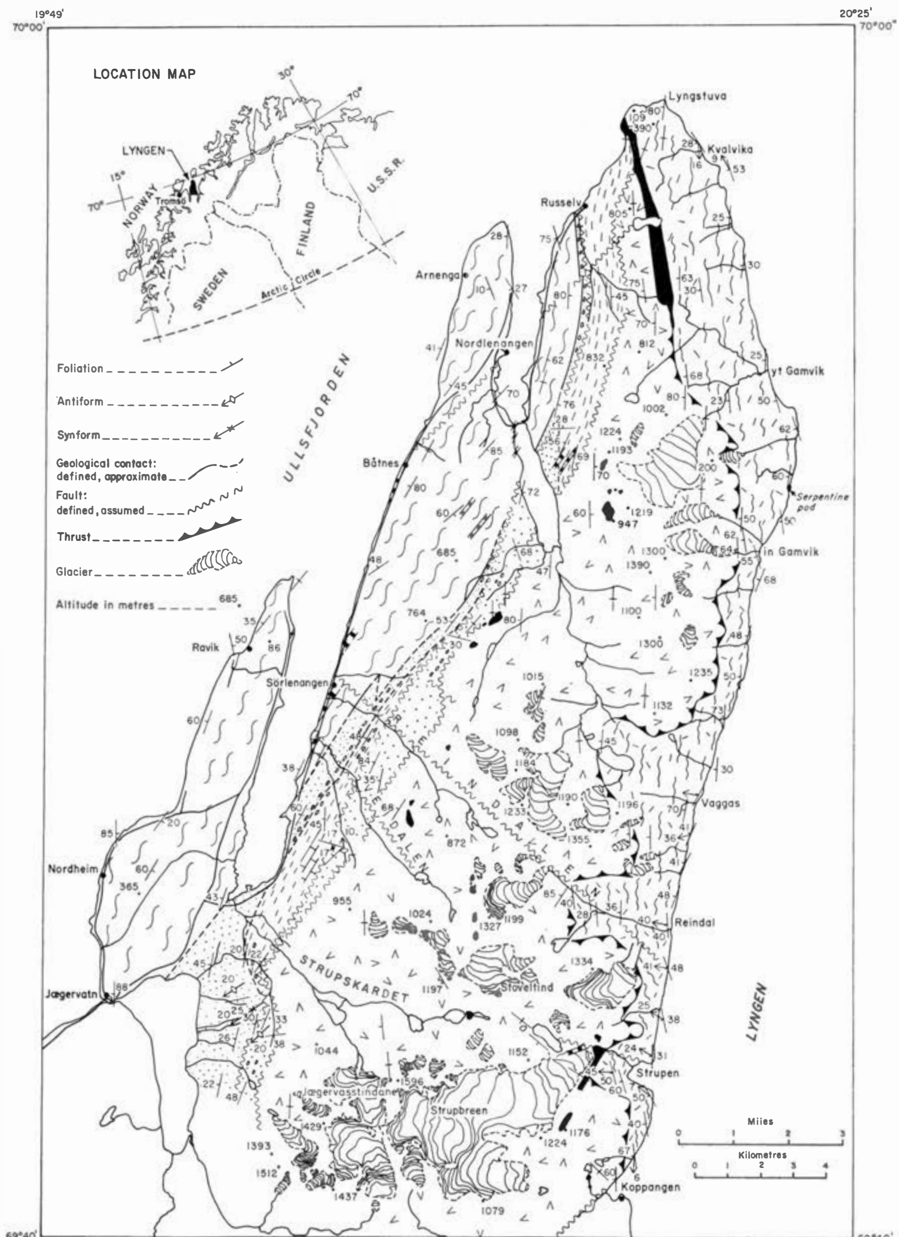
Lyngen peninsula can be divided into three distinct parts (Fig. 1). Forming the axis of the peninsula is the Lyngen gabbro, a layered intrusion now largely uralitized and saussuritized. The gabbro is fault bounded and intensely deformed. To the east and structurally below the gabbro is the Kjosen Formation, a series of greenschists, mafic gneisses, amphibolites and massive hornblendites. West of, and structurally above, the gabbro are the Western Metasediments, which have been sub-divided into a series of groups and formations based on lithological variations. No fossils have been found. Ultramafic rocks occur as discrete bodies within the gabbro and as lensoid masses along a major fault zone within the Western Metasediments.

Three deformational episodes have been recognized. A strong schistosity in the pelitic rocks is axial planar to rare fold closures which are related to the earliest identified deformation, D_1. A persistent northwesterly mineral lineation, especially in the high grade schists at southeastern Lyngen (Randall 1971) is also considered to be a D_1 structure. The second deformation, D_2, is responsible for the general disposition of strata in Lyngen. Second generation fold axes plunge gently to the north-northeast or south-southwest; axial surfaces have similar strike but variable dip due to coaxial folding by a third deformation episode, D_3. The Lyngen gabbro was tectonically emplaced during D_2.

General geology

The Lyngen gabbro

The gabbro body extends 85 km in a 190° direction and approaches 12 km in width. Layering is always distinct (Fig. 2) and results from variation in



both grain-size and the relative amounts of mafic and felsic constituents. Rhythmic layering can be identified at some localities but the direction of 'younging' is never conclusive. A strong igneous lamination is apparent in many thin sections taken from specimens of fresher gabbro and this lamination is parallel to the general layering.

When fresh, the gabbro is composed of augite, orthopyroxene, a very calcic plagioclase and magnetite. Olivine has been found in some specimens from southern Lyngen. The compositions of co-existing pyroxenes and plagioclase are given in Table 1. A rim of green hornblende has frequently developed around the pyroxene and ore crystals, and some irregular cross cutting veins of quartz, plagioclase (An 52 in one example) and green hornblende occur.

However, over most of Lyngen, the gabbro is completely altered to fibrous uralite and granular saussurite, making any identification of cryptic variation impractical. The uralite optically resembles tremolite but chemical analysis showed it to be hornblende (Munday 1970). The saussurite consists of clinozoisite set in clear albite; occasionally a selvage of epidote surrounds the clinozoisite grains.

Numerous shear planes cut the gabbro and the adjacent rocks display varying degrees of alteration. Where shearing has affected fresh gabbro, the pyroxenes and ore have altered to green, strongly pleochroic hornblende and the plagioclase has recrystallized to a less calcic composition. This mineralogy is consistent with recrystallization under amphibolite facies con-

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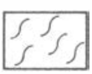
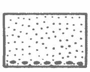
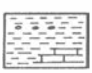
Fig. 1. Geological map of the northern part of the Lyngen peninsula.



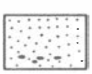
Svensby Formation; a series of pelitic and semipelitic schists composed of quartz, muscovite, chlorite with minor biotite and albite.



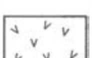
Jægervatnet Formation; mainly orthoquartzites with some rare pelitic breaks. Oligomictic quartz pebble conglomerates occur at the base of the formation.



Lakselvdalen Formation; lustrous schists, calcareous arenites and polymictic conglomerates carrying dolomite and calcite pebbles.

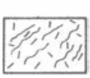


Vardtind Group; generally massive, blastopsammitic, feldspathic grits with a few pelitic breaks and some polymictic conglomeratic beds.



Lyngen gabbro; a hypersthene gabbro which is largely uralitized and saussuritized.

Kjosen Formation; a series of mafic gneisses, amphibolites and massive hornblendites.



Ultramafic rocks; pyroxenites, peridotites and serpentinites.

Mafic dikes.

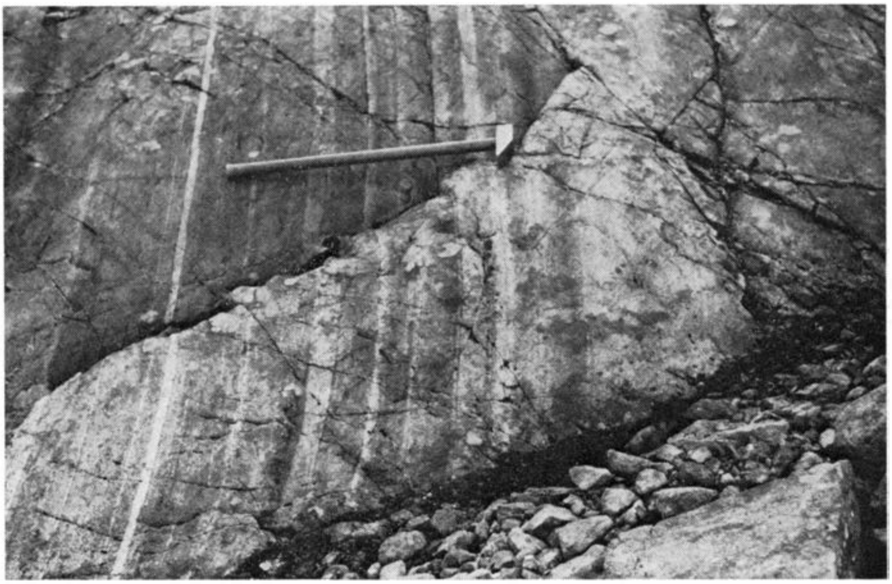


Fig. 2. Layering in the Lyngen gabbro. The distinct colour banding on outcrop surfaces results from variations in the mafic:felsic ratio and also the grain size of the rock. This variation is further emphasized in specimens of altered gabbro as the plagioclase has reverted to a very light coloured albite:zoisite aggregate.

ditions. More intense shearing, for instance above the sole of the thrust beneath the gabbro, or in the vicinity of major dislocations with the gabbro, has caused the rocks to develop a gneissic appearance. Uralite and saussurite in blebs, stringers, and augen (some of which are porphyroclastic), are aligned parallel to the gneissic foliation. Large quantities of quartz have been introduced along these shears, locally changing the rocks into leucocratic quartz schists. Some quartz appears to actually replace the constituents of the rock, a phenomenon seen in both fresh and altered gabbro. The uralite in sheared gabbro has a distinctly deep green colour and this is taken to indicate an introduction of iron during shearing.

In Table 2, chemical analyses of fresh, sheared fresh, and altered gabbro from Lyngen are given. The extremely low K_2O content of the gabbro is

Table 1. Optical determinations of the composition of some co-existing pyroxenes and plagioclase from the Lyngen gabbro.

Spec. no.	Plagioclase	Orthopyroxene		Clinopyroxene (En:	Fe:	Wo)
# 1461	An 89	En 72:	Fe 28	45:	11:	44
# 913	An 88	En 69:	Fe 31	44	12:	44
# 318	An 81	En 60:	Fe 40	40:	15:	45

Table 2. Analyses of Lyngen gabbro. Major elements were determined by wet chemistry, trace elements by X.R.F. bar for Ba, Co and Cu which were measured semi-quantitatively by optical spectrograph.

	913	318	699
SiO_2	47.2 %	54.7 %	39.1 %
Al_2O_3	17.3	16.2	17.2
Fe_2O_3		2.9	
	10.7*		19.5*
FeO		8.7	
MnO	0.26	0.24	0.35
MgO	9.3	4.7	6.6
CaO	14.4	10.0	13.4
Na_2O	0.79	1.40	0.75
K_2O	0.15	0.10	0.22
TiO_2	0.26	0.70	0.61
H_2O	0.37	1.2	3.2
	100.7	100.8	100.9
Cr	116	38	96
Ni	51	8	8
K	380	265	2200
Rb	1	1	11
Sr	143	182	100
Zr	8	8	6
Ba	11	20	30
Co	40	40	50
Cu	150	150	100

* Total iron as Fe_2O_3.
913 is fresh hypersthene gabbro; 318 is slightly sheared fresh gabbro with introduced quartz and a little iron; 699 is a sheared altered gabbro with introduced iron.

very marked and is reflected in the low Ba and Rb values. The low Ni content is a result of the lack of olivine. That iron is introduced during shearing, is well demonstrated by the far higher total iron values in the sheared specimens.

The Lyngen gabbro is fault bounded and adjacent rocks show no contact metamorphic aureole. It is believed that the gabbro has been tectonically emplaced into its present position and the general westerly dip and structural evidence from the schistose rocks of Lyngen indicate that emplacement was from the west. A gravity survey across Lyngen peninsula by Chroston (1972) showed the gabbro to be a westerly dipping wedge and that its maximum thickness occurs along the contact with the Western Metasediments. The gabbro may be derived from an area of positive gravity anomaly along the Norwegian coast, about 100 km west of Lyngen (Brooks & Chroston 1971). This anomaly could be caused by a large basic igneous body in an upper crustal environment or may represent a thrust slice from the lower crust, as noted by Brooks 1970. If the anomaly is caused by a basaltic intrusion, then the lower part of such a body could correspond mineralogically to the

Lyngen gabbro in that no marked cryptic variation would be apparent (Wager & Brown 1967), the plagioclase would be very calcic, and potassium would be present in very low concentrations. Further evidence for this theory comes from the close resemblance of the Lyngen gabbro to the lower parts of proven stratiform cumulate igneous bodies such as the Stillwater and Bushveld intrusions.

Ultramafic bodies within the Lyngen gabbro

Numerous ultramafic bodies occur within the Lyngen gabbro. They vary in size from augen 50 × 20 cm to the mass at Lyngstuva, 6 km in strike length, but all have tectonic contact against the gabbro. A crude zoning from a dunitic core to a clinopyroxenite margin has been established by Jebson (1966) for the Rødberg body beside the fjord of Kjosen. He also showed, by petrofabric analysis, that the body was emplaced as a crystal mush. This intrusion of ultramafic material appears to predate the tectonic emplacement of the Lyngen gabbro.

The ultramafic bodies are composed of olivine, clinopyroxene, serpentine and magnetite, with accessory talc, hornblende, chlorite and magnesite. No orthopyroxene or plagioclase has been observed. One dunitic rock carries olivine with a composition of Fo 92; electron probe analysis of two pyroxenes gives their composition as En 49: Fe 5: Wo 46 which is in good accord with optical determinations.

These ultramafic bodies closely resemble the zoned ultramafic bodies from Alaska, described in Wyllie (1967). An important difference is that the Lyngen ultramafics show no sign of any contact metamorphic aureole against the gabbro.

The Kjosen Formation

The schists and gneisses of the Kjosen Formation can be completely conformable with the layering in the overlying sheared Lyngen gabbro but in many localities a marked angular discordance is apparent or, as at Lyngstuva, an ultramafic body intervenes. Much of the formation consists of medium to coarse-grained mafic gneiss. These gneisses are composed of fibrous, pale green, uralitic hornblende, saussurite, quartz and epidote and are frequently indistinguishable from sheared gabbro. Sphene is nearly ubiquitous and often rims magnetite. When the plagioclase from within the saussurite can be identified it is albite. Quartz schists are interlayered with these gneisses and probably represent mafic gneiss nearly completely replaced by quartz.

Amphibolite layers commonly occur within the formation and show complete concordance to the foliation in the adjacent schists and gneisses. The amphibolites are composed of green, strongly pleochroic hornblende, albite, epidote, and magnetite rimmed by sphene. One amphibolitic lens, identical in composition to the other amphibolites, carries relict garnet and the plagioclase is much clouded by fine saussurite. It is thought to be a

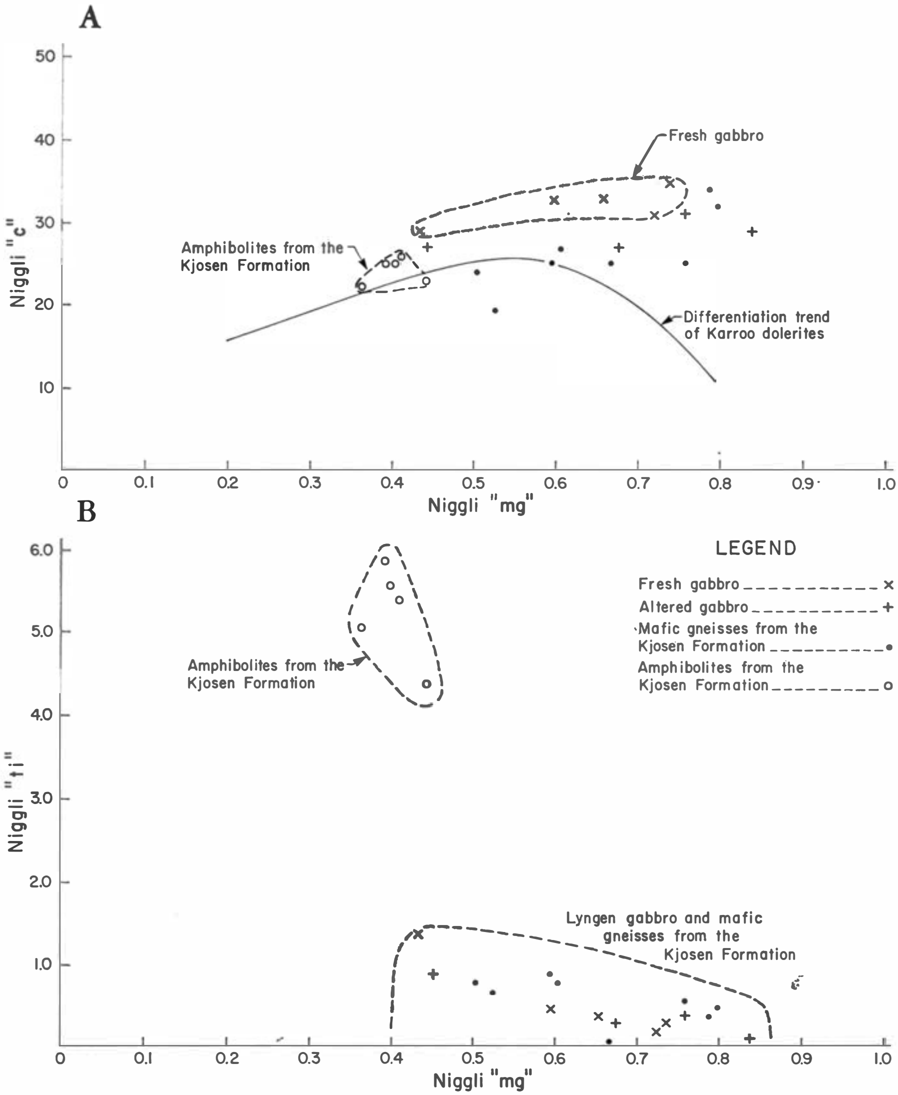


Fig. 3. A: Plot of Niggli 'mg' against 'c' for analysed rocks from the Lyngen gabbro and Kjosen Formation. The differentiation trend of basalts from the Karroo of South Africa is given as reference. Note the very calcite trend for fresh Lyngen gabbro; the restricted field for amphibolites from the Kjosen Formation; and the large scatter for specimens of mafic gneiss and altered gabbro.
B: Plot of Niggli 'mg' against 'ti' for analysed rocks from the Lyngen gabbro and Kjosen Formation. Specimens of gabbro and mafic gneiss plot in a restricted area totally separated from the amphibolite field.

fault emplaced pod of amphibolite, derived from an area of higher, amphibolite facies, metamorphism. All other greenstones in the Kjosen Formation have mineralogy of the greenschist-amphibolite transitional facies of Turner (1968).

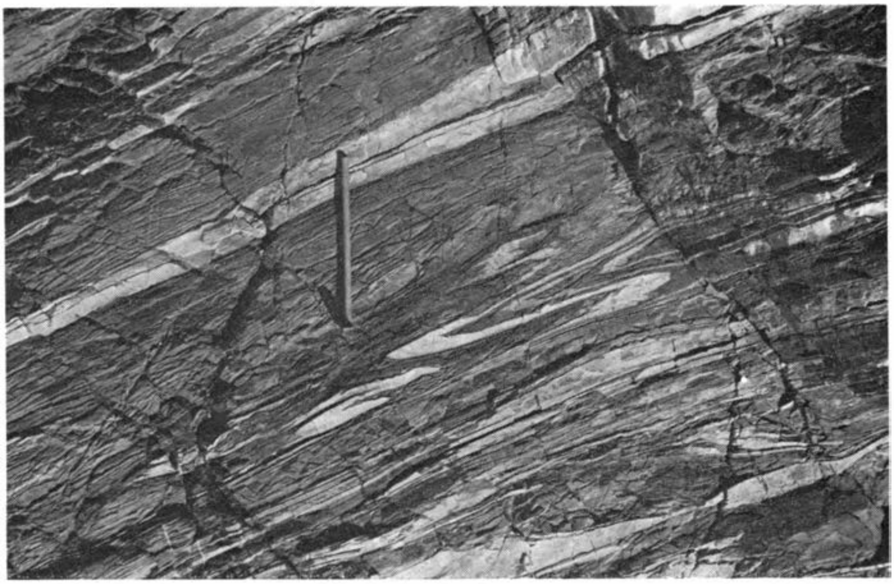


Fig. 4. Tight folds of D_2 age within the Kjosen Formations. These folds deform a schistose fabric which is axial planar to still earlier folds.

Several other types of schist have been recognized, including chlorite schists, garnet-bearing chlorite schists and feldspar-free, quartz–chlorite–biotite–epidote schists. Several bodies of massive hornblendite outcrop in the Lyngstuva area. Sharp boundaries cannot be mapped for these hornblendites, as movement along slip and shear planes imperceptibly transforms the massive rock into foliated hornblende schist and gneiss. The hornblendites are composed of green xenoblastic hornblende crystals up to 2 cm long, set in a matrix of greenish saussurite. A specimen of troctolite was collected from within the hornblendites and is believed to represent the mother rock from which the hornblendite developed. The troctolite is composed of olivine (Fo 84) and bytownite (An 90), both occurring in anhedral crystals up to 1 cm across. Interesting coronas have developed between the olivine and bytownite. The zone nearest to the olivine consists of small orthopyroxene (En 82) rhombs generally with their 'c' axes oriented radially. This corona abruptly changes to an amphibolite corona which in turn alters to an amphibole-spinel symplectite along the plagioclase contact. Similar coronas have been described by Spry (1969).

The origin of the Kjosen Formation is obscure. Much of the formation is indistinguishable from sheared varieties of the Lyngen gabbro and also the relict troctolite within hornblendite at Lyngstuva could well be derived from the gabbro. A geochemical investigation was undertaken to test the concept that the Kjosen Formation is mainly sheared gabbro. Thirty-four specimens of the gabbro and greenstones were analysed by X.R.F. and certain parameters calculated from their chemical composition were plotted

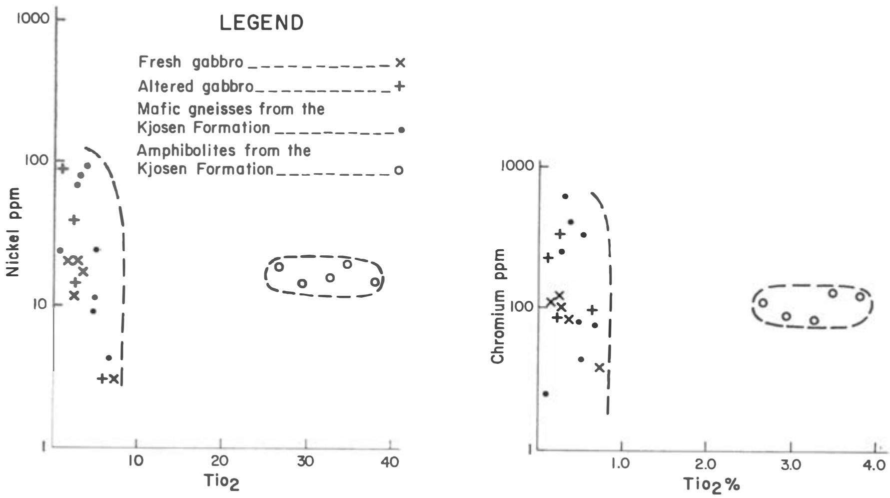


Fig. 5. Plot of TiO_2 against Ni and Cr. Gabbro and mafic gneiss are intermixed within a restricted field totally separated from the amphibolite plot.

onto a series of graphs (Figs. 3 and 5), using an approach advocated by Leake (1964). As can be clearly seen, the amphibolites from the Kjosen Formation plot in a distinct field but no substantial distinction can be drawn between gabbro and the remaining Kjosen Formation greenstones. The uniform composition of the amphibolites and their mineralogical resemblance to meta-diabase suggest they represent a distinct phase of magmatic intrusion.

The above data indicate that the Kjosen Formation probably represents the sheared and folded basal part of the Lyngen gabbro. Sometime during the emplacement of the gabbro, diabase invaded the sheared lower part of the gabbro, now recognized as the Kjosen Formation, but did not penetrate the upper, less deformed, part. This conclusion is supported by the occurrence, within the Kjosen Formation, of a sheared lens of serpentine indistinguishable from the ultramafics within the Lyngen gabbro.

The Western Metasediments

The Western Metasediments have been divided to form the following succession:

Svensby Formation
Jægervatnet Formation
Lakselvdalen Formation] Western Metasediments
fault ________
Vardtind Group
fault ________
Lyngen gabbro

This succession is based upon the lithostratigraphic nomenclature described by Randall (1971). The westerly dip of the metasediments results in the Svensby Formation being the highest, most westerly member of the succession, while the Vardtind Group occurs at the base, fault bounded against the Lyngen gabbro. Some poorly preserved sedimentary structures indicate the sequence is probably inverted.

The Svensby Formation

The schists of the Svensby Formation are well foliated and consist of alternating quartz and muscovite rich layers. Flakes of pale green chlorite are associated with the muscovite and grains of clear albite can occasionally be identified amongst the quartz. Tabulae of an opaque mineral (probably hematite) are oriented parallel to the schistosity and graphite is a nearly ubiquitous accessory. Biotite flakes, with random orientation, overgrow the foliation in some specimens. At two localities, Nordheim and Arnenga, along the extreme western margin of Lyngen, garnet-bearing muscovite and biotite schists occur. These garnet-bearing schists are believed to indicate a progressive increase in metamorphic grade from the greenschist facies of most of the Western Metasediments to possibly just within the amphibolite facies along the western margin of the Lyngen peninsula.

Elongate dyke and sill-like bodies of amphibolite occur within the Svensby Formation and show discordant contacts against the schists. The amphibolites generally trend in a 220° direction and appear to be of syn-D_2 age, intruded along planes parallel to S_2. A schistosity has developed in the intrusions, parallel to their contacts, but this schistosity is less pronounced in the central part of the bodies. Locally, the S_3 cleavage intersects the amphibolites but no small scale folds have been observed within them.

The Jægervatnet Formation

This formation is a uniform, white weathering quartzite with a few muscovite partings. Albite occurs in some specimens but is of very limited importance. Rare pelitic breaks and a persistent 'flaggy' texture are thought to be parallel to original sedimentary bedding, S_0. Conglomeratic beds are found at the base of the formation, containing pebbles as much as 25 cm across but usually averaging 9 cm × 6 cm × 3 cm. Several pebble types occur, with white, sugary, pure quartzite pebbles predominating over softer, greenish, chloritic quartzite and grey mica schist pebbles. The matrix is a fine psammite or pure quartzite; distinct sand breaks occur in the Nord-Lenangen area. South of Reindalen, the conglomerates have a tectonic aspect, although some beds retain their sedimentary features.

Lakselvdalen Formation

This formation is composed of interbedded limy shales, calcareous sandstone, polymictic conglomerates and graphitic limestones. The metamorphic grade is very low, with little more than recrystallization into lustrous phyllites in the pelitic horizons. The conglomeratic beds are very distinct as they contain pebbles of dolomite and limestone, as well as quartz, quartz schist and mica schist, in a sandy calcareous matrix. They can be traced from Sør-Lenangen through Jægervatnet, over Kjosen to the extreme south of Lyngen. Landmark (pers. comm. and map 1968) has encountered similar conglomerates in the Målselv area and Holtedahl & Dons 1960 (Geologiske kart over Norge) indicate that these may well be the same as those on Lyngen. This makes the conglomerates excellent stratigraphic markers as they undoubtedly are the same formation, even though they may not necessarily represent the same horizon.

The Vardtind Group

This group consists of a thick, uniform succession of blastopsammitic feldspathic grits. Rare pelitic breaks indicate bedding planes (S_0) but in most exposures the grits are completely massive. Conglomeratic horizons have been found and one of these contains diabase pebbles. Graded and cross bedding are well enough preserved in a few rare exposures to indicate that the group youngs to the east; hence it is inverted.

Amphibolitic bodies occur within the feldspathic grits. They are composed of hornblende, albite, quartz, biotite, chlorite, epidote, sphene and magnetite. Chemical analysis indicates affinity to hornblende lamprophyre (Munday 1970).

A prominent fault separates the Lakselvdalen Formation from the Vardtind Group. Ultramafic bodies, 30–50 metres wide and several hundred metres long, are found along this fault and tend to weather out as conspicuous scars on ridges. The ultramafic rock when fresh is hard, dark green and is composed of green chlorite and perfect octahedra of magnetite as much as 1 cm in diameter. Alteration to soft calcareous 'soapstone' is common, especially along the margins of the bodies. Serpentine, talc, tremolite, chromite, brucite and carbonate have been identified in various specimens of the rock. Iddingsite pseudomorphing olivine also occurs. The feldspathic grits of the Vardtind Group have developed a contact aureole adjacent to the ultramafic rocks. The aureole is visible as much as 3 metres from the contact and is characterized by the development of acicular crystals of tremolite overgrowing the blastopsammitic texture of the grits.

These ultramafic pods are thought to be material of originally peridotitic composition intruded into a fault zone. At the time of intrusion, the peridotite was warm and partially non-serpentinized. Percolating solutions completed the steatitization after final emplacement of the ultramafic material.

Structural geology

Structures within the Lyngen peninsula

Three major episodes of deformation have been recognized in the rocks of the Lyngen area. The evidence for these deformations is mainly preserved within the schistose rocks of the Svensby and Kjosen Formations, however, all rocks in the area display folds of varying complexity.

The strong schistosity in the pelitic rocks of the Svensby Formation is axial planar to intraformational or rootless fold closures, defined by quartz veins or siliceous beds, and these folds are taken to represent D_1 minor structures. Similar structures are visible in the green schists of the Kjosen Formation. These isolated, early fold closures are believed to result from a period of intense isoclinal folding during which sedimentary bedding was severely attenuated parallel to the present axial planar schistosity. Another structure of D_1 age is a persistent northwesterly mineral lineation. This lineation is displayed in the Kjosen Formation by alignment of hornblende crystals. Randall (1970) reported that in the high grade schists from southeastern Lyngen, both kyanite and diopside are oriented in a northwesterly direction. No such mineral lineation occurs in the Western Metasediments but pebbles are frequently oriented and probably elongated in a northwesterly direction. These lineations fit in well with the regional orientation of early lineations from north Norway, as described by Hooper (1968).

Minor folds which deform the D_1 structures are abundantly exposed in the schistose rocks of Lyngen. These folds plunge gently to the north-northeast (020°) or south-southwest (200°) and in the Kjosen Formation axial surfaces dip at about 45° to the west (Fig. 4). A third deformation, coaxial to D_2, has affected the Western Metasediments and flexed D_2 axial surfaces to yield the variable dips now observed. The D_3 axial surfaces generally dip steeply to the west but this dip tends to approach the vertical, or even steeply east, as the Lyngen gabbro is approached. No D_3 folds have been identified within the Lyngen gabbro or Kjosen Formation.

The Lyngen gabbro is internally deformed but its structure appears to have no resemblance to that found in the adjacent schists. Large overfolds have been recognized in the gabbro from south Lyngen by Randall (1959) but only one minor overfold has been seen in the northern part of the gabbro. However, numerous low angle thrusts occur throughout the gabbro. The layering of the gabbro in north Lyngen varies in strike from southeast to southwest, with the north-south strikes more common to the west; dips are steep to vertical. The northwest strikes are found along prominent valleys, also with northwest trend, such as Reindalen or in the area of the bay of Strupen. A zone of melange, up to 1 km thick, is found at the base of the gabbro in the Strupen, Reindalen and Vaggåsen areas.

Structural synthesis

Several factors have to be taken into account when considering the age of emplacement of the Lyngen gabbro.

The style of deformation within the gabbro bears no relation to that in the adjacent schistose rocks.

The Kjosen Formation and Western Metasediments display similar D_2

structures, and this deformation appears to be responsible for the gross structure of the Western Metasediments and Kjosen Formation.

Compositionally the Lyngen gabbro is indistinguishable from the bulk of the Kjosen Formation.

The Lyngen gabbro has been thrust over the Kjosen Formation.

The faults which bound the Lyngen gabbro show little evidence of subsequent deformation.

Geophysical evidence indicates that the Lyngen gabbro may have crystallized about 100 km west of its present location.

The third deformation D_3, produced only minor wrinkles, which are restricted to the schistose rocks of the Western Metasediments.

These data are consistent with the concept that the Western Metasediments and Lyngen gabbro originated in spatially distinct environments. During the earliest recognizable deformation, D_1, the Western Metasediments were isoclinally folded whilst the basal part of the Lyngen gabbro was both sheared and folded, to yield the Kjosen Formation. Sometime during this deformation, diabase dykes were intruded into the basal part of the Lyngen gabbro and are now visible as amphibolite sheets within the Kjosen Formation. The large folds in the upper part of the Lyngen gabbro may also have developed during D_1.

The Lyngen gabbro and basal sheared unit, now recognized as the Kjosen Formation, appear to have been emplaced in their present position during the second deformation. If emplacement was pre-D_2 it is difficult to reconcile the similarity of D_2 fold styles either side of the gabbro with the absence of D_2 folds within the gabbro. Also the faults bounding the gabbro are undeformed. It is proposed that the D_2 folds in the Kjosen Formation occurred during emplacement of the gabbro and that the same deformational episode was responsible for the thrusting of the Western Metasediments over the gabbro and the internal deformation of the metasediments. The local overthrusting of the gabbro over the Kjosen Formation might be a D_2 feature or it could be related to the compressional episode which produced the minor D_3 folds in the Western Metasediments.

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