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Sammendrag

The Vaddasgaisak Metagabbro is an internally deformed and recrystallized gabbroic intrusion. Layered and non-layered zones, zones of different grainsize, and zones with and without olivine have been mapped. The western margin shows intrusive relationships with Ankerlia Metagreywacke. The eastern contact against Loftani Greenstone, is very schistose, but is problably not a regional-scale thrust. Basic dykes have intruded the Metagabbro and Metagreywacke, and small felsic intrusives both of anatetic and possible differentiates from the gabbro, are present. The gabbro, dykes and greenstones are oceanic tholeiites. The greenstones were extruded on shallow shelf sediments. The gabbro and dykes intruded greywacke possibly composed of island arc detrius.

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STATENS BERGRETTIGHETER

NGU rapport nr. 1900/47H

The Vaddasgaisak Metagabbro,
Nordreisa, Nord-Troms

October 1982

Norges geologiske undersøkelse

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Rapport nr. 1900/47H	Åpen/~~Fortrolig~~
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Nøkkelord		
	Metagabbro	Tholeiite
	Greenstone	Felsite
	Dykes	Deformation

Ved referanse til rapporten oppgis forfatter, tittel og rapportnr.

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INTRODUCTION

This report presents the results of a 6-month investigation into the nature of the Vaddasgaisak metagabbro and associated basic rocks. The main aim of the investigation was to determine whether the metagabbro is part of an ophiolite complex. The work was carried out in three stages:

1. May-June 1982: Literature research; study of thin sections from previous studies of the Vaddas area, collected by T. Vogt and I. Lindahl; visits to ophiolite occurrences at Løkken and Leka.

2. Late June-August 1982: Field work involving detailed mapping of the Vaddasgaisak area, and collection of samples for thin section and for chemical analysis.

3. Drafting and interpretation of maps, study of thin sections, interpretation of whole-rock geochemical data, report writing.

The short duration of the project did not permit complete investigation of all aspects of the rocks. Further work which would be of value includes:

1. Additional detailed mapping of adjoining areas with emphasis on: (a) delineating the boundaries of the gabbro (or metagabbro) bodies,

(b) delineating the extent of amphibolite zones and interpreting their origin and relationship to the gabbros,

(c) delineating the extent of the zone of dykes/sills in the Oksfjord schists,

(d) study of the boundary between the Loftani Greenstones and the overlying Oxfjord Schists, to determine whether this is conformable or a major thrust.

2. Detailed petrological study of the Vaddasgaisak metagabbro, to determine whether there is a cyclic mineralogical variation. This study should include microprobe studies of the minerals.

3. Radiometric dating of the metagabbro. Unfortunetaly all of the phases of the metagabbro contain very little of any K-bearing phase. The most suitable rock for dating may be the K-feldspar-biotite rich variety of granitic-pegmatitic rock, which occurs in the margin of the metagabbro and in adjacent metasediments. This variety probably formed by partial melting of the metasediments, during emplacement of the gabbro.

"Map reference" (M.R.) or "Location" given in this report is the same as UTM-coordinates on the AMS map sheets. Locations and samples marked BS are from the work in 1982, while samples and locations VR are from the work by Lindahl (1974).

ACKNOWLEDGEMENTS

This project was undertaken while I was working for NGU, on a 6-month exchange, from the Geological Survey of New South Wales, in Sydney, Australia. The project was part of the larger USB project, led by Ingvar Lindahl of Malmgeologi Section.

I wish to thank Ingvar Lindahl for a great deal of assistance in organizational matters and for valuable discussions on the Vaddas geology. Thanks are also due to K. B. Zwaan for introducing me to many aspects of the regional geology, for valuable discussions about the regional implications of interpretations of Vaddas area, and for assistance in many practical matters. Ron Boyd provided valuable advice on the geology of gabbroic intrusions and showed me the suspected ophiolite at Lyngen.

Rolf Nordheim, from Tromsø, provided very able assistance during the period of field work, with his considerable experience of conditions in the mountains of north Norway.

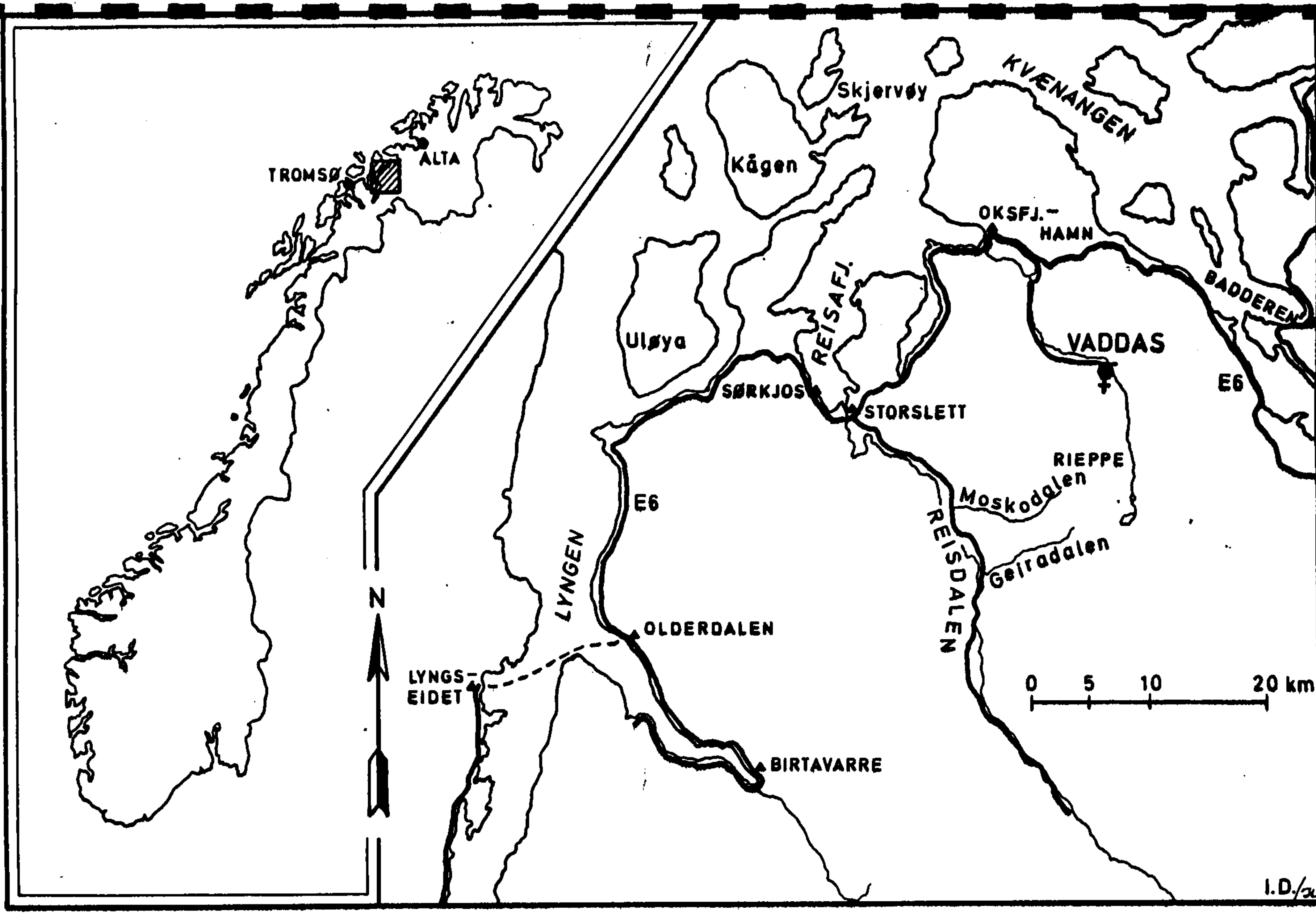
I wish also to acknowledge the general hospitality and assistance offered by many people at NGU, in particular Knut Heier (Admin. Director), Peter Padget (Director, Geology), Arne Bjørlykke, and Gunnar Juve, Herbert Mendelsohn, Lars Holiløkk, Morten Reitan and Gjert Faye & staff. The hospitality and goodwill of the people of Oksfjordhamn was greatly appreciated.

GEOGRAPHY

The Vaddasgaisak is a large, flat topped mountain located near the village of Oksfjordhamn, mid-way between Tromsø and Alta in north Norway. Access is by unsealed road up the valley of Oksfjordalen, adjacent to the river known as Storelva. The road leads to old buildings (associated with the Vaddas mine), at the junction of Storelva and Littlelva, at the foot of Vaddasgaisak. Further slow access from here is possible by four-wheel drive vehicles, mainly southwards up the valley of Storelva, towards Rieppe. Mostly, however, access is only by foot or by helicopter. The main access road at the base of Vaddasgaisak reaches an altitude of little over 100 m above sea level. The plateau level on top of Vaddasgaisak is at about 1100 m, with small peaks rising to 1293 m. The plateau level can be reached by several routes, both on the eastern and western sides. The north face is near-vertical at the top and access to the plateau from this side would be very difficult.

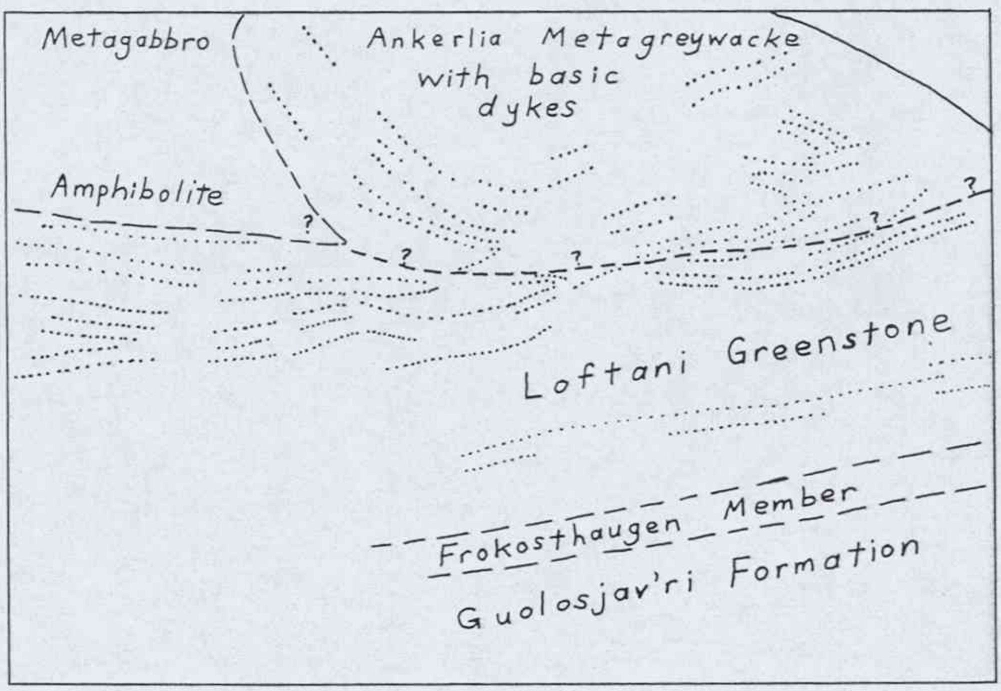
Field work in the area is hampered by the climate and can also be hazardous. There is extensive snow cover over the area for many months of the year. The plateau level in particular, may be well-exposed for only a very brief period of the summer. In the summer of 1982, a heavy snow-fall at plateau level occurred in July, before all of the winter snow had melted. It was not until mid-August that the rocks at plateau level became well-exposed. Fog and rain were frequent in the summer of 1982, and hampered field work.

A special hazard in the area, is falling rocks and snow avalanches. These were common in 1982, on the steep sides of Vaddasgaisak, adjacent Kirkefjell (or Girkovarre) and Ruksis-gaissa. The largest summer fall was from the northeast corner of Vaddasgaisak, some of the boulders coming right down into the birch forest on the eastern side of the mountain (see photo 2), and one boulder continuing into Storelva. Another hazard in the area, is the steep slopes on which much of the geology is exposed. Most exposures of the amphibolite zone and gneissic zone at the



TROMSØ
ALTA
N
Skjervøy
KVÆNANGEN
Kågen
Uløya
OKSFJ.-HAMN
REISAFJ.
BADDEREN
VADDAS
E6
SØRKJOS
STORSLETT
RIEPPE
Moskodalen
E6
REISDALEN
Geiradalen
LYNGEN
OLDERDALEN
LYNGS-EIDET
BIRTAVARRE
0
5
10
20 km
I.D./

Photo 1: Western part of the north face of Vaddasgaisak. Lower half is southerly dipping Váddas Group sediments and Loftani Greenstone. Upper half is mostly folded Ankerlia Metagreywacke and basic dykes/sills



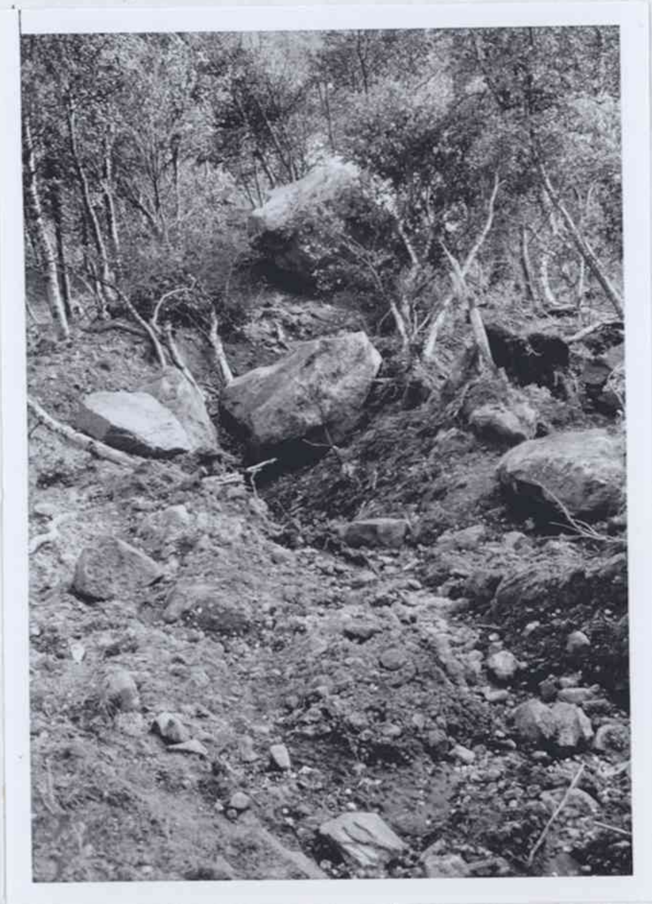


Photo 2: Geological hazard at Vaddas. The boulders pictured rolled approximately 800 m down from Vaddasgaisak into Storelvdalen during the field work time

margins of the metagabbro, occur on the steep eastern, northern or western slopes of Vaddasgaisak.

MAPPING

The first stage in the mapping programme at Vaddas, was to study several profiles across the strike of the rocks, at various places around the Vaddasgaisak. Detailed notes were made of all of the rock units observed, and the nature of previous mapping by Lindahl (1974) was assessed. It was found that Lindahl's mapping of the sedimentary series up to the lower greenstone, was quite adequate for the purposes of the present study, and only very limited changes are made to this part of the sequence. Consequently mapping was concentrated on the areas of greenstone, Oksfjord Schist and metagabbro.

During the early profiles, the nature of lithological variation within the rocks of interest, was assessed, and tentative interpretations of the origin of various rocks was made. At the end of this early work, a letter symbol code system (see following sub-section) was devised, for use in detailed mapping of greenstones, Oksfjord Schist, metagabbro, and associated rocks. The aim of such a system, is to reduce the time required to write field notes, to place as much information as possible on the face of the maps (i.e.field sheets), and to systematize the observations, while still retaining enough flexibility to allow for uncertainty in identification and interpretation of the rocks.

The remainder of the mapping time consisted mostly of profiles across accessible outcropping rocks, using the code system on plastic overlays over aerial photographs enlarged to a scale of approximately 1:5 000. Spacing between profiles was determined by the regularity/irregularity of the rocks along strike, by the availability of outcrop, and by access. Spacing between profiles ranges from about 250 m to over 1 km. The larger spacings permit too much uncertainty between profiles. A maximum spacing of 500 m would have been more desirable.

Some difficulties were experienced in use of the aerial photographs. On some of the photographs the very steep mountainsides virtually disappear, while north faces in shadow tend to appear almost completely black. Where photo overlap was available in steep areas, the photo with greatest "stretch" of the steep faces was used, providing the light conditions were satisfactory. Lack of contrast in the photos caused some difficulties in precise location. Poor contrast, combined with angular distortion, led to specific problems of location in the profile along the base of the cliffs on the north side of Njoamelvagge. Location of data along this profile is considered unreliable.

Letter Symbol Code System

The following letter symbol code system was used in mapping the greenstones, Oksfjord Schists, metagabbro and related rocks. The letter symbols were used on the field sheets (approx. 1:5.000 scale).

The code consists of three parts:

1. A lower case letter f, m, c, v, or combination of these, denoting grainsize (in hand specimen).

   f = fine = < 0,5 mm
   m = medium = 0,5-2 mm
   c = coarse = 2-5 mm
   v = very coarse = > 5 mm

   Note: these grainsize terms are applied to all of the rocks whether igneous, meta-igneous or metasedimentary

   The grainsize ranges are the same as those used in the Geological Survey of New South Wales mapping project in metamorphic rocks at Broken Hill, Australia.

2. An upper case letter, denoting the rock type.

   P (from "pyroxene") = gabbro or metagabbro
   A = amphibolite
   F = felsic rock (mostly granitic to pegmatitic mobile material)
   D = basic dykes/sills
   I = basic rock with igneous texture (mainly dykes)
   G = greenstone (metamorphically altered basic volcanic)
   M = metasediment, generally only used for Oksfjord Schists (fine grained, finely bedded grey and whitish psammite). Other metasediment types of schist, carbonate, are generally written in full.

3. A lower case letter, or letters, following 2. These are used to record the dominant tectural/structural features, including layering, schistosity, gneissosity, and some mineralogical features, as follows:

p = polygonal/granoblastic texture

n = non-layered on outcrop scale

w = weakly layered, and includes well-developed but diffuse layering

l = well-layered on outcrop scale

g = gneissic

s = schistose, only recorded where the schistosity is a prominent feature of the rock

b = used with F, where the felsic rock encloses blocks of other lithologies

o = olivine probably present (recognized by yellow colouring on the weathered surface of the rock)

h = pyroxene streaks (thought to be hypersthene - common in parts of the metagabbro

Also a few abbreviated words were used in the same way as the above letters:

phen = phenocrysts present

lath = interlocking laths, usually of plagioclase, and denoting an igneous origin

felt = felted texture of interlocking needle - like grains, a typical low to medium grade metamorphic texture in basic rocks

Examples:

1. mPpn - medium grained (0,5-2 mm) gabbro or metagabbro with equigranular/polygonal grainshape and no layering at outcrop scale

2. cPloh - coarse grained (2-5 mm) gabbro or metagabbro, well-layered, and containing olivine, plus pyroxene streeks

3. fGsphen - fine grained (< 0,5 mm) greenstone with prominent schistosity, and some relict phenocrysts

4. fMl - fine grained (< 0,5 mm) psammitic metasediment, well-layered

5. mAws - mGws - medium grained (0,5-2 mm) rock with weakly developed layering and prominant schistosity - may be an amphibolite or a greenstone.

PREVIOUS WORK

The major previous reference for the Vaddas-Rieppe area is an unpublished thesis by Lindahl (1974). This work included detailed mapping, particularly of the metasediments, greenstones and sulphide mineralization, and also investigation of the nature of the mineralization, plus the results of a drilling programme to establish tonnages and grades.

Earlier work was mostly unpublished reports concerned with the mining at Vaddas and Rieppe, although Vogt (1927) published a geological map and description of the area. The earlier references include Barkey (1964), Bjørlykke (1956), Bjørlykke and Færden (1956), Færden (1954, 1955), Lindahl (1969), Louis (1907), Sjøgren (1907, 1913), Smith (1910), Vogt (1920), and Vogt (1952). Further theses in nearby areas include Armitage (1972), Kleine-Hering (1973), Minsaas (1981), Padget (1955), Pearson (1970), Randall (1959), Strand (1971), Vokes (1957).

Most up-to-date regional mapping is by Zwaan (1975) and regional geology is described by Zwaan & Roberts (1978).

GENERAL GEOLOGY

Tectono-Stratigraphy

The Vaddasgaisak Metagabbro is situated within a sequence of Early Palaeozoic metasediments and minor basic volcanics (greenstones) described by Lindahl (1974). The sequence is contained in the Vaddas Nappe which overlies the Čorrovarri Nappe. Both nappes are parts of the Kalak/Reisa Nappe Complex (Zwaan and Roberts 1978). The Vaddas Nappe forms the lowest unit of the Reisa Nappe Complex, the Čorrowarri forms the highest unit in the Kalak Nappe Complex. The Čorrovarri Nappe contains probable Eo-Cambrian meta-arkose of the Napojåkka Group, and is thrust over allochthonous Precambrian basement. This thrust is characterized by a garnet-bearing blastomylonitic augen gneiss. The Napojåkka Group outcrops extensively east of Storelva near Vaddasgaisak (Lindahl 1974).

The Vaddas Nappe contains the Vaddas Group and Oksfjord Group. The Vaddas Group is a sequence of grey and yellow marbles, mica schists, calc-mica schists, quartzites, graphitic phyllite, and conglomerate. Depositional environment is interpreted as shallow marine to deltaic. The sequence appears to be internally conformable, both on a local scale (Lindahl 1974, and my own observations), and on a regional scale (K. B. Zwaan 1978, and pers. comm. 1982). However regional correlations of the lower part of the sequence with rocks containing Cambrian fossils on Sørøy to the north (Holland & Sturt 1970), and the upper part of the sequence with rocks containing Late Ordovician corals near Guolasjav'ri to the southwest, require an unconformity within the sequence (corresponding with the Finnmarkian Orogeny). Two conglomerates occur in the upper part of the sequence (Guolasjav'ri Formation), and have been taken as a convenient position for an unconformity (Ramsay et.al 1981). K. B. Zwaan has concluded that the Vaddas Group is internally conformable and that the major discontinuity is a thrust lying at the base of the group. He has shown that the basal unit, the Gæirajav'ri Marble rests on successively lower units as it is followed to the southwest. The meta-arkoses, Precambrian gneisses and even the blastomylonite thrust zone cut out completely to the southwest. The rocks beneath the Gæirajav'ri Marble display penetrative mylonitization with only weak recrystallization. All of the Vaddas Group is probably of Late Ordovician-Silurian age. The Vaddas Group is well exposed between Storelva and the steep upper part of Vaddasgaisak. It is also well developed further west in Kirkjefjell, Heindalstind and adjacent mountains.

The Oksfjord Group overlies the Vaddas Group, within the Vaddas Nappe. It contains psammitic and minor pelitic metasediments and basic metavolcanics, and is intruded by the Vaddasgaisak Metagabbro. In the Vaddas area the lower part of the Oksfjord Group consists of the upper and lower units of Loftani Greenstone separated by the Ak'kejav'ri Calc-Biotite Schist. The Loftani Greenstone is overlain in part by the Gryta Amphibolite and Vaddasgaisak Metagabbro, and in part by the Ankerlia Metagreywacke. The Metagreywacke is a very thick unit essentially consisting of finely bedded quartz-plagioclase-hornblende-biotite-clinozoisite rocks, which may have contained a large proportion of basic or intermediate volcanic detritus. These rocks are well exposed in Grasdalen and occupy a large area to the west.

Tectonic History

The major Palaeozoic tectonic events in this part of Norway, were the Late Cambrian Finnmarkian Orogeny and the Silurian Scandinavian Orogeny (Zwaan and Roberts 1978). These appear to have had remarkably (perhaps even unbelievably) similar effects. Both produced major nappe structures, both produced medium pressure-temperature metamorphism up to staurolite-kyanite grade, both appear to have had about three generations of folding, and it is possible that syn-orogenic intrusion of layered gabbros accompanied both events (i.e.the Seiland province-Finnmarkian, and the Vaddasgaisak Metagabbro-Scandinavian).

Structural Style

Although there are upright folds in the sequence, the dominant structural style is flat-lying folds and extensive boudinage. Both folding and boudinage occur largely sub-parallel to bedding and to the flat-lying thrusts bounding the nappes.

Intrusives

Amphibolites and gabbros are abundant in the region. Extensive areas of gabbro and related plutonic rocks in the Seiland Province to the north are regarded as syn- and post-Finnmarkian intrusions (see Robins and Gardner 1974 for summary). The long zone of gabbros and ultrabasic rocks in the Lyngen Peninsula to the east, is regarded as part of an ophiolite complex obducted during the Finnmarkian (R. Boyd, pers.comm. 1982, Minsaas 1981). These ophiolite rocks are unconformably overlain by Late Ordovician - Early Silurian sediments.

In addition to the above-mentioned gabbros, there are small granitic intrusions, including the Rappesvarre Granite which intrudes the Skardalen Quartzite just north of Vaddas.

THE VADDASGAISAK METAGABBRO – GENERAL DESCRIPTION

In the present investigation the Vaddasgaisak metagabbro was mapped as far south as the major eastsoutheast trending fault passing through Rieppesjav'ri. The metagabbro and related rocks continue south of this fault (Zwaan 1975). Another large metagabbro body occurs in the mountains north of Oksfjordvatnet, about 11 km north of Vaddas.

The Vaddasgaisak metagabbro occupies almost the entire Vaddasgaisak plateau and the top of adjacent Ruksisgaissa. The margins of the mountain contain the marginal zones of the metagabbro, underlain by Cu-Fe sulphide mineralization and greenstones, which overlie the metasedimentary sequence. The metagabbro outcrops over a strike length of about 6 km from the Rieppe fault to the top of the north face of Vaddasgaisak, and over a width of about 5 km at the south end, narrowing to about 2 km at the north end.

As a result of detailed mapping, the metagabbro body has been sub-divided into several zones (see map 1). These can be broadly grouped from east to west, as follows:

1. Amphibolite zone. Forms the eastern margin of the metagabbro and appears to wrap around the northern end of the metagabbro. It consists of equigranular amphibolite with polygonal grain shapes, plus abundant porphyritic amphibolite + gneissic amphibolite. Towards the south there appears to be some gradation to non-layered medium grained metagabbro, and a unit of layered metagabbro occurs within the amphibolite zone.

2. Zone of coarse to very coarse olivine metagabbro. Apart from the amphibolite zone, most of the eastern half of the metagabbro consists of coarse and very coarse olivine metagabbro. At outcrop scale the rock is essentially non-layered or weakly layered, although some large-scale layering is present. Within the zone there are thin units of layered medium grained gabbro, and this becomes more abundant southwards. Outcrop-scale layering is well-developed in the eastern part of the zone of coarse to

very coarse metagabbro, but this is at least in part due to intrusion of numerous finer grained dykes into the metagabbro, more or less parallel to strike.

3. Zone of medium to coarse olivine metagabbro. Medium and coarse grained, layered and non-layered olivine metagabbros occupy the central-western part of the metagabbro body. They have sharp boundaries against the very coarse metagabbro to the east, buth rather diffuse boundaries against the olivine-poor metagabbros to the west.

4. Zone of medium grained olivine-poor metagabbro. This is the westernmost major zone of the metagabbro body. It is mostly non-layered, but minor layered units have been mapped out.

5. Gneissic zone. Along the western margin of the metagabbro body there is a thin zone (about 200-250 m) in which the rocks have developed a gneissosity and in places exhibit broader lithological layering and intense folding. It is difficult to identify the original rock in places. The zone appears to contain deformed and contact metamorphosed metasediments (Oksfjord Schists), but may also contain deformed metagabbro.

The Vaddasgaisak metagabbro consists mostly of plagioclase, clinopyroxene and orthopyroxene, but olivine, hornblende, opaque oxides and green spinel are common minor constituents. Hornblende is a major mineral in places, particularly in the amphibolite zone.

The term "metagabbro" is used because virtually all of the rock exhibits typical metamorphic textures. Gneissosity, schistosity, polygonal recrystallization and mechanical deformation of grains are common features, developed to various degrees.

MINERALOGICAL VARIATION IN THE METAGABBRO

Variation in mineralogy and in composition of minerals from bottom to top, is a common feature of layered gabbroic intrusions (eg. Wager & Brown 1968). In the Vaddasgaisak Metagabbro there is some variation, but not all is systematic.

The most important variation is in olivine content. The layered and non-layered medium grained metagabbro units on the western side of the Metagabbro, contain no olivine. The mapped units in the central and eastern parts of the Metagabbro (except for the amphibolite zone) contain minor olivine. Some samples contain no olivine, but from 5 to 15% olivine is common. One sample from a small lens of very rusty weathered rock in the eastern part of the coarse to very coarse metagabbro, contains approximately 50% olivine. The olivine variation suggests that the Metagabbro is asymmetrical and the eastern part is the original base.

There appears to be no systematic variation in the percentage or composition of plagioclase. Plagioclase compositions were determined by flag-stage microscopic techniques which are not the most accurate. However there appears to be a non-systematic variation in plagioclase compositions. Plagioclase compositions are generally between An_{50} and An_{80}. A few samples have apparently more sodic plagioclase, but this may be only a result of unsuitable grain variations in the thin sections. The most calsic compositions (An_{70-80}) were found in the amphibolite zone, in the coarse to very coarse olivine metagabbro, in the coarse to medium metagabbro, in the layered olivine metagabbro and in the non-layered medium grained metagabbro. Similarly the most sodic plagioclase (less than An_{60}) is found in several mapped units. Average compositons for all mapped units is from about An_{60} to about An_{70}. The eastern units (except the amphibolite zone) may be more calcic on average than the western units.

Clinopyroxene is present in all samples of metagabbro. Orthopyroxene was not identified in some samples, but there was no consistent pattern.

In a few places, narrow zones of metagabbro contain high concentration of opaque minerals. These are non-magnetic to weakly magnetic and resemble ilmenite. Sample BS-114 from the non-layered medium grained metagabbro unit contains about 15% opaque minerals and 5% apatite. Both are relatively coarse grained and appear to have been present before the general recrystallization.

THE AMPHIBOLITE ZONE

The amphibolite zone forms the eastern margin of the Metagabbro, and appears to wrap around the northern margin (there are some physical difficulties in examining the northern margin of the Metagabbro). An apparent sharp upper contact can be mapped against the coarse to very coarse metagabbro. This is discussed belox. The lower contact against the Loftani Greenstone is a highly schistose zone with diffuse layering (see discussion in section on "sulphide mineralization).

Most of the amphibolite zone consists of intermixed medium grained, equigranular amphibolite with polygonal grain shapes, apparently porphyritic amphibolite, and gneissic amphibolite, with many apparent gradations. The porphyritic amphibolites are probably amphibolite - altered basic dykes, similar in origin to the dykes in the adjacent coarse to very coarse metagabbro. The gneissic amphibolite probably developed mostly from deformation of prophyritic amphibolite, but some may represent minor partial melting or metamorphic segregation development in the equigranular amphibolite.

Near Oaivoščokka there is an apparently lenticular zone of very well layered amphibolite. The layering and folding of the layering are similar in character to that observed in the layered medium grained metagabbro. The layered amphibolite consists almost completely of plagioclase and hornblende (and clinopyroxene in one sample), with no biotite and apparently no quartz. It is interpreted as an amphibolite - altered layered metagabbro, and not as a metasediment.

Although most of the amphibolite zone is medium grained in contrast with the adjacent coarse to very coarse metagabbro, there is a transition in places, with rocks which are texturally a coarse metagabbro, but consist of hornblende and plagioclase.

The amphibolites are chemically very similar to the metagabbros and greenstones. The equigranular amphibolite is texturally similar to the medium grained non-layered metagabbro, the layered amphibolite is very similar to the layered metagabbro, and some rock with coarse to very coarse metagabbro texture is now amphibolite.

Therefore the amphibolite zone is interpreted as a zone containing various types of altered metagabbro, and probably a large number of amphibolite - altered and deformed basic dykes.

Table 1 : Estimated modal mineral content of rocks from the amphibolite zone on the eastern margin of the Metagabbro

Sample	Plag	(An)	Cpx	Amp	Cz	Opaq	Sph	Ap	Zirc	
BS 10	40	(55)	-	50	10	1	1	-	x	
BS 36A	45	(60)	-	55	-	3	x	x	-	
BS 36B	42	(55)	-	55	-	3	-	-	-	
BS 78	50	(64)	-	47	-	3	-	-	-	D
BS 117	45	(72+)	23	30	-	2	-	x	-	
VR 258	40	(70)	-	55	5	x	-	x	-	
VR 260	55	(45)	15	25	-	x	-	x	-	

D indicates possible dyke

Table 2 : Estimated modal mineral content of rocks from the layered part of the amphibolite zone, near Oaivoščokka

BS 58	60	(65)	15	20	5	x	x	x	x	
BS 59	50	(80)	-	50	x	1	x	-	-	
BS 75	57	(28?)	-	40	-	3	-	x	-	
BS 75A	40	(38)	x	55	-	1	4	x	-	

Photo 3: Porphyritic amphibolite grading into medium grained granular amphibolite. The porphyritic amphibolite may have been a dyke rock. The granular amphibolite was probably medium grained gabbro. Location BS 65 (Map Reference 2280-4130)

Photo 4: Typical polygonal texture from medium grained granular plagioclase - hornblende - clinopyroxene amphi bolite. Crossed polars. Location VR 260 (M.R. 2248-3850).

Photo 5: Layered amphibolite disrupted by felsic mobile material. Probably originally a layered gabbro. (East slope of Oaivoščokka)

Photo 6: Intense folding in layered amphibolite. Felsic material mobilized into axial plane direction. Location BS 77 (M.R. 2290-3994)

THE COARSE TO VERY COARSE OLIVINE METAGABBRO

Except for the amphibolite zone, most of the eastern part of the Vaddasgaisak Metagabbro consists of coarse to very coarse olivine metagabbro and coarse to medium olivine metagabbro. Both types are mostly non-layered to diffusely layered. The coarse to very coarse metagabbro grades into the coarse to medium metagabbro. There is a main mass of coarse to very coarse metagabbro with a core of coarse to medium metagabbro, and a narrow internal zone of layered metagabbro. The layered zone is poorly exposed. In fact there is much rubble covering outcrop on the Vaddasgaisak plateau, so boundaries within the metagabbro can only be inferred in many places.

Two elongate bodies of coarse to very coarse metagabbro occur west of the main mass and are separated from it by medium grained well-layered metagabbro. These bodies have the shapes of doubly-plunging folds, but could also be large boudins.

In outcrop the very coarse metagabbro mostly shows a gneissic texture, with large rotated crystals or augen of pyroxene in a matrix of lenticularly layered plagioclase and mafic minerals. The plagioclase typically shows a sugary texture of fine subgrains within the plagioclase lenses. Where the gneissosity is not so well developed, there are coarse pseudo-grains of plagioclase between the mafic grains. In these areas also, recrystallization of plagioclase to finer grained aggregates is obvious in hand specimen. Some of the pyroxene appears to have retained its coarse grainsize. Other coarse mafic pseudo-grains are aggregates of finer grained pyroxene or pyroxene-olivine. There is also a considerable amount of fine grained plagioclase – minor pyroxene/olivine aggregates.

In hand specimen and thin section the very coarse metagabbro has the texture of a very coarse rock which has been strongly deformed and to various degrees finely recrystallized.

In places there appear to be originally pegmatitic patches within coarse to very coarse metagabbro. These too have suffered deformation and recrystallization, and plagioclase in particular is finely recrystallized.

Table 3 : Estimated modal mineral content of samples from the coarse to very coarse olivine metagabbro

Sample	Plag (An)	Cpx	Opx	Oliv	Amp	Cz	Opaq	Sph	Chl*	
BS 11	55 (70)	32	-	10	3	-	x	-	-	
BS 39	60 (72+)	25	?	10	3	-	2	-	-	
BS 40	55 (70+)	35	-	7	3	-	x	-	-	
BS 60	40 (76)	-	-	-	50	10	1	x	-	
BS 68	45 (75)	33	-	-	20	x	2	-	-	D
BS 85A	50 (65)	30	-	10	5	-	5	-	x	D
BS 85B	50 (68)	30	-	7	10	-	3	-	x	D
BS 116	40 (68+)	50	?	5	5	-	x	-	x	
BS 120	60 (55+)	23	-	-	10	-	5	-	2	
BS 121	25 (55+)	15	-	50	9	-	1	-	-	
VR 107	70 (70)	30	x	-	x	-	x	-	-	
VR 108	70 (65)	30	x	x	x	-	x	-	-	
VR 109	65 (55)	30	-	-	-	-	5	-	-	
VR 110	60 (70-75)	20	5	10	5	-	-	-	-	Spinel
VR 256	45 (70+)	30	8	5	8	-	x	-	-	
VR 259	60 (55)	35	10	x	-	-	x	-	-	
VR 261	40 (70)	5	?	-	50	2	x	x	-	Carb 3, Ap
VR 262	60 (50)	25	10	-	-	-	5	-	-	Ap
VR 264	55 (55)	20	10	5	2	-	5	-	-	Ap

D indicates possible dyke

* includes yellowish + greenish alteration products of olivine

Photo 7: Typical gneissic texture in very coarse grained olivine metagabbro. Pyroxene augen in a plagioclase rich matrix. Location BS 140 (M.R. 2210-4205)

Photo 8: Originally pegmatitic area in coarse to very coarse olivine metagabbro. Location BS 68 (M.R. 2220-4120)

Weakly developed lithological layering in the coarse to very coarse metagabbro is mostly parallel to the gneissosity. However in a few places layering and gneissosity intersect at a small angle. In some of these occurrences, the lithological layering may be due to dykes in the metagabbro.

Folding of the gneissic layering is fairly common. Many of the folds are tight to isoclinal with axial planes parallel to the general trend of gneissosity and layering. Axial plane structures in the folds are generally absent or at least not obvious (see photo 9).

Some small-scale faulting was observed in the coarse to very coarse metagabbro, and some plastic deformation is associated with the faulting (photo 10) suggesting the faulting took place at relatively high temperature.

Minor very plagioclase rich layers (anorthosite) occur in the coarse to very coarse metagabbro. They are up to a few metres thick and may continue for tens of metres, or perhaps greater distances. In this project no attempt was made to follow anorthosite bands for very far.

Zone of Dykes

In the most easterly unit of coarse to very coarse metagabbro there is a considerable amount of lithological layering. Some of the layers are confidently identified as dykes, with chilled margins on both sides, and a coarser grained, porphyritic centre (photos 15 to 18). In thin section the dykes show a considerable amount of relict igneous texture, including plagioclase phenocrysts and interlocking plagioclase lath textures in the matrix. Extensive metamorphic recrystallization of the matrix is also common.

In some outcrops the dykes show splits around screens of metagabbro (photo 15) and have irregular off-shoots.

In many outcrops however, the nature of the probable dykes is not clear. Some do not show chilled margins, and are deformed internally to a gneissic texture. There is extensive boudinage of probable dykes and coarse to very coarse metagabbro, also obscuring the original relationships (photo 17).

The mineralogy of the dykes is the same as that of the enclosing metagabbro. The chemistry is similar, but not the same, as shown by samples BS-85A (dyke) and BS-85D (coarse metagabbro adjacent to the dyke) - see appendix 3 and photo 18. The dykes have a higher Al_2O_3 content, higher TiO_2 and a higher FeO/MgO ratio.

THE COARSE TO MEDIUM GRAINED NON-LAYERED OLIVINE METAGABBRO

Mapped units of coarse to medium grained non-layered olivine metagabbro occur in the eastern and central parts of the Vaddasgaisak Metagabbro. They are the least distinctive sub-units of the Metagabbro, grading into coarser grained and finer grained non-layered varieties, and apparently into layered varieties. A diffuse, poorly defined layering is common in the coarse to medium grained "non-layered" metagabbro, and in places pyroxene lenses and streaks are present. These lenses and streaks are also common in other metagabbro units and may represent boudinaged thin pyroxene cumulate layers, although some are too sparsely distributed to have been layers. See table 4 and 5 p. 38.

Photo 9: Folded gneissosity in coarse to very coarse olivine metagabbro. No obvious axial plane schistosity. Location BS 122 (M.R. 2230-4210)

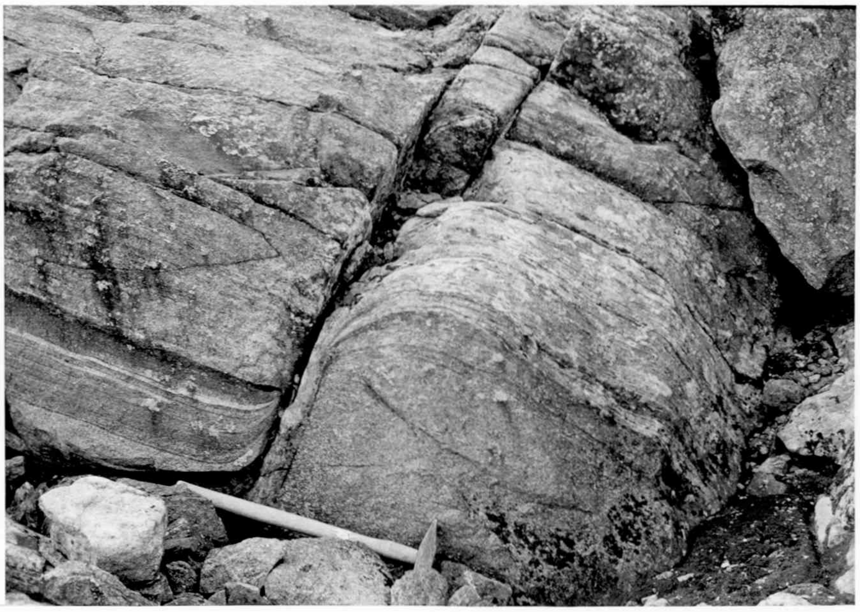


Photo 10: Faulted felsic layer in coarse olivine metagabbro. Metagabbro next to the fault shows plastic deformation. Location BS 119 (M.R. 2160-4355)

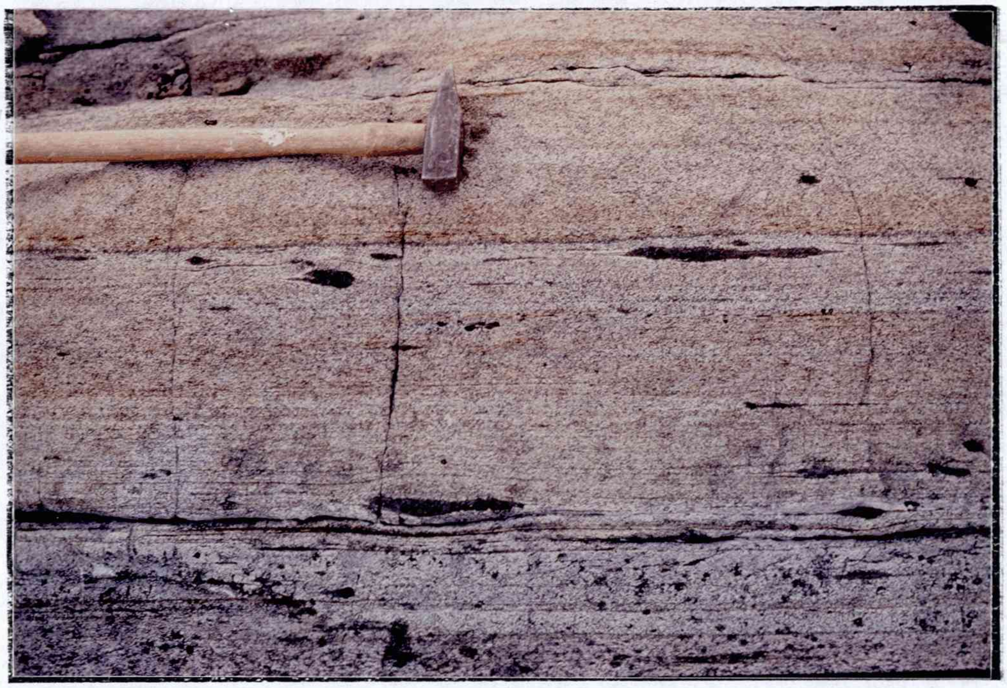


Photo 11: Typical occurrence of pyroxene lenses in coarse olivine metagabbro. Location BS 139 (M.R. 2115-4295)

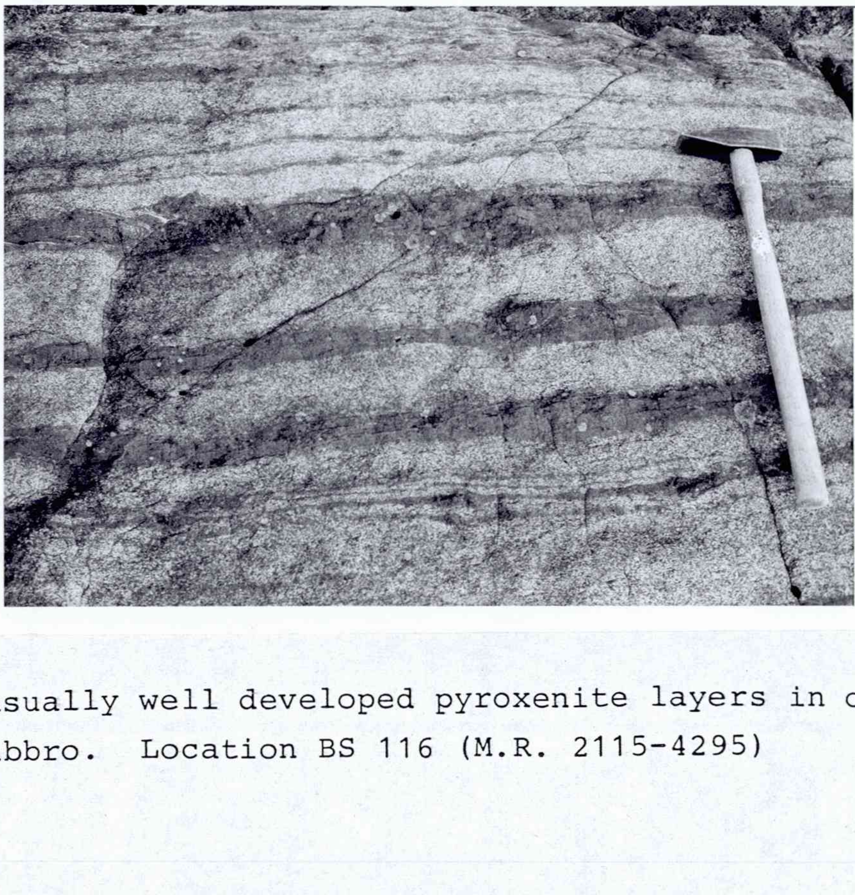


Photo 12: Unusually well developed pyroxenite layers in coarse olivine metagabbro. Location BS 116 (M.R. 2115-4295)

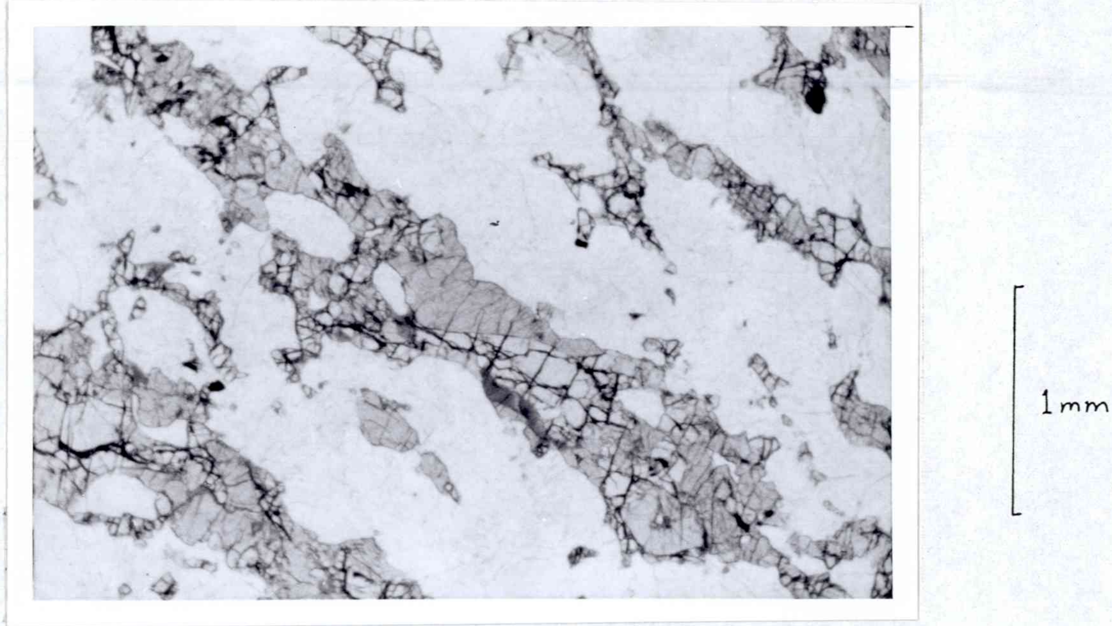


Photo 13: Gneissic layering defined by mafic aggregates (mostly clinopyroxene/olivine) alternating with plagioclase. Plane polarized. Location VR 110 (M.R. 2135-4371)

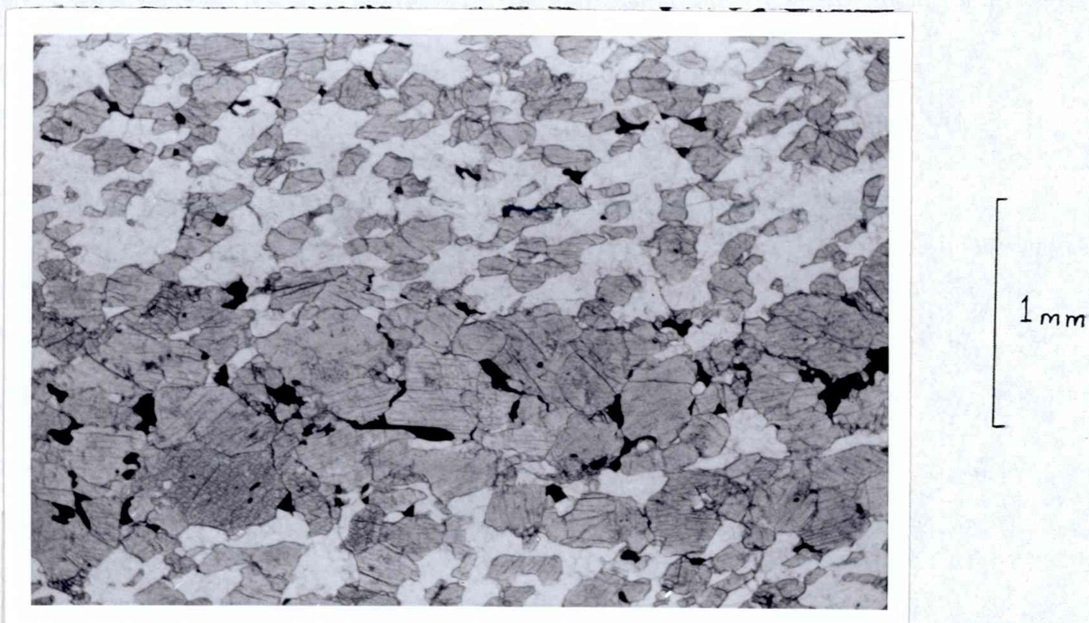


Photo 14: Probable cumulate layering in coarse olivine meta-gabbro (clinopyroxene - plagioclase - orthopyroxene - opaque). Interstitial opaque minerals may represent intercumulate growth. Note the oblique schistosity in the plagioclase rich layer. Location VR 256 (M.R. 2162-4391)

Photo 15: Irregular basic dykes (dark) in coarse to very coarse olivine metagabbro (paler). Some chilled margins can be seen, and inclusions of metagabbro. Location BS 123 (M.R. 2245-4200)

Photo 16: Basic dyke in coarse metagabbro. Dyke has chilled margins and porphyritic centre. Near Gryta (M.R. 222432)

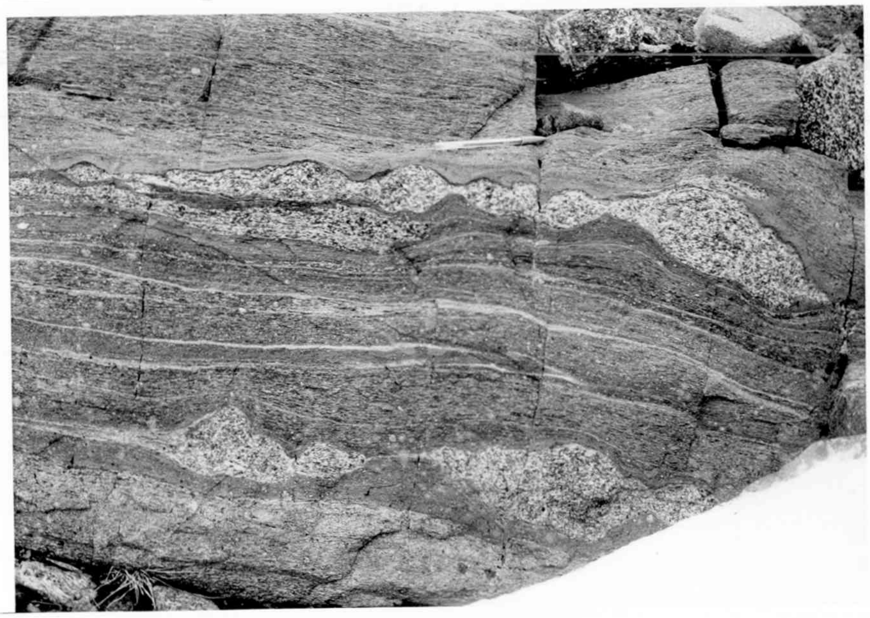


Photo 17: Irregularly layered and boudinaged coarse to very coarse metagabbro and medium to fine grained rocks which are probably deformed dykes. Location BS 84 (M.R. 2210-3895)

Photo 18: Medium grained olivine bearing dyke rock intruding coarse to very coarse olivine metagabbro, and apparently cutting the gneissosity. Both dyke and host rock were analysed (BS 85A & BS 85D) Location BS 85 (M.R. 2210-3900)

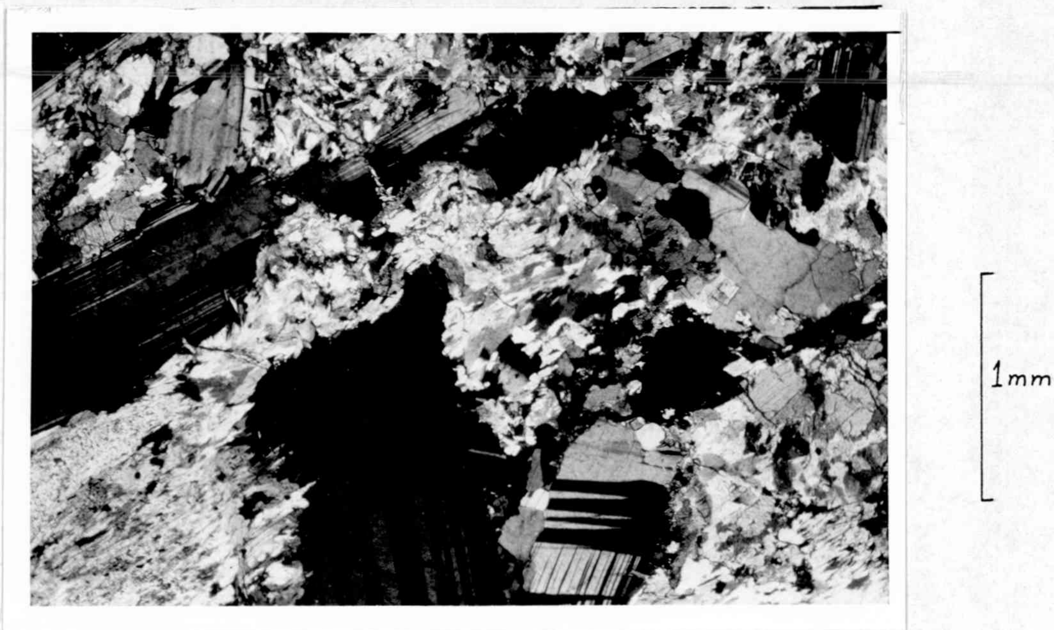


Photo 19: Coarse igneous texture in rock from the zone of dykes in the coarse to very coarse metagabbro. The rock is probably from a dyke. Shows substantial metamorphic alteration. Crossed polars. Location VR 261 (M.R. 2205-3910)

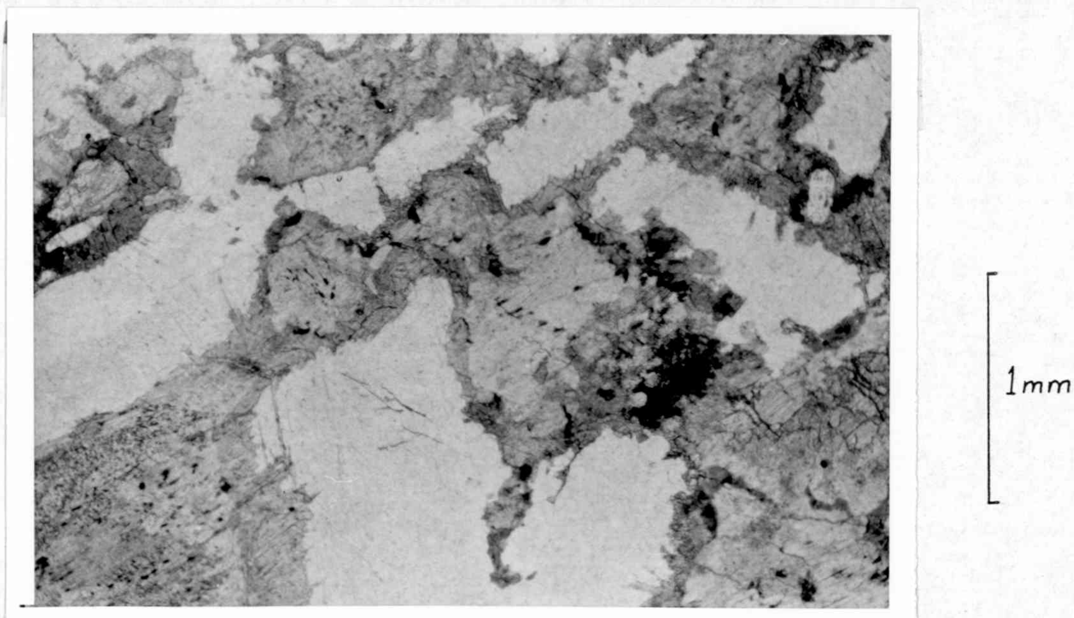


Photo 20: Same rock as photo 19, plane polarized light. Shows original igneous plagioclase - clinopyroxene texture, with dark hornblende alteration around grain margins.

Table 4 : Estimated modal mineral content of samples from the coarse to medium grained non-layered metagabbro

Sample	Plag	(An)	Cpx	Opx	Oliv	Amp	Opaq
BS 70	60	(75)	20	-	15	3	1
VR 257	65	(75+)	20	5	5	5	x
VR 263	65	(65)	20	5	8	x	x
VR 432	60	(70)	30	?	10	-	-

Table 5 : Estimated modal mineral content of samples from the mapped units of layered, medium grained olivine metagabbro

Sample	Plag	(An)	Cpx	Opx	Oliv	Amp	Opaq	Biot	Ap	
BS 44	55	(70)	27	-	15	-	3	-	-	
BS 49A	55	(45)	35	-	-	8	2	-	-	
BS 49B	50	(50)	30	10?	-	10	1	-	-	
BS 82	45	(54)	35	-	5?	5	10	-	-	
BS 87	60	(82)	25	-	12	3	x	-	-	
BS 90	55	(62)	30?	10?	-	2	4	-	-	
BS 109	60	(36)	15	10	10	1	3	1	x	
VR 259	60	(55)	35	10	x	-	x	-	-	
VR 265	x		30	-	-	x	-	-	x	Qtz 60?
VR 266	55	(66)	35	10	x	5	5	-	x	
VR 431	60	(65)	20	?	10	x	-	-	x	Spinel
VR 438	45	(12)	-	-	-	-	5	x	-	Qtz 40, Cz
VR 439	45	(75)	30	?	15	3	5	x	-	
	55		30	?	3	x	5	5	-	
VR 560?	60	(70)	25	?	10	x	x	-	-	

THE LAYERED, MEDIUM GRAINED OLIVINE METAGABBRO

These form some of the most spectular outcrops in the Vaddasgaisak Metagabbro, with strongly contrasting yellow, grey and white layers, which in places outline folds of very fluid appearence.

The mapped units of layered olivine metagabbro, however, also contain substantial amounts of non-layered and poorly layered metagabbro. The units of layered metagabbro shown on the map should be considered only as zones in which there is a large proportion of layered metagabbro. With this in mind, it can be seen that the proportion of well-layered metagabbro (olivine bearing and non-olivine) in the whole Vaddasgaisak Metagabbro body is much less than half.

The main types of layers in the well-layered medium grained olivine metagabbro are:

1. white plagioclase rich layers

2. yellow - weathering layers containing a significant amount of olivine (but probably no more than 15%), with plagioclase and pyroxene

3. grey to brown-grey pyroxene rich layers

4. dark brown, thin pyroxene layers and lenses.

Of these types only the last is commonly monominerallic, consisting of clinopyroxene (orthopyroxene and olivine may also occur as minor minerals). There are all gradations in composition and colour between the white, yellow and grey to brown-grey layers.

The scale of the layering ranges from 1 mm to several centimetres in thickness. Layered sequences are interrupted in places by thick to thin intervals of massive metagabbro (photo 22). Graded layering is poorly developed. but there are many lenticular structures and low-angle truncations which resemble sedimentary structures.

The layering is interpreted as an igneous cumulate layering, modified to some extent by deformation. It is similar to rhythmic cumulate layering described from other layered gabbros (eg. Wager & Brown 1968, Munday 1970, Robins & Gardner 1974), but is more strongly and finely developed than in some other layered gabbros.

There is much folding of the layering, and irregularities in the folding suggestive of fluid behaviour are common (photo 24). Most of the folds show no axial plane structure. At map reference 200398 (Nordreisa 1:50 000) there is a relatively large open fold in a coarse grained, diffusely layered phase of the layered metagabbro. The fold has the overall shape of an asymmetrical antiform, with near-vertical axial plane, an axial plane schistosity (photo 25), and a shallow northerly plunge. The mapped units within the Metagabbro do not show any special relationship to this fold, so it appears to be not of major significance.

Photo 21: Medium to coarse olivine metagabbro with well developed cumulate layering, and scattered small pyroxene lenses. Location BS 137 (M.R. 2078-4290)

Photo 22: Medium grained finely layered metagabbro with one thick layer of olivine metagabbro. Such features are common near the boundary of layered and non-layered zones. Location BS 138 (M.R. 2100-4305)

Photo 23: Medium grained olivine metagabbro with very well-developed cumulate layering showing some lenticularity. Minor pyroxene streaks. Yellow, olivine bearing layers are slightly coarser. Location BS 138 (M.R. 2100-4305)

Photo 24: Layered medium grained metagabbro with intense folding Axial planes parallel to layering, no obvious axial plane schistosity. Location BS 91 (M.R. 2025-3980)

Photo 25: Folded layering in coarse olivine metagabbro, part of a large upright fold with axial plane schistosity. Location BS 92 (M.R. 2002-3980)

Photo 26: Folded, layered olivine metagabbro with extensive mobilization of felsic components. Could be syn-magmatic or tectonic. Location BS 104 (M.R. 2100-4128)

Photo 27: Folded olivine metagabbro showing mobilization of felsic material. Location BS 104 (M.R. 2100-4128)

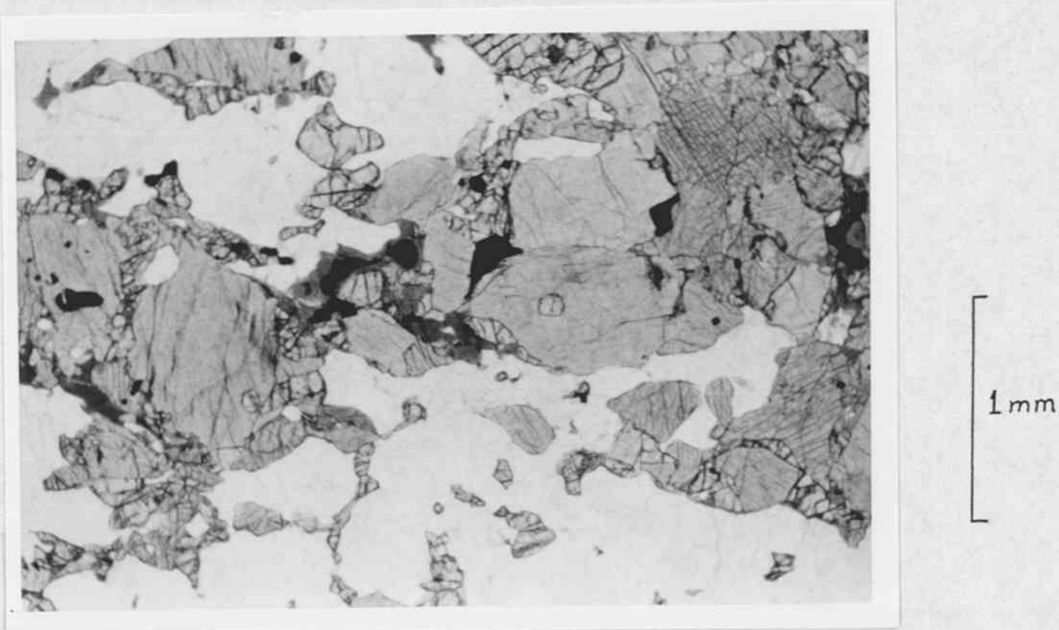


Photo 28: Microtexture of a medium grained, layered olivine metagabbro. Clinopyroxene and plagioclase form large, nearly polygonal grains. Olivine grains are small, interstitial. Hornblende rims opaque grains. No reaction between plagioclase and olivine. Plane polarized. Location VR 439 (M.R. 2020-4010)

Photo 29: Partial recrystallization of coarse metamorphic texture in metagabbro. This may be related to late-stage faulting. Location VR 560 (M.R. 1965-3826) north of major east-west fault.

THE LAYERED, MEDIUM GRAINED METAGABBRO WITH NO OLIVINE

This occurs only in the western part of the Metagabbro, although the layered amphibolite near Oaivoščokka on the eastern side is similar in general character.

The layered metagabbro with no olivine is very similar to the layered olivine metagabbro. Apart from the absence of olivine there is little mineralogical difference. The olivine-poor layered rocks were consistently mapped as medium grained (apparent grainsize of 0,5-2 mm in hand specimen), while the olivine-bearing layered rocks appeared to range from medium to coarse (2-5 mm) grained. In thin section the apparent grainsize ranges overlap, but the olivine poor rocks appear to have a more restricted grainsize range. Grainsizes of the olivine poor rocks range between about 0,2 & 0,6 mm, while those of the olivine bearing rocks ranges from 0,2 to 2,5 mm, but is very variable.

Graded layering is relatively common in the layered olivine-poor metagabbro, in the area near map reference 197427, and gives some indication that west is up. This impression is supported by indications from scattered graded layering observations elsewhere.

Layering in the layered olivine-poor metagabbro is just as well developed as in the olivine-bearing metagabbro. It is defined by alternating whitish and grey or grey-brown layers.

Table 6 : Estimated modal mineral content of samples from the layered, medium grained metagabbro with no olivine

Sample	Plag	(An)	Cpx	Opx	Amp	Opaq	Sph	Biot	Ap	
BS 48	60	(65)	36	–	–	2	–	2	x	
BS 112	20	(42?)	25	?	30	5	–	–	–	Qtz 20?
VR 105	70	(62)	–	15	10	5	x	–	x	
VR 428	60	(60)	38	?	–	2	–	–	–	

Table 7 : Estimated modal mineral content of samples from the non-layered, medium grained metagabbro with no olivine

Sample	Plag	(An)	Cpx	Opx	Amp	Opaq	Ap	
BS 114	30	(40+)	–	–	50	15	5	
BS 132	50	(80)	30	–	15	2	–	Chl 3 D
VR 441	40	(75)	15	5	30	5	x	

D indicates possible dyke

Table 8 : Estimated modal mineral content of samples from the gneissic zone along the western margin of the Metagabbro

Sample	Plag	(An)	Cpx	Opx	Amp	Cz	Opaq	Sph	Biot	Ap	Zirc	Qtz	
BS 27	55	(46)	20	?	25	–	x	–	5?	–	?	–	
BS 28	30	(50)	5	–	25	–	x	?	5	–	–	35	
BS 45A	50	(50)	15	–	25	7	3	–	–	–	–	–	D
BS 111	40	(70)	8?	7?	3	–	x	–	12	x	–	30	
BS 131	35	(35+)	25	–	3	5	–	2	–	–	x	–	

D indicates possible dyke

Photo 30: Layered, medium grained metagabbro with no olivine; showing typical very fluid folding with no axial plane schistosity. Location BS 113 (M.R. 2080-4395)

THE NON-LAYERED MEDIUM GRAINED METAGABBRO

Most of the western part of the Vaddasgaisak Metagabbro consists of medium grained non-layered to poorly layered metagabbro containing no olivine. The grainsize was classified as medium (0,5-2 mm) in the field, and probably averages less than 1 mm. The rock is very fine grained for a gabbroic rock, is essentially massive and featureless. It has a brown surface colour from weathering of pyroxene, grading to grey where honrblende becomes abundant.

In hand specimen the texture ranges from granular to slightly gabbroic (with poorly developed intersecting laths). Pegmatitic to granitic textured felsic material is common in places within the non-layered medium grained metagabbro. It commonly contains blocks of metagabbro.

Photo 31: Poorly layered medium grained metagabbro. Massive appearance and brownish weathered surface are typical of the mapped units of "non-layered" medium grained metagabbro. Location BS 136 (M.R. 2350-3457)

THE GNEISSIC ZONE

On the western margin of the Metagabbro there is a zone about 100-150 m wide, in which it is difficult to distinguish metagabbro from metasediment. The rocks are variable in character, are strongly folded and contain gneissic, granitic and pegmatitic felsic rocks (examples of some features in photo 32 and 33).

Many of the rocks are layered; the layering is similar to that in the Ankerlia Metagreywacke in some places and similar to that in the layered metagabbro in others. The rocks are generally fine to medium grained, with brown, grey and whitish weathering colours.

In thin section, a mixture of mineralogical types can be seen. Some samples are plagioclase - pyroxene - hornblende rich like a metagabbro. Others contain quartz and biotite in addition to plagioclase, pyroxene and amphibole, corresponding more closely with Ankerlia Metagreywacke compositions.

The zone is called "gneissic" because of the common fine-scale, folded layering and in particular the thin lenticular felsic laminae which resemble those formed by metamorphic processes in gneisses.

The most likely interpretation of the zone is that it contains both metagabbro and metasediment, both intensely folded, and is disrupted by felsic rock derived from local partial melting of the metasediment (Ankerlia Metagreywacke).

Photo 32: Tight folds with flat axial planes; minor mobilization of felsic material into axial plane directions. Pyroxene bearing rock, probably Ankerlia Metagreywacke, from gneissic zone. Location BS 18 (M.R. 1895-4345)

Photo 33: Folded and boudinaged gneiss with felsic material containing elongate fragments. From gneissic zone. May be deformed and partly melted Ankerlia Metagreywacke. Location BS 29 (M.R. 1955-4310)

THE BASIC DYKES/SILLS IN THE ANKERLIA METAGREYWACKE

Ankerlia Metagreywacke was mapped along the western margin of the Vaddasgaisak Metagabbro, over an area about 5 km long, and about 1 km wide (it extends much further than that). In the mapped area the Ankerlia Metagreywacke contains a high density of basic dykes/sills. The density of basic intrusives is between about 10 & 50% of the rock volume, perhaps over 50% in places. Most of the intrusions are sub-parallel or parallel to bedding and could be called sills. Some low to high-angle discordances are apparent, however, where exposure is good, and here the intrusions could be called dykes. Boudins of basic rock within bedding are also common and are interpreted as deformed sills/dykes.

The basic sills/dykes are basaltic in compositon. Mineralogy and textures are igneous with various degrees of metamorphic recrystallization and metamorphic mineral growth. The igneous mineralogy appears to have been essentially plagioclase - clinopyroxene, with plagioclase compositions between about An_{54} & An_{70}. One sample (VR 538) contains olivine. Hornblende is the most abundant metamorphic mineral, commonly appearing as a partial replacement of clinopyroxene. Clinozoisite, sphene and chlorite are minor alteration products.

Porphyritic textures are common, with plagioclase phenocrysts in a matrix of interlocking plagioclase laths with interstitial clinopyroxene. The original igneous textures have been modified to various degrees by metamorphic recrystallization, and in places deformation has converted the rocks to basic gneisses. In outcrop some of the basic dykes/sills appear to be completely undeformed, while others are intensely deformed. It is tempting to suggest pre & post-deformation intrusion events. However even the least deformed rocks show considerable alteration of clinopyroxene to metamorphic hornblende. The apparent differences in deformation are probably results of local differences in behaviour of the rocks.

Intrusion of the dykes/sills occured before the last episode of amphibolite grade metamorphism, but it is difficult to be more precise. One dyke (BS-127, map reference 178403 Nordreisa 1:50 000) appears to cut through folded metasediment (photo 34), but it is possible that the fold formed later along the margin of the dyke. No examples of folded dykes were observed, but boudinage is common.

It is difficult to interpret the time relationship between the dykes/sills and the Metagabbro. The dykes in the Metagabbro have a similar metamorphic history and could have formed at the same time as those in the Ankerlia Metagreywacke.

Table 9: Estimated modal mineral content of metasediments from Ankerlia Metagreywacke (see also Appendix 1, table 8)

Sample	Plag	(An)	Cpx	Amp	Cz	Opaq	Sph	Biot	Zirc	Qtz	Scapolite
BS 21	50	(64)	-	-	20	x	1	10	-	20	-
BS 98E	30	(50)	-	5	20	1	1	3	-	40	-
BS 101	10	(6?)	15	7	-	-	1	10	x	50	7
BS 128	-		-	30	30	-	2	-	-	?	-

Table 10: Estimated modal mineral contents of dykes or sills intruded into the Ankerlia Metagreywacke

Sample	Plag	(An)	Cpx	Oliv	Amp	Cz	Opaq	Sph	Biot	Chl	Ap	Zirc
BS 3	41	(50)	-	-	55	-	x	x	-	x	x	-
BS 20	46	(65)	-	-	50	-	1	2	1	x	-	-
BS 25	42	(66)	-	-	50	-	2	1	-	-	-	x
BS 98A	50	(60)	35	-	10	-	5	x	-	-	-	-
BS 98B	50	(54)	17	-	30	-	3	-	-	-	-	-
BS 98D	45	(44)	-	-	50	x	3	2	-	-	-	-
BS 127	50	(72)	15	-	32	-	3	-	-	-	-	-
VR 538	60		10	15	10	-	5	-	-	-	-	-
Va 137	35	(50)	x	-	65	-	x	-	-	-	-	-

Photo 34: Basic dyke cutting typical finely bedded, fine grained Ankerlia Metagreywacke, at a high angle. Dyke appears to intersect a fold, but the fold may have formed later. Location BS 127 (M.R. 1790-4030)

Photo 35: Dyke in dyke occurrence. The head of the hammer marks the edge of the chilled margin of one dyke (or sill) intruding another. Ankerlia Metagreywacke on the left. Location BS 125 (M.R. 1880-4215)

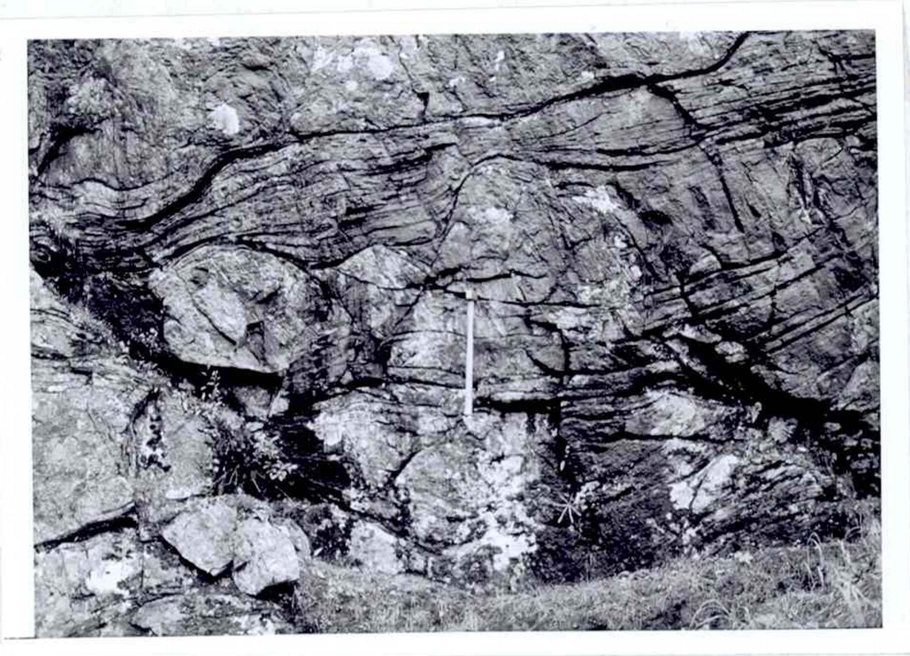


Photo 36: Bedded Ankerlia Metagreywacke wrapping around amphibolite boudins, probably derived from deformation of dykes/sills. Location BS 106 (M.R. 1835-4795)

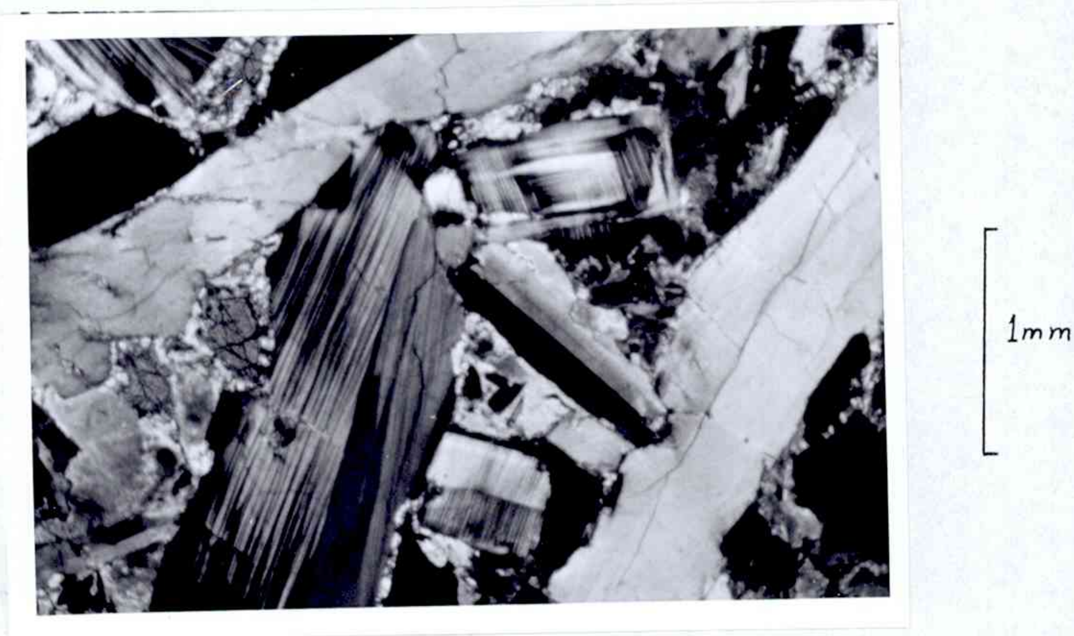


Photo 37: Coarse igneous texture in olivine dolerite intrusion in Ankerlia Metagreywacke. This is coarser than most. Hornblende alteration around grain boundaries. Location VR 538 (M.R. 1782-3973)

THE FELSITES

The term "felsite" is used here only as a generalization to cover the range of felsic igneous and meta-igneous rocks associated with the Vaddasgaisak Metagabbro and the adjacent Ankerlia Metagreywacke. The felsites range in character from pegmatitic to granitic and gneissic. They range in mineralogy from trondhjemite or oceanic plagiogranite to granite and probably diorite.

In the main part of the Vaddasgaisak Metagabbro felsites occur sporadically as pegmatites filling joints. The rocks are generally quartz - feldspar - hornblende pegmatites, but some biotite may be present.

Near the western and norther margins of the Metagabbro it is common to find irregular granitic to pegmatitic felsite bodies. These commonly form a breccia, incorporation blocks of metagabbro. The felsites consists of quartz and feldspar with various amounts of biotite and/or hornblende.

Felsites are also abundant in the gneissic zone on the western margin of the Metagabbro. Many of these felsites appear to have undergone the same deformation which affected the other rocks in gneissic zone. The felsites show evidence of folding and boudinage, and some have developed a biotite schistosity. In the gneissic zone there are deformed breccias with elongate fragments of country rock in deformed felsite.

The felsites in and near the Vaddasgaisak Metagabbro may be of two separate types or may represent a continous range of variation. The present study was not conclusive, but it appears likely that there are two separate types: high-K and low-K. The difference in potassium content is reflected in mineralogy. The high-K type contains abundant K-feldspar and biotite, while the low-K type contains little of these.

The felsites may have formed in two ways. The low-K felsite have compositions suitable for late-stage differentiates of the very K-poor Metagabbro. This seems a likely origin for them, but it is difficult to explain how such differentiates could have remained in liquid form until crystallization, recrystallization and folding of the gabbroic parent was completed, and planar joints formed. For this to have happened the deformation of the gabbro would have had to have taken place at temperatures above the melting point of the low-K felsites.

The high-K felsites have compositions closer to minimum granitic melts, and could have formed by partial melting of the Ankerlia Metagreywacke. Winkler (1974) describes anatectic reactions in occuring in rocks containing biotite but no K-feldspar. From Winkler's experimental work it could be inferred that suitable melts should form from Ankerlia Metagreywacke at 700-750°C at 2 kb water pressure, perhaps around 700°C if water pressure was 4-6 kb.

Table 11: Estimated modal mineral content of samples of felsic mobile material (granitic to pegmatitic rocks)

Sample	Qtz	Plag	K-fels	Amp	Cpx	Biot	Musc	Opaq	Sph	Cz	Zirc	Chl
BS 45	30	30?	30?	7	1	-	-	1	1	-	x	-
BS 51	40	54	-	2	-	x	x	x	2	2	x	x
BS 98C	35	35	20	10	-	-	-	x	x	-	-	-

Table 12: Estimated modal mineral content of samples of Loftani Greenstone (see also Appendix 1, tables 9 & 10)

Sample	Plag	(An)	Amp	Cz	Opaq	Sph	Chl	Carb	
BS 13	45	(38)	40	10	2	1	2	-	Upper greenstone
BS 74	35	(60)	45	20	x	x	-	-	Upper greenstone
BS 83	45	(45)	48	2	3	2	-	-	Upper greenstone
BS 62	40	(36)	50	8	1	1	-	x	Lower greenstone
BS 72	27	(42)	55	15	1	2	-	-	Lower greenstone

Photo 38: Rolf Nordheim studying a felsite breccia. Felsite is a granitic rock containing hornblende and biotite. The felsite is intruding non-layered medium grained metagabbro near the western margin. Blocks are metagabbro. Location - east of Grasdalen (M.R. 195423).

FELSITES AND DYKES IN MOSKODALEN

During the Vaddas field work, some trips were made to Moskodalen, a smaller valley joining the major valley of Reisadalen. In Moskodalen, loose boulders of felsite breccia containing blocks of basic rock were examined, and a dyke complex in the north wall was sampled and photographed.

At about map reference 135-325 (Reisadalen 1:50 000) there are numerous boulders of felsite breccia on the valley floor. One is shown in photo 39. Included in the breccia are angular blocks of basic rocks of various types. Many have a doleritic texture with intersecting plagioclase crystals, closely resembling textures of some of the dykes/sills in the Ankerlia Metagreywacke at Vaddas. In some places the doleritic blocks show partial reaction rims with felsite matrix.

Other blocks appear to have block-in-block textures (photo 39). In these only the innermost zone has a doleritic texture. The other zones are more or less equigranular amphibolites. These blocks could be fragments of a metagabbro breccia, incorporated into the felsite breccia. However metagabbro breccia was not seen outside of the felsite breccia, so it is more likely that the equigranular amphbolite represents a product of reaction between dolerite and felsite.

Several blocks of coarsely porphyritic dolerite were also seen in the felsite. These are probably also dyke rocks.

A small number of the fragments are layered metasediments, most probably Ankerlia Metagreywacke.

Some adjacent blocks can be seen to have fitted together, but others are different from their neighbours. The proportion og matrix to blocks is very variable.

In the north wall of Moskodalen at about map reference 131-333 (Reisadalen 1:50 000) some apparent dykes intersecting felsite were noticed by K.B. Zwaan. These features were confirmed by observation from a helicopter, and were checked on foot by myself and Rolf Nordheim. Doleritic dykes have intruded both Ankerlia Metagreywacke and an irregular felsite mass within Metagreywacke. Many dykes are parallel to each other, but some dykes intersect other dykes (photo 41). There are some complications in the relationship between dykes and felsite. One dyke grades from basic rock at the top to felsic rock at the base (photo 42). Another basic dyke is cut by a thin felsic dyke.

Five samples, BS 98A-E, were taken for thin section and for chemical analyses (see appendix 2 & appendix 3). The felsite is of the high-K type, probably derived from partial melting of metasediments. The dykes are similar to dykes in the Vaddas area, but higher in K_2O, perhaps indicating some contamination of the dykes by the felsite.

Geological Relationships in Moskodalen

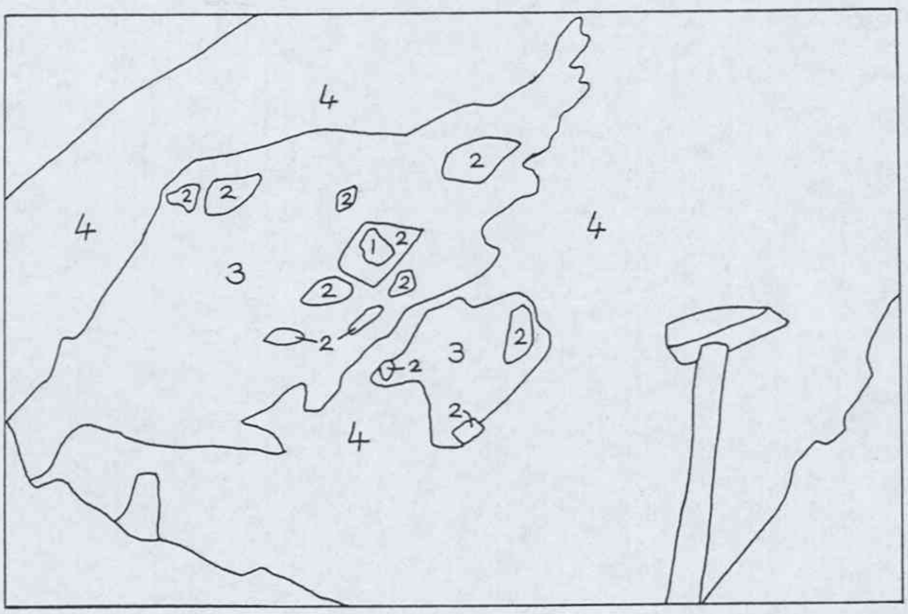
The outcrop in the north wall shows that the felsite intrudes the Ankerlia Metagreywacke, and that basic dykes intrude both. There is minor intrusion of felsite after the dykes.

The boulders in the floor of the valley show that felsite magma has enclosed blocks of basic rock whose textures suggest they were dykes.

The most reasonable conclusion is that the basic dykes and felsites were emplaced at about the same time, with dykes intruding felsites in some places, and felsites intruding and brecciating dykes in other places. If the felsite formed by anatexis as a result of the gabbro intruding, then the dykes were probably emplaced at about the same time as the gabbro.

If this is correct it is a little strange that the dykes and the felsite show very little deformation while the Vaddas-gaisak Metagabbro is intensely deformed internally.

Photo 39: Amphibole-bearing felsite containing blocks of more basic rocks. Apparent block-in-block textures may be due to reaction of felsic and mafic components. Loose boulder, Moskodalen.



1. Gabbroic rock with large mafic crystals - igneous texture
2. Amphibolite or dolerite - granular texture
3. Leucocratic amphibolite - granular texture
4. Amphibolite-bearing felsite with minor biotite-bearing pegmatite

Photo 40: Part of north wall of Moskodalen, taken from helicopter. Field of view about 100-200 m wide. Part of the dyke complex in the Ankerlia Metagreywacke. Pale area is felsite intruded by basic dykes, dark area is Metagreywacke intruded by basic dykes. Location BS 98 (M.R. 132-333 Reisadalen 1:50 000)

Photo 41: Two basic dykes cutting another basic dyke, in a felsite host rock. Both sets of dykes have substantial hornblende alteration of the pyroxene. Samples analysed:

BS 98A - from margin of thick, later dyke

BS 98B - from earlier dyke

BS 98C - from felsite host

Location BS 98, north wall of Moskodalen (M.R. 132-333 Reisadalen 1:50 000)

Thickest dyke is 2-3 m thick

Photo 42: Unusual dyke, about 3 m thick, grading from basic at the top to felsic at the base. Underlain by another basic dyke. Wit felsite host. Location BS 98. north wall of Moskodalen (M.R. 132-333 Reisadalen 1:50 000)

THE LOFTANI GREENSTONE

Lindahl (1974) mapped two greenstone units along the eastern side and folded around the north side of Vaddasgaisak. The two units were shown merging into one to the west, and the lower unit becomes very narrow and pinches out to the south.

The greenstone units are composed entirely of metabasic rocks, which occur in various forms. Some of the greenstone is massive to weakly schistose. Much of this is massive fine to medium grained metabasalt containing scattered plagioclase phenocrysts. Some rare well-developed pillow structures were observed in this type in the north face of Vaddasgaisak (see photo 43). More commonly there is a fracture pattern which resembles pillow structures (photo 44). These could be pillow structures, but the "pillows" show no concentric zoning, so it is possible that the feature is just a fracture pattern developed in a non-pillowed lava flow.

Some massive greenstones are coarser grained, with a matted texture of interlocking plagioclase and hornblende. The hornblende is metamorphic, but the plagioclase is at least in part relict igneous. Some of these rocks may have been basalts with a higher proportion of crystals than the rocks described above.

Schistose greenstone is also common, with all gradations from massive greenstone to fine grained schist.

There are also some medium grained sub-equigranular rocks without a strong schistosity and without phenocrysts. These may have been non-porphyritic basalts or tuffs.

The upper section of the upper Loftani Greenstone is a schistose rock with apparent diffuse lithological layering. It is difficult to distinguish between this and the schistose margin of the overlying amphibolite zone (see photo 45 and further discussion in the sulphide Mineralizationsection).

The greenstones are essentially hornblende - plagioclase rocks, commonly containing 5-15% clinozoisite, and minor sphene and opaque minerals. Quartz and/or chlorite are abundant in some specimens and minor carbonate occurs in a few samples.

Microtextures include the following:

(a) altered basalts or gabbroic - interlocking plagioclase phenocrysts with interstitial randomly oriented, matted amphibole and finer plagioclase and clinozoisite (e.g. samples VR 339, VR 309, VR 164),

(b) relict porphyritic texture - with individual deformed plagioclase phenocrysts in a schistose metamorphic matrix of amphibole, plagioclase, clinozoisite ± quartz (e.g. VR 334, VR 127),

(c) completely metamorphic - sub-equigranular amphibole plagioclase ± clinozoisite, quartz etc, with or without a strong preferred orientation of grains (e.g. VR 63, VR 603).

In all three textural types the metamorphic minerals indicate amphibolite facies metamorphism. Plagioclase and hornblende were formed at the highest metamorphic grade. Clinozoisite and sphene may have been formed at the highest grade, or later; the textures are not conclusive. Metamorphic plagioclase appears to range in composition from An_{35} to An_{68}.

The relict igneous plagioclase has compositions of about An_{55} to An_{65}, indicating that the original rocks were basaltic in composition. The microtextures and outcrop characteristics suggest that most of the greenstone was originally basaltic lava; at least some was pillow lava. A small proportion may have been basic tuff. Some of the greenstones originally had a high proportion of crystals. It is possible that these were dykes or sills, but more field study would be necessary before reaching any conclusion.

Photo 43: One of the few good examples of pillow structures in the Loftani Greenstone at Vaddas. Location BS 135 (M.R. 2065-4500)

Photo 44: A more typical example of possible pillows in Loftani Greenstone. There are no zoning textures, only fracture patterns resembling pillows. Location - Frokosthaugen (M.R. 235-422)

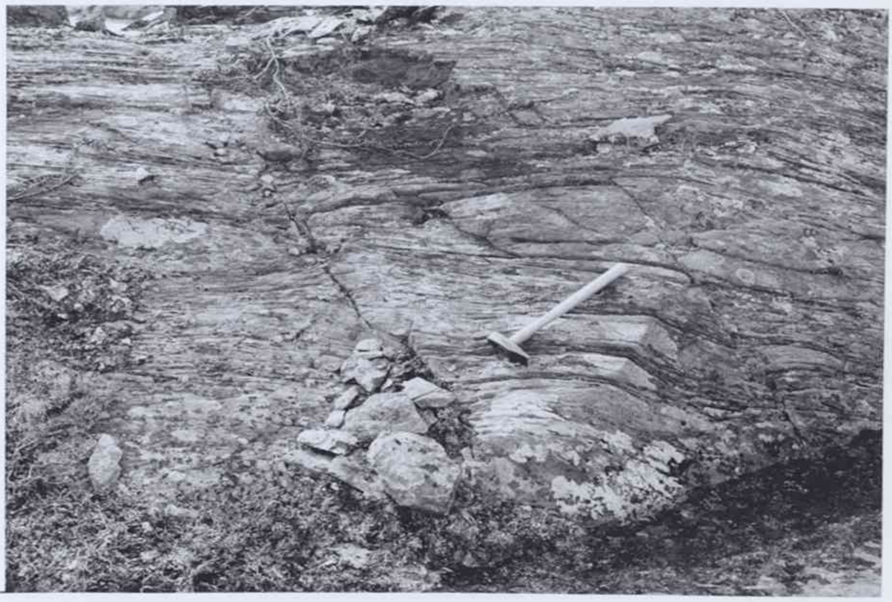


Photo 45: Schistose, somewhat layered rock from the schistose zone at the top of the Loftani Greenstone. The rock has greenstone mineralogy, and could be sheared metabasalt, sheared amphibolite, or schistose basic tuff.
Located near Oaivoščokka (approximately M.R. 233-392)

Photo 46: Relict, aligned plagioclase phenocrysts in a recrystallized matrix. Upper Loftani Greenstone. Crossed polars. Location VR 334 (M.R. 2260-3720)

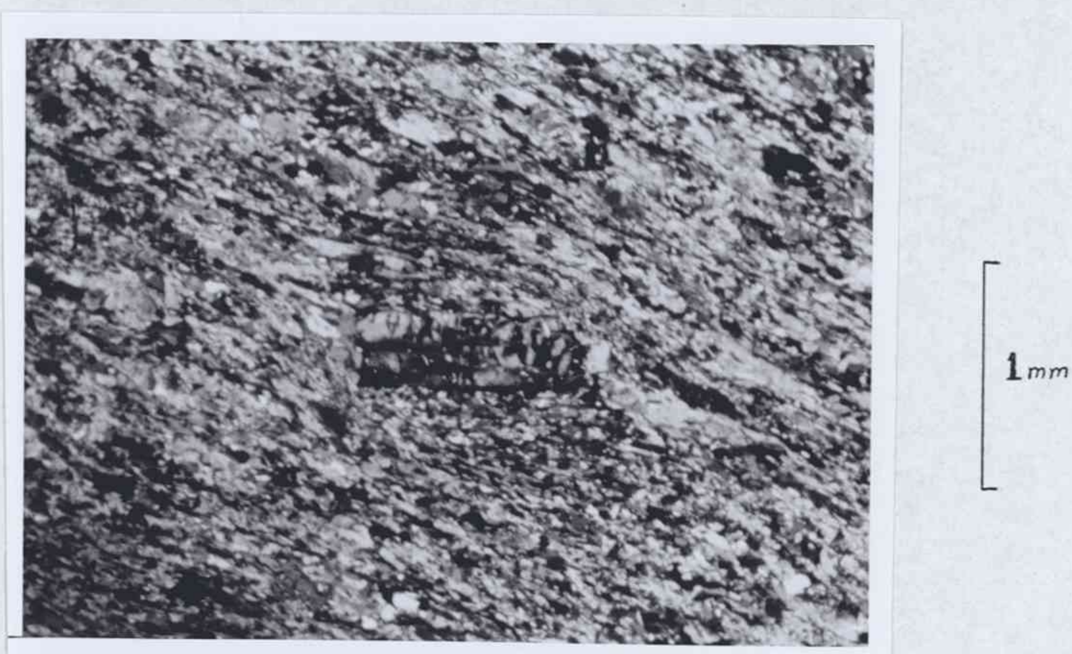


Photo 47: Relict plagioclase phenocryst in a very schistose matrix. Upper Loftani Greenstone. Crossed polars. Location VR 127 (M.R. 2115-3240)

Photo 48: Relict igneous texture of interlocking plagioclase laths in a matrix rich in large ragged metamorphic hornblende. Crossed polars. Upper Loftani Greenstone, south of mapped area. Location VR 309 (M.R. 2300-3640)

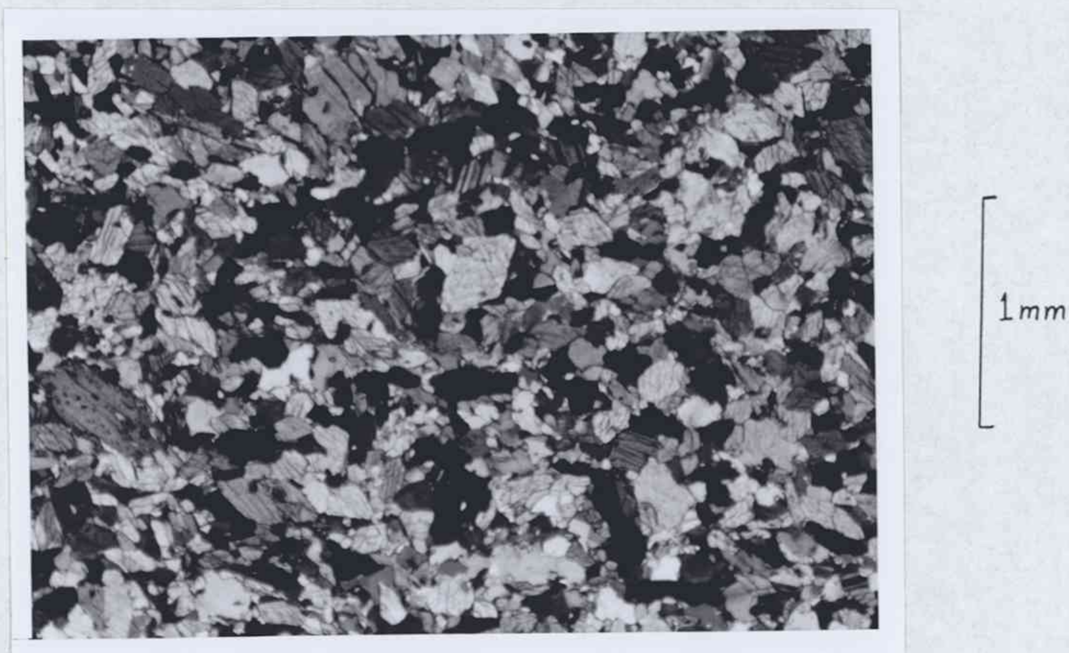


Photo 49: Sub-equigranular metamorphic texture in upper Loftani Greenstone (hornblende - plagioclase). Crossed polars. Location VR 603, west of mapped area (M.R. 1280-4425)

THE METASEDIMENTARY SEQUENCE[x]

Differences with Lindahl's (1974) Mapping

Lindahl (1974) mapped the metasedimentary sequence underlying the greenstones, in great detail (1:5.000 scale). My field observations, though sparse in this part of the sequence, are almost in complete agreement with Lindahl. My observations suggest that Lindahl's mapping is not quite as complete along the north side of Vaddasgaisak as it is on the east side. The quartzite-pebble conglomerate immediately above the Vaddas Quartzite, extends further east than shown by Lindahl, and may even occur in very sheared form, near Frokosthaugen. The interval between the major carbonate and the lower greenstone contains greenstone and minor quartzitic metasediments. The metasediment interval between the two greenstones is definitely not continuous and may pinch out somewhere in the east side or centre of the north face. Further south, near the Rieppe Fault, Lindahl's Vaddas quartzite is a mixture of carbonate and quartzite, with carbonite predominating. It is emphasized that this is only local, and that in most places the Vaddas Quartzite is almost entirely quartzite.

General character of the sequence

The lowest metasedimentary unit in the mapped area is a late Precambrian (Eocambrian arkosic facies in Norway and Sweden, which is interpreted as terrestrial (fluvial) sediment derived from erosion of Precambrian basement.

The interval between the meta-arkose and the Loftani Greenstones is occupied by about 600-900 metres of calc-mica schist, mica schist, quartzite, carbonate, conglomerate and graphitic phyllite. This represents a shale - sandstone -

[x] Note: This section was written before formal stratigraphic names were proposed after discussion with I.Lindahl and K.B. Zwaan. See table 13 for correlation of the informal units with proposed formal names.

limestone - minor conglomerate sequence, a typical shallow marine to fluvial assemblage. Bedding in these rocks is largely destroyed by deformation, including boudinage, near parallel to bedding. The calc-mica schists and mica schists show some near-planar bedding, but bedding is mostly destroyed in these rocks. The lower quartzite ("Rustkvartsit" of Lindahl, 1974)

Table 13: Correlation of proposed formal stratigraphic units (Zwaan, in preparation) and rock units mapped by Lindahl (1974)

Proposed Formal Names	Rock Units of Lindahl (1974)
Ankerlia Metagreywacke	Oksfjord Schist Ba 29
Vaddasgaisak Metagabbro	Gabbro Gneiss Ba 28 Olivine Gabbro Ba 27
Gryta Amphibolite	Contact Zone (part) Ba 25
Loftani Greenstone	Loftani Greenstone Ba 21 & 24
Ak'kejav̀ri Calc-Biotite Schist	Brown mica schist Ba 23
Guolāsjav'ri Formation	Pale, impure, conglomeratic marble and calcareous mica schist Ba 16, 17, 18, 19, 20
Skardalen Quartzite Member	Vaddas Quartzite Ba 15
Oksfjorddalen Schist Member	Mica schists with grey, clean marble beds Ba 10, 11, 12, 14
Rieppesjåkka Quartzite Member	Rusty quartzite and graphitic phyllite Ba 9
Gæirajav̀ri Marble	Gæirajav̀ri Marble Ba 6, 7
Napojåkka Group	Lilleelv Group Ba 1, 3, 4, 5

occurs as thin (up to 1 m thick) layers and lenses, alternating with graphitic schist. Many of the quartzite lenses are channel-shaped, but they may well be boudins. The Vaddas Quartzite is mostly massive, with no definite bedding planes. Both the lower, grey marble intervals, and the upper, yellow-brown marble units, are finely laminated, with planar to lenticular lamination, probably representing bedding. The lowest conglomerate interval immediately overlies the Vaddas Quartzite (except for a thin shaly interval in places), and consists of quartzite pebbles and cobbles in a micaceous matrix (photo 50). The proportion of clasts is greater than that of matrix, and the clasts are in contact. Bedding is present on a broad scale, and in places there is an upward decrease in pebble size. Other conglomerates occur in or adjacent to the yellow-brown carbonate, higher in the sequence. There are very different conglomerates, with clasts of quartzite, carbonate and mica schist in a carbonate matrix (photo 51). There is a large proportion of matrix; commonly with fine bedding, and the clasts are not generally in contact with one another.

The metasedimentary (brown schist) interval between the upper and lower Loftani greenstones is not greatly different in composition from the underlying calc-mica schists. In places it is well-bedded, with thin to thicker (1-10 cm) shaly and lesser sandy beds. Bedding is planar to lenticular and some graded bedding may be present.

The Oksfjord Schists (Oksfjordskifer) overlying the greenstones contrast greatly with the other metasediments. The Oksfjord Schists in the area studied, are intermediate to basic in composition, containing a substantial proportion of plagioclase, hornblende and clinozoisite. They are well-bedded, fine grained psammitic rocks, with thin to thicker (less than 1 cm to about 10 cm), mostly planar beds. Bedding is defined by strong contrasts in proportions of minerals. In the area studied the rocks are generally finely banded grey and white, with some brownish colour. No definite graded bedding was observed. Elsewhere in the district the Oksfjord schists are generally planar bedded, non-graded rocks, but some intervals of graded bedding do occur. The thick, relatively monotonous sandy sequence of Oksfjord Schists (and also perhaps the similar

Photo 50: Stretched quartzite pebbles in micaceous matrix; clast-supported conglomerate. Grasdalen Conglomerate Member, overlies Skardalen Quartzite Member. Location approx. M.R. 195452

Photo 51: Scattered quartzite pebbles and poorly defined carbonate clasts in a carbonate matrix; polymictic matrix-supported conglomerate Location 238422.

Photo 52: Finely bedded marble, typical of the non-conglomeratic marble unit. Jiek'kejåkka Marble Member. Location Frokosthaugen (M.R. 241-424)

Photo 53: Typically finely bedded Ankerlia Metagreywacke with possible low angle cross-beds. Location BS 126 (M.R. 1790-4069)

Photo 54: Schistose texture in Ankerlia Metagreywacke. Normally the texture is more equigranular. Analysed sample, location VR 128 (M.R. 2095-3245). Crossed polars.

Ankerlia Schists and Kåfjord Schists), with planar - non graded and minor graded bedding is best explained either as:

(1) a thick sequence of air-fall andesitic tuff with minor turbidite reworking, or

(2) a thick turbidite sequence derived at least in part from a volcanic source area, and largely reworked by contour currents to produce contourite sediments.

Composition of the Metasediments

Following is a description and discussion of the metasediments based on restudy of thin sections from samples collected by Th. Vogt and I. Lindahl (see also appendix 1).

Lindahl (1974) labelled his mapped rock units Ba 1 - Ba 30, and grouped these into 8 litho-stratigraphic units (Table 1.3, Lindahl, 1974). The lowest litho-stratigraphic group, he termed the Lillelv Group, and the uppermost group, the Oksfjord Group. The other 6 litho-stratigraphic units were placed in the Vaddas Group. These names are not formally published except for the simplified division by Vogt (1927).

In the following desctriptions, Lindahl's grouping is adopted, for convenience.

1. Napojåkka Group = Lilleelv Group - Sparagmite mica schists ("Vaddas Schists") and Pale Sparagmite

This litho-stratigraphic unit comprises rock units Ba 1, Ba 3, Ba 4, Ba 5.

Ba 1 is distinctive. All of the thin sections are quartz-feldspar rich psammites. Feldspar is generally more abundant than quartz, and both plagioclase and K-feldspar are present. Muscovite and biotite are minor minerals, each ranging up to 10%. Minor amounts of garnet, epidote and opaque-minerals are present in many samples.

The mineralogy is similar to a granitic rock, so the rocks may well be arkoses. More of the other rock units at Vaddas is similar.

Ba 3, Ba 4, Ba 5. There is little difference in mineral percentages in these three rock units. The graphite-mica schist unit (Ba 4) is probably only a more graphite rich variation of the "Vaddas Schist" (Ba 3 and 5). Samples from Ba 5 tend to contain greater percentages of mica than Ba 3. Most samples from Ba 3, Ba 4 and Ba 5 can be described as mica schists or mica-garnet schists. They are mostly pelitic[x] (mica > quartz + feldspar) or psammopelitic (quartz + feldspar > mica), with only three psammites (quartz + feldspar >> mica).

The psammites of Ba 3 and Ba 4 (there were none sampled from Ba 5) are quartz rich, with minor plagioclase, and apparently contain no K-feldspar. This may indicate a different source of detritus than that for Ba 1.

The metasediments of Ba 3, Ba 4 and Ba 5 vontain no amphibole and little or no carbonate, in contrast with overlying schist units. There is therefore, a significant change to more calcic sedimentation, at the top of Ba 5.

2. Gæirajav'ri Marble

This unit comprises rock units Ba 6 and Ba 7.

Ba 7 - all samples are relatively pure marble, with very minor quartz, muscovite and some with minor zoisite.

Ba 6 - nearly all samples are essentially quartz - amphibole - biotite - carbonate rocks, perhaps originally impure dolomitic marble.

3. Rieppesjåkka Quartzite Member = Rusty Quartzite and Graphitic Phyllite

This is a single rock unit Ba 9.

Ba 9 - Most samples are quartzite with minor albite, and very minor mica. One sample is a carbonate - mica - quartz - amphibole rock. Another is a chlorite rich schist, and one other is a muscovite - biotite - garnet rich schist with an estimated 10% of opaque grains. Minor cubic opaques are common in many samples, and pyrite was observed in the field.

[x]The terms "pelitic", "psammopelitic", "psammitic" are used in the same way as Stevens et al (1980).

The composition indicates that the rock may have originally been an acidic tuff (or reworked tuffaceous material), either sodic in original composition, or altered to a sodic composition. The rock could also have been a quartz sandstone with minor detrital albite (no obvious source) or with albite, or calcite as a cementing material.

There are no thin sections of the graphitic phyllite, but in the field this is a fine grained dark-grey to black rock, and is different from all other micaceous rocks in the sequence.

4. Oksfjorddalen Schist Member = Mica Schist with Grey, Clean, Marble beds

This litho-stratigraphic unit comprises rock units Ba 10, Ba 11, Ba 12, Ba 14.

Ba 12 - relatively pure marble, almost identical in composition to Ba 7, except that minor zoisite crystals are present in some samples of Ba 12.

Ba 10 - all four samples are pelitic quartz muscovite - biotite - garnet schists. Three also contains staurolite crystals. The amphibole may have derived from an original carbonate component, or less likely, from basic-volcanic detritus.

Ba 11 and Ba 14 - Both are essentially quartz - muscovite - biotite - garnet schists. Individual samples contain amphibole, chlorite, plagioclase or epidote/clinozoisite. Ba 11 and Ba 14 are similar in composition to Ba 3, 4 and 5, the "Vaddas Schist" (Lilleelv Group by Vogt (1927)) and are the only schists which contain a very low percentage of calcium minerals.

5. Skardalen Quartzite Member = Vaddas Quartzite

This is a single rock unit Ba 15.

Ba 15 - There is no obvious difference, except that opaque minerals are more common in Ba 9, between this unit and the Rusty Quartzite (Ba 9). Ba 15 consists of quartz, minor albite, and very minor muscovite and/or biotite. One sample is carbonate rich, and one is muscovite rich.

6. Guolasjav'ri Formation = Pale, Impure, Conglomeratic Marble and Calcareous Mica Schist

This comprises rock units Ba 16, Ba 17, Ba 18, Ba 19, Ba 20.

Ba 16, Ba 17, Ba 19 - are mostly carbonate - quartz - muscovite rocks, ranging from almost pure marble, to quartzite containing minor plagioclase and carbonate. Rocks with nearly equal amounts of quartz and carbonate, plus lesser muscovite are very common. This contrasts with the lower marble units (Ba 7 and Ba 12).

Some samples from Ba 19 are from conglomerate pebbles. Three pebbles are quartzite with minor albite, as in rock units Ba 9 and Ba 15, and one pebble is nearly pure marble. The pebbles are from within the Vaddas Group.

Ba 18 and Ba 20 - are essentially psammopelitic to pelitic quartz - muscovite - biotite - schists containing minor carbonate and/or other calcium minerals (amphibole, epidote/clinozoisite). Garnet is a common minor mineral in both units, very minor plagioclase occurs in some samples of Ba 18, and minor plagioclase is present in two of the three Ba 20 samples.

Sample VR 488 from Ba 20 contains minor kyanite and staurolite (no other samples contain kyanite).

The relatively consistent minor carbonate component in Ba 18 and Ba 20 distinguishes them from stratigraphically lower pelitic/psammopelitic schists (except Ba 6).

7. Loftani Greenstone and Ak'kejav'ri Calc-Biotite Schist (Brown mica Schist)

This unit comprises rock units Ba 21, Ba 23, Ba 24. Ba 21 and Ba 24 are respectively, the lower and upper greenstone unit, discussed elsewhere in this report.

Ba 23 - most samples are quartz - biotite - carbonate schists. Other calcium minerals (amphibole, epidote/clinozoisite, calcic plagioclase) occur in some samples, white garnet and chlorite are less common minor components. Minor muscovite is present in many of the samples, but is less abundant than in Ba 18.

Ba 23 is very similar to Ba 18 and Ba 20, but the samples contain significantly less muscovite than Ba 18. Ba 23 probably represents a continuation of a similar type of sedimentation as in Ba 18 and Ba 20. The lower muscovite content may reflect a reduction in deposition of potassium-rich clay. Perhaps the eruption of basalts (now greenstone) cut off the source of clay, or the basaltic rocks contributed some potassium-poor detritus to the sediment.

8. Ankerlia Metagreywacke (Oksfjord Schists) and Vaddasgaisak Metagabbro

This unit comprises Ba 25, Ba 27, Ba 28 and Ba 29.

Rock units Ba 25, 27 and 28 are essentially basic igneous rocks, and are discussed elsewhere in this report.

Ba 29 in the Oksfjord Schists, which are mostly quartz - plagioclase - amphibole - biotite - clinozoisite rocks. The proportions of the minerals are variable. This rock unit is not like any of the underlying metasediments.

The minerals quartz and biotite are normal products of metamorphism of sediment derived from a cratonic source. However the combination of amphibole and calcic plagioclase and epidote/clinozoisite, may represent metamorphic products of detritus from a basic igneous source. Such a source may be the underlying gabbros, amphibolites and Loftani Greenstones or perhaps a more distant greenstone terrain.

The Pattern of Sedimentation

From the foregoing descriptions and from Lindahl's facies correlations (plans 1.12 and 1.13, Lindahl 1974), some observations and comments can be made.

The Lilleelv Group rocks were calcium-poor and carbonate-poor detrital sediments, in contrast with the calcium and carbonate-rich, overlying Vaddas Group. There is some similarity between the schists (Ba 3, 4, 5) in the upper part of the Lilleelv Group and two of the schist units (Ba 11 and 14) in the Vaddas Group, but this may not be significant.

The sparagmite unit (Ba 1) of the Lilleelv Group is unlike any other rock unit in the area. The schists (Ba 3, 4, 5) of the Lilleelv Group may represent a shaly facies associated with the arkosic sparagmite facies, or may be unrelated.

The Vaddas Group metasediments define a carbonite shale facies with quartz (-minor albite) sand lenses. There is no major change in the composition of the carbonate/shale rocks, within the Vaddas Group, although above the Vaddas Quartzite (Ba 15), the carbonates and shales tend to be less pure (more mixed). The conglomerates in Ba 19 are discontineous and contain fragments from within the Vaddas Group. The rounded quartzite pebbles, angular carbonate and shaly clasts, and bedded carbonate matrix, suggest a complex depositional process involving components from different sources. The quartzite pebbles could have been carried by floodwater from a nearby land area into a lagoon or shallow marine environment, where carbonate was being deposited. The floodwaters may have locally ripped up semi-consolidated mudstone and limestone and redeposited all the coarse clastic components together with locally derived carbonate sand.

The quartzite-pebble conglomerate (with micaceous matrix) closely overlying the Vaddas Quartzite, has the character of a normal fluvial conglomerate, and indicates at least local subaerial erosion of the Vaddas Quartzite.

The albite-bearing quartzite units (Vaddas Quartzite Ba 15 and Rusty Quartzite Ba 9) are unrelated in composition, to the carbonate/shale rocks of the Vaddas Group. The lenticular shapes of these quartzite units, the presence of crossbeds (Lindahl, pers. comm. 1982), and the nearly pure quartz (-minor feldspar) composition, suggests that they were deposited in channels, from traction currents. If the quartzites are interbedded with the carbonate/shale sequence, and not tectonically emplaced, the environment may be interpreted as a shallow carbonate shelf, with sandy channels bringing detritus from the mainland or from an island.

As discussed earlier the Oksfjord Schist may be airfall tuffs partly reworked by turbidity currents, or turbidites largely reworked by contour currents, to produce contourites.

Interpreted Sedimentation History

In summary, if the stratigraphic sequence observed does not contain major tectonic breaks, it may have been formed in the following manner:

1. Continental arkosic sedimentation, derived form erosion of Precambrian gneisses.

2. Shallow carbonate/shale sedimentation in a shelf-style environment, with channels carrying quartz (-minor plagioclase) sand from nearby land area.

3. Uplift of and partial erosion of consolidated Vaddas Quartzite, leading to deposition of fluvial quartzite conglomerate.

4. Slow subsidence, leading to renewed carbonate/shale deposition with local transport of quartzite pebbles and shale clasts into the carbonate-forming environment, perhaps explained by floods carrying quartzite pebbles and ripped-up shale clasts into a lagoonal or shallow-marine environment.

5. Extrusion of pillow-basalts, minor pyritic sulphide mineralization. Abundant copper in the pyritic mineralization may indicate deeper water environment.

6. Deposition of Oksfjord Schists as contourites and turbidites, downslope from basaltic-volcanism, or deposition as airfall tuffs.

The time of formation and emplacement of the Vaddasgaisak Gabbro and the Rappesvarre Granite Gneiss are here considered to be unknown.

THE SULPHIDE MINERALIZATION

The mineralization was studied in considerable detail by Lindahl (1974). The following information is taken directly from the summary in Lindahl's thesis.

From Lindahl (1974)

The sulphide deposits in the Vaddas-Rieppe area occur in four different stratigraphic positions, each ore horizon occupying a fairly narrow thickness or a single horizon. Lowest in the stratigraphy a single deposit (Nedre Nomilolgi) occurs in brown mica schist just above the lower Loftani Greenstone unit. The next horizon contains a single deposit, Rieppe, where the ore occurs in the lowest part of the upper Loftani Greenstone (basaltic lava)unit. On the top of the upper Loftani Greenstone unit occurs an extensive mineralized horizon, the Vaddas horizon, which can be followed for 35 kilometres along the strike. Massive sulphides are not present along the whole strike length but occur in separate bodies which are linked together by impregnation or thin sulphide bands (rusty horizon). The Vaddas horizon contains the main mineralization in the area. The Birtavarre mineralized zone in the Oksfjord schist Group (= Ankerlia Schist) contains a few massive sulphide bodies in this area - Indre Gressdal, Røieldal, Høgfjellvatn and Moskodal. The Stoll I and Øvre Lankavarre deposits may belong to the Birtavarre zone but they are different in mineralogical features and occur in the metamorphic aureole around the Vaddasgaissa gabbro.

The ore deposit in Vaddas-Rieppe area are pyrrhotitic with varying amounts of pyrite. The deposits in the Birtavarre zone contain pyrrhotite as the only primary iron sulphide, and no primary pyrite. In the Vaddas horizon the sulphide:silicate ratio in the ores is about 50:50, and therefore the gangue minerals are important for the mineralogy of the ores. The base metals in the deposits occur in chalcopyrite (Cu) and sphalerite (Zn).

Oxidation of the ores in the area after the last glaciation has been very minor, and most of the preglacial gossan has been removed by ice action. In depressions in the terrain and high in the steep mountain sides, however, preglacial oxidation of the ores to a depth of 3 metres is found. Below that level protore is found under a few dm thick cementation zone.

The mineralogy of the ore has been studied in thin and polished sections. Analyses have been made of mineral concentrate and of minerals in polished sections by microprobe, and the sulphide and oxide mineralogy of the ores has been determined.

The iron content (weight %) in sphalerite (131 point analyses) is normally between 7 and 9% in most of the ores except the Indre Gressdal deposit where the sphalerite has an iron content of nearly 11 % as an average. There is also a variation in the iron distribution within individual sphalerite grains. The cadmium content in sphalerite varies from 0.1 - 1.3%. The manganese content in sphalerite is very low in all deposits except Nedre Nomilolgi, a deposit in mica schist. Point analyses on pyrite have shown up to 1.75% Co, but with great variation. The pyrites normally show zoning of cobalt with the highest content towards the crystal faces, but picture is very complex. In pyrrhotite the cobalt content is higher than the nickel content.

Haemoilmenite is a characteristic intergrowth occurring in the ores in the Vaddas horizon, and additionally magnetite is present. The haemoilmenite has a haematite dominated core, surrounded by a rim of pure ilmenite, but sometimes with very small patches of haematite also in the rim. This rim is thick where the intergrowth has a grain boundary against oxides and sulphides, but is missing or very thin where the intergrowth is in contact with silicates. The haemoilmenite intergrowths occur only in the ore horizon; In the wall rock the titanium minerals are rutile and sphene.

Native Bi is found where small amounts of galena are present, Hedleyite ($Bi_{14}Te_6$) is another rare mineral in the galena paragenesis, and is here found for the first time in Norway.

The silicate minerals in the ore are mainly plagioclase and hornblende. In varying amount anthophyllite, staurolite, spinel and talc (typical for Rieppe) are found. The iron content in the ores is extreme for a silicate rock, and the silicate mineralogy indicates that the ores also have a high magnesium content.

The deposits are mainly of Cu-Zn, but in Rieppe Zn dominates and it is a Zn-Cu ore. There is a change in the Zn-content along the strike in the Vaddas horizon from Doaresgaissa to Nedre Lanka-varre, where the Zn content increases to the south, from 0.1% to about 1%. The copper content in the Vaddas horizon varies between 1 and 2% on average. In the Rieppe deposit the zinc content in the ore is 2% as an average in ore reserve estimates and additionally there is about 0.5% Cu. The lead content in the ores is very small.

The base metal content varies a lot within the ores, both copper and zinc. Systematic variations from foot wall to hanging wall are not observed for either the Rieppe deposit or the deposits in the Vaddas horizon. However, in Rieppe the upper ore body have a higher zinc content than the lower one.

Histograms of copper for ores with less than 15% S, 15-25% S, and more than 25% S for the Vaddas deposit show an increasing sulphur content. The distribution of copper is a symmetric with a peak at about 1% Cu and an arithmetic mean at about 1.5% Cu.

The Co/Ni ratio in the ores of the Vaddas horizon is most commonly between 5 and 10, similar to that in metamorphic massive sulphide deposits from other parts of the world. The metamorphism has redistributed the cobalt and the pyrites have a far higher cobalt content than the pyrrhotite in the ore. The cadmium content in sphalerite increases with decreasing zinc content in the ore but the total cadmium metal content in the ores increases with increasing zinc. Precious metal contents in the ores based on the analyses of chalcopyrite flotation concentrates are low.

The textures of the ores show that the deposits are meta-morphosed, and the silicate mineralogy in the ore and sediments in the area make it clear that the ores have taken part in the same grade of metamorphism as the rocks. Idiomorphic minerals such as pyrite, arsenopyrite, and magnetite are poikilitic, while minerals such as sphalerite, chalcopyrite, and pyrrhotite show a typical metamorphic texture. During the metamorphism local mobilization has taken place and mineral phases such as chalcopyrite and galena have migrated to strain shadows.

The ore deposits have been strongly tectonized before or during metamorphism. The ores are "durchbewegt" whereby fragments from the wall rock have been involved and where rounded wall rock and quartz fragments lie enclosed in the sulphide matrix.

A genetic model is proposed for the ores in the Vaddas-Rieppe area. The conclusion is that the ore is premetamorphic and pretectonic. The metamorphism and the tectonic movements in the ore have destroyed all primary textures. The stratigraphic position and the surrounding rock types indicate that the ores are volcanogenic and of the same age as the host rock. In other words, they are considered to be syngenetic volcanogenic sulphide deposits, emplaced on top of a submarine eruption of basaltic lava, with base metals of magmatic origin. Deposits such as Nedre Nomilolgi and the deposits in the Birtavarre zone are widespred in sediments, but appear to have association with volcanic rocks.

Comments from this study

The only comments resulting from the recent mapping, relate to the host rocks for some of the mineralization and to the continuity of mineralization.

The major Vaddas level of mineralization is well-represented along the eastern side of Vaddasgaisak. Lindahl (1974) states that it occurs "on the top of the upper Loftani Greenstone" and on his detailed maps shows the mineralization as just within the greenstone unit. In the present study, only the lower section of this upper greenstone was found to be definite metavolcanics. The upper section, containing the Vaddas mineralization is a non-porphyritic basic rock, often with weak or diffuse layering, and generally schistose, becoming very folded and schistose towards the upper contact with the amphibolite zone. There are several possible origins for this zone:

1. highly sheared metabasalt
2. folded and sheared metabasaltic tuff
3. folded and sheared amphibolite, part of the overlying amphibolite unit, probably originating as part of the gabbro.

There generally does not appear to be a distinct upward gradation from porphyritic metabasalt to layered and schistose rock, so explanation 1. above, is not favoured. Further work would be necessary to choose between 2 & 3, and such a choice would not be easy to prove.

The main comment on continuity of mineralization, relates to the north face of Vaddasgaisak. Lindahl (1974) showed a zone of sulphides extending continuously eastwards across the north face, from the outcrops above Stoll G (main Vaddas mine). My limited observations on the north face, suggest that there is not a continuous zone, and the structural interpretation for the western side of the north face also predicts some irregularity. In one profile near the western end, fairly massive, but thin sulphide mineralization was observed in amphibolite (location BS 54), both overlain and underlain by metasediments of the Ankerlia Metagreywacke (Some rocks directly below may be schistose greenstone). This is in Lindahl's inferred Vaddas position.

Interpretation of the origin of the mineralization can be affected by interpretation of the host rocks. If some of the host rocks are amphibolite derived from intrusive gabbro, then the mineralization was either: 1. derived from the gabbro, or formed later, 2. remobilized into the amphibolite from its original position in or adjacent to the greenstones.

The regional correlation of mineralization and greenstone, even where the gabbro is not present, supports Lindahl's conclusion that the mineralization is volcanogenic and related to the greenstones.

STRUCTURE

The Vaddas Group and Loftani Greenstone

The major structure of this sedimentary/volcanic sequence is simple. The rocks define a large, open fold (figure 2) with its hinge at the northeast corner of Vaddasgaisak. There is approximately a 90° change in strike around this hinge. One limb strikes east and dips south at 30° to 45°, the other strikes south and dips east at 40 to 55°. The dips tend to be less on both limbs, away from Vaddasgaisak. The axial plane of the fold should strike southeastwards and the axis should also plunge southeastwards.

In detail there is more complexity. Small recumbent folds, boudins of amphibolite, and intense schistosity were observed in the metasediments. Such features are common results of nappe development. The units below the Skardalen Quartzite show a particularly intense schistosity development and abundant boudinage structures. The schistosity is mostly defined by fine mica and was probably developed at lower grade than the amphibolite facies maximum experienced by the sequence. It is probably a retrograde schistosity. The schistosity is particularly intense and fine grained in the graphitic phyllites of the Rieppesjåkka Quartzite Member.

Zwaan (pers.comm. 1982) has proposed a major thrust at the base of the Vaddas Group. The zone of intense retrograde schistosity almost directly overlies the suggested thrust.

Younging Directions in the Vaddas Group

It is of great importance to know whether the Loftani Greenstone is right-way-up, or overturned. If it were overturned, then there would be an ophiolite sequence of metagabbro - amphibolite - greenstone - sediments.

Both from regional geology and from local observation the greenstone/sediment contact seems to be conformable and not thrust.

Evidence for the younging direction within the Vaddas Group underlying the Greenstone is not great. On a regional scale there is no evidence to suggest overturning (K. B. Zwaan, pers.

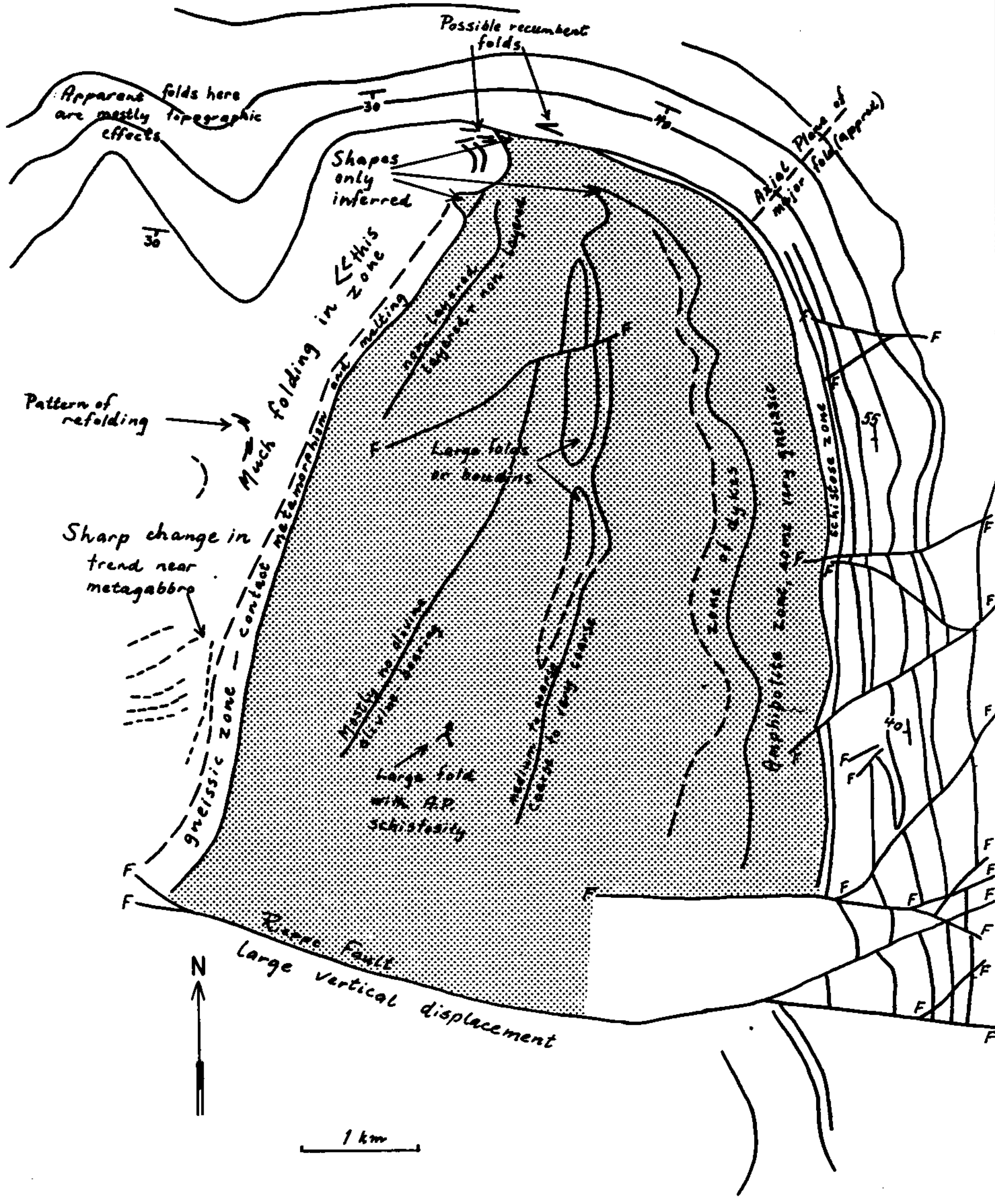


Figure 2 : Sketch map of Vaddasgaisak showing some struktural features.

Photo 55: Amphibolite boudin in finely bedded marble. Guolasjav'ri Formation. Boudinaged amphibolites are common structural features in the Vaddas Group. Location approx. M.R. 244-407

comm. 1982). At the Vaddas there is some indication from the conglomerates. The Rassavagge Conglomerate Member and Frokosthaugen Conglomerate Marble Member both overlie the Skardalen Quartzite Member, and both contain detrital pebbles of identical quartzite (even containing minor albite as does the quartzite). The conglomerate do not contain clasts from the overlying Loftani Greenstone. In addition the Grasdalen Conglomerate Member shows upward-fining of pebble sizes, in places. The Vaddas Group is probably not overturned, nor is the Loftani Greenstone.

The Napojåkka Group

The trend of bedding in the Napojåkka Group is parallel to that in the Vaddas Group. Small folds in the Napojåkka Group were not studied in this project.

Most of the Napojåkka Group is quartz - feldspar rich Loddevagge Meta-Arkose which does not show deformation effects very well. However the overlying Luovosskaide Meta-Arkose is more micaceous and strongly schistose. This unit should directly underlie the thrust discussed above (Zwaan, pers. comm.).

The proposed thrust is overlain by 80-150 m of very schistose Vaddas Group and underlain by a thinner schistose section of Napojåkka Group. This could be taken as supporting evidence for the thrust, but could also be explained by competency differences, with micaceous intervals sandwiched between more competent upper Vaddas Group rocks and thich Loddevagge Meta-Arkose.

The Vaddasgaisak Metagabbro - Major Structure

The eastern and northern boundaries of the Metagabbro are concordant with the trends in the underlying sedimentary/ volcanic sequence. The major fold in the underlying sequence has affected the northeast part of the Metagabbro, but seems to die out inside the Metagabbro.

The western boundary of the Metagabbro is quite discordant, meeting the Loftani Greenstone at a high angle.

Internally, the Metagabbro is not symmetrical. Although the main zone of coarse to very coarse metagabbro resembles the core of a large fold, the rocks on either side do not correlate. It is more likely that the apparent closure at the north end of the coarse to very coarse metagabbro, represent a pinching-out. Similarly the northern termination of the whole Metagabbro resembles the pinched-out end of the Metagabbro, have the appearance in the field of shallowly - plunging synforms. However they could also be boudins.

The Vaddasgaisak Metagabbro - Minor Structures

Within the Metagabbro, intense folding on outcrop scale is very common (see photos in earlier section of this report). Most of the folding is flat, more or less recumbent, with axial planes parallel to the main trends of layering. Very few of the folds have an axial plane schistosity, and very fluid disharmonic behaviour of folded layering is common. In places felsic material disrupts the layering. This felsic material is very similar to felsic layers in the metagabbro and probably originated as such layers.

The nature of the folding suggests very plastic behaviour, which would not be expected in a relatively dry gabbroic rock under amphibolite or lower temperature conditions. Assuming that there is no major internal fold in the Metagabbro, then the body as a whole is only slightly bent, and squeezed out at the northern end. The intense minor folding is therefore not consistent with the relatively undeformed outer shape of the body.

Much of the minor folding in the Metagabbro would have taken place before the rock was completely crystallized. At this stage it could still behave in a very plastic manner. If the gabbro was intruded during deformation, then tectonic movements during crystallization could easily have disrupted the cumulate layering and remobilized some of the remaining liquid. No axial plane schistosity would be expected in the folds.

Western Contact of the Metagabbro

The westernmost part of the Metagabbro is mostly medium grained, non-layered metagabbro, showing little evidence of internal structure. However near map reference 193-424 there is some sharp variation in dip of the minor layering, indicating a similar style of folding to that in the adjacent Ankerlia Metagreywacke.

The gneissic zone along the margin of the Metagabbro shows intense folding (see photos in earlier section), apparently associated with metamorphic segregation and partial melting. This zone may represent a zone of compression related to intrusion of the gabbro, or perhaps a zone of relative movement along the margin of the gabbro.

Further south (M.R. 181402), just outside the Metagabbro there is mylonization of the Ankerlia Metagreywacke, parallel to the Metagabbro. Here also there is a sharp change in trend within the Metagreywacke, with trends very discordant to the Metagabbro, becoming abruptly concordant near the gneissic zone.

The western contact of the Metagabbro is essentially an intrusive contact, possibly modified by later deformation (see also earlier description of gneissic zone, and later section of metamorphism).

Eastern Margin of the Metagabbro

The eastern margin of the Metagabbro is a schistose zone between the amphibolite zone of the Metagabbro and the upper Loftani Greenstone. There are no apparent contact metamorphic effects in the Greenstone.

Metamorphic grade of the schistose zone is not known, although the rocks are mostly dark greenish like the Loftani Greenstone. It is suspected that the zone was developed at amphibolite grade and is not a low grade schist zone.

The eastern contatct of the metagabbro could be a tectonic contact with the Metagabbro thrust over the Greenstone. However, if this is correct, the thrust should continue along strike at the top of the Greenstone. The transition from Greenstone to Ankerlia Metagreywacke, south and west of the Metagabbro, does not have the character of a thrust.

The eastern contact of the metagabbro may be a deformed intrusive contact against amphibolite grade greenstones. The greenstone shows no obvious contact effects because it is refractory in composition, because it lay beneath the gabbro (therefore receiving less heat than the rocks above the upper contact), and perhaps because the eastern (lower) part of the Metagabbro dispersed its heat into circulation fluids, related to amphibole alteration of the Metagabbro.

Northern Margin of the Metagabbro

The northern margin is essentially similar to the eastern margin. However there are some complications where the Metagabbro diverges from the Greenstone. From nearby Rappesvarre mountain, there appear to be irregularities in structure in this area, perhaps recumbent folds (photo 1, figure 2). The topography of the critical areas make them particularly difficult to examine on the ground, but limited inspection showed strong divergences in trend within the Ankerlia Metagreywacke, as compared with the very even trend in the Vaddas Group.

Structure of the Ankerlia Metagreywacke

No marker beds were found in the Metagreywacke, and only a limited part of the unit was mapped. Hence little can be said about the major structure within the Metagreywacke.

A major fold shown by both Vogt (1927) and Lindahl (1974) in Grasdalen, is confirmed by variation in bedding trends. However the variation is not simple, and further work would be needed to fully understand the structure. At M.R. 183-424 the major fold changes the general dip from very shallow on the west limb, to near-vertical on the east limb. My observations indicate that there are earlier very tight folds, refolded by the major fold.

In much of the area between Graselva and the Metagabbro there are open folds with a shallow-dipping limb and a near-vertical limb.

The folds west of Graselva are mostly more open, although some of the early tight folds are present. The tighter folding near the Metagabbro may be the result of its intrusion, or perhaps formed during later deformation, as the incompetent sediments buckled around the more competent Metagabbro.

Many of the dykes/sills in the Ankerlia Metagreywacke show little sign of deformation (especially south of Grasdalen). In other places (both sides of Grasdalen), the intrusives occur largely as boudins. This could be interpreted as more than one generation of intrusion, or as different amounts of strain in different parts of the area.

METAMORPHIC GRADE OF THE METASEDIMENTARY - METAVOLCANIC SEQUENCE

The metasediments and metavolcanics have undergone medium grade metamorphism (amphibolite facies). Most of the textures observed in thin section are metamorphic in origin. Rare detrital grain shapes may remain in the Ankerlia Metagreywacke, and pebbles can be seen in thin sections from the Frokosthaugen Conglomeratic Marble Member. Many of the metamorphic texture are not equilibrium texture. In many rocks there is evidence of deformation of coarse grains and recrystallization to finer grains. Some of the rocks show evidence of mylonitic deformation after the highest grade of metamorphism.

Evidence for the highest grade of metamorphism undergone by each rock group is summarized below:

1. Napojåkka Group: Amphibole and garnet are present, and plagioclase compositions range up to An_{40}. The rocks were probably metamorphosed to amphibolite facies.

2. Vaddas Group: Staurolite is present in the Oksfjorddalen Schist Member and the Guolasjav'ri Formation; sample VR-488 from the Guolasjav'ri Formation (map reference 151 459, Nordreisa 1:50 000) contains both staurolite and kyanite. Sample VR 488 was from 5 km west of the Vaddasgaisak Metagabbro, so the kyanite is not likely to be related to intrusions of the Metagabbro. Calcic plagioclase occurs in several units within the Vaddas Group. Maximum compositions are as follows: Gæirajav'ri Marble - An_{66}, Jiek'kejåkka Marble Member - An_{36}, Frokosthaugen Conglomeratic Marble Member - An_{55}, undifferentiated Guolasjav'ri Formation - An_{50}. These compositions indicate that the whole of the Vaddas Group has undergone amphibolite facies metamorphism. The differences in plagioclase composition between different units within the Vaddas Group is probably related to rock composition, not to metamorphic grade. Amphibole is present in several Vaddas Group rock units, including the lowest and highest units. The amphibole largely occurs as coarse hornblende crystals, also indicating amphibolite facies.

Muscovite is present in many of the rocks, and was apparently stable in the presence of quartz and plagioclase. This indicates an upper limit of about 650-680°C on metamorphic temperatur (Winkler 1976, p 82-87). Similarly hornblende was stable in the presence of quartz, and no orthopyroxene is present. This indicates that the rocks did not reach granulite grade. Co-existing staurolite and kyanite, indicate minimum temperatur of about 550°C and minimum pressure of about 5 kb (Winkler 1976, p 77, p 84).

It is concluded that the Vaddas Group was metamorphosed to relatively high pressure amphibolite facies, with pressure greater than 5 kb, and temperature between 550°C and 650-680°C.

3. Oksfjord Group: The rocks of the Oksfjord Group appear to have been metamorphosed to amphibolite facies, as have those of the Vaddas Group.

The Loftani Greenstone contains plagioclase with compositions ranging to An_{70} (at least some of the calcic plagioclase appears to be metamorphic), and abundant hornblende, typical amphibolite facies minerals. Clinozoisite and sphene are also abundant. The assemblage calcic plagioclase and clinozoisite may indicate that metamorphic conditions imposed an upper limit on anorthite content of plagioclase. Alternatively, the clinozoisite may be retrograde. The total absence of pyroxene implies that high temperature breakdown of hornblende did not occur. There is no obvious contact metamorphic effect on the Loftani Greenstone.

The Ak'kejav'ri Calc-Biotite Schist consists of quartz + biotite + carbonate with sporadic hornblende, clinozoisite, muscovite and plagioclase. The mineralogy is consistent with amphibolite facies.

The Ankerlia Metagreywacke is variable in mineralogy and perhaps in metamorphic grade. Most samples contain quartz + plagioclase (up to An_{64}) + hornblende + biotite. Clinozoisite and sphene are also common. All of these minerals are consistent with amphibolite facies. However in two unlocated samples (Va 164 & Va 166) and in sample BS 101 (map reference 1835 4215), 600 m west of the Metagabbro, clinopyroxene is present, and there is little or no clinozoisite. Also, within the gneissic zone next to the Metagabbro, samples BS 28 and BS 111 contain clinopyroxene with no clinozoisite, and appear to be metamorphosed Ankerlia Metagreywacke. Sample BS 111 also contains orthopyroxene. It is possible that pyroxene was produced at the expense of clinozoisite and hornblende, near the Metagabbro. Scapolite is also a common mineral near the Metagabbro (eg. sample BS 101).

Within the gneissic zone and within the western margin of the Metagabbro, pegmatitic to granitic quartzo-feldspathic segregations (felsites) containing biotite with or without hornblende, are common. Some of these are also K-feldspar rich and as discussed elsewhere in this report, are most probably products of partial melting of the Ankerlia Metagreywacke, during emplacement of the Metagabbro. This also indicates a locally higher temperature near the Metagabbro (at least on the western margin).

METAMORPHISM OF THE INTRUSIVE ROCKS

Intrusive rocks in the mapped area, are the Vaddasgaisak Metagabbro, the basic dykes/sills in the Ankerlia Metagreywacke, and the basic dykes and amphibolite lenses in the Vaddas and Napojåkka Groups. The Metagabbro appears to have a comples metamorphic history, while that of the dykes and amphibolite lenses appears to be simpler.

Amphibolite Lenses and Dykes in the Vaddas and Napojåkka Groups

The amphibolite lenses and dykes in the Vaddas and Napojåkka Groups were not studied in detail in the present project. However samples collected by Vogt (see appendix 1, this report) show that some dykes from the Napojåkka Group retain an igneous mineralogy of pyroxene - olivine - plagioclase while others, and basic intrusives from the Vaddas Group are hornblende - plagioclase (± clinozoisite) rocks with no pyroxene or olivine. Garnet is present in some specimens. Most of the rocks have amphibolite facies mineral assemblages, compatible with the host rocks. The dykes with igneous mineralogy may be either post-metamorphic rocks or perhaps pre-metamorphic rocks with meta-stable igneous minerals.

Basic Dykes/Sills in the Ankerlia Metagreywacke

The basic dykes and sills in the Ankerlia Metagreywacke mostly retain an igneous texture, with various proportions of plagioclase phenocrysts, and a matrix of interlocking plagioclase with interstitial clinopyroxene. Metamorphic effects range from minor hornblende alteration of the clinopyroxene, to total replacement of clinopyroxene by hornblende, minor alteration of plagioclase to clinozoisite, and alteration of titanium oxides to sphene. In some places close to the Vaddasgaisak Metagabbro, the dykes/sills are deformed and gneissic. Plagioclase compositions range up to An_{70}, but much of the plagioclase is relict igneous. Metamorphically recrystallized plagioclase ranges up to at least An_{50}. The assemblage: plagioclase + hornblende + sphene (± clinozoisite) indicates amphibolite facies, as in the Ankerlia Metagreywacke.

Metamorphism of the Vaddasgaisak Metagabbro

In considering metamorphic effects in the Metagabbro, there are three groups of rocks: 1. the hornblende - poor metagabbros, 2. the amphibolite zone on the eastern margin, and 3. the dykes within the coarse to very coarse metagabbro near the eastern margin.

1. Most of the Metagabbro body consists of non-layered and layered hornblende - poor metagabbro. The rocks are named "metagabbro" because they show tectonic struxtures such as gneissosity, schistosity and folded layering, in outcrop, and in thin section show abundant evidence of polygonal recrystallization. Some samples are polygonal aggregates of minerals with no apparent monominerallic aggregates. The texture of these rocks could also be explained as an igneous accumulate texture (see Vernon 1970). However other samples, particularly those from the coarse and very coarse grained metagabbros, show monominerallic aggregates of polygonal grains, undoubtedly resulting from recrystallization of the originally large grains.

The texture evidence indicates that the metagabbros have been deformed and recrystallized in the solid state. The minerals which took part in this recrystallization were plagioclase, clinopyroxene, orthopyroxene and olivine. All appear to have been in equilibrium. In most places where olivine and plagioclase are in contact there is no reaction corona, as is commonly developed during cooling of gabbros at moderate and high pressures (Gardner & Robins 1974, Nesbitt et al 1970, Esbensen 1978, Griffin & Heier 1973, Sapountzis 1975). The presence of only rare reaction coronas may indicate that total pressures after intrusion of the gabbro, approached the level of plagioclase - olivine stability (about 6-8 kb between 600 and 1 300°C).

Hornblende occupies some complete polygonal grain shapes, but largely occurs as a product of partial alteration of pyroxene grains. It is also common as a reaction rim around opaque minerals. Hornblende appears to have been formed later than the general polygonal recrystallization of the gabbro.

It is suggested that the gabbro was intruded, crystallized, then underwent recrystallization, above the stability limit of hornblende. Hornblende probably formed as an alteration product at lower temperature.

The alternative interpretation is that the recrystallization occured under dry, lower temperature conditions, with hornblende forming later as water entered the metagabbro.

Reasons for my preferance for the former interpretation are:

(a) The polygonization of the metagabbro is extremely well developed. In may experience such well developed texture are rarely achieved at amphibolite facies (it may be noted however that there are also well developed polygonal texture in some hornblende - plagioclase rocks in the amphibolite zone of the metagabbro).

(b) It is very unlikely that the gabbroic magma was completely dry or that the crystallized gabbro was completely dry (see e.g. Wager & Brown 1968). If hornblende was not present during recrystallization of the gabbro, it is most probable that recrystallization took place at a temperature above the stability limit of hornblende.

(c) In many places the gneissosity in the metagabbro is isoclinally folded without apparent development of an axial plane foliation. This suggests very plastic behaviour, probably requiring very high temperature in an almost anhydrous gabbroic rock. Much of the folding of the cummulate layering also suggests very plastic behaviour.

Some time after the high temperature recrystallization, minor hornblende formed in the metagabbro, by replacement of pyroxenes and by growth around opaque grains. Total or almost total pseudomorphous replacement pyroxene by hornblende also took place within a few centimetres of many joints in the metagabbro.

Later mylonitic deformation appears to have had little mineralogical effect on the metagabbro.

2. The amphibolite zone on the eastern margin of the metagabbro has an amphibolite facies mineralogy characterized by hornblende and plagioclase (An_{38} - An_{80}) and opaque minerals. Minor clinozoisite and sphene probably represent lower grade alteration. Most of the zone texturally resemble the medium grained non-layered metagabbro. One area near Oaivoščokka closely resemble the medium grained, layered metagabbro. A little of the coarse to very coarse metagabbro next to the amphibolite zone is also completely altered to amphibolite, but still preserves the coarse metagabbro texture. Some porphyritic textured rocks within the amphibolite zone were probably basic dykes.

The amphibolite zone was developed by deformation and alteration of part of the gabbro and dykes which intruded it. It is difficult to be sure whether the gabbro first recrystallized to metagabbro, then was altered to amphibolite, or whether amphibolite alteration and recrystallization occured at the same time. The latter is favoured because the hornblende occurs as single polygonal grains rather than the more irregular forms typical of alteration (such as the irregular partial replacements of pyroxene seen in the dykes/ sills in Ankerlia Metagreywacke).

3. The dykes within the coarse to very coarse metagabbro show partial recrystallization and contain various percentages of hornblende. Sample BS-68 contains about 20% hornblende and the hornblende forms polygonal grains in apparent equilibrium with clinopyroxene and plagioclase (An_{75}). It appears that hornblende was stable when recrystallization occured.

It was suggested above that the host metagabbro recrystallized at a temperature above the stability limit of hornblende. It follows from this that the dykes have intruded after the major recrystallization of the metagabbro. This may be why igneous textures are better preserved in the dykes than in the metagabbro.

Relationship between Metamorphism and Deformation of the Metagabbro

The metagabbro has been deformed and recrystallized. Recrystallization is not a necessary consequence of cooling of a gabbro, therefore another cause should be sought. Deformation of a rock involves the addition of mechanical energy and often produces recrystallization. Hence it seems reasonable to correlate the recrystallization of the metagabbro with folding and gneissosity formation. The temperatures suggested for recrystallization in the metagabbro are higher than the metamorphic temperatures of the enclosing sedimentary/volcanic sequence. This is best explained by recrystallization of the gabbro before it had cooled to the same temperature as the enclosing rocks.

In determining the metamorphic and deformation history of the metagabbro, many factors must be considered:

1. The relationship between recrystallization and formation of hornblende in the metagabbro, in the marginal amphibolite zone and in the dykes in the metagabbro.

2. The development of gneissosity in the metagabbro, more or less recumbent insoclinal folding of the gneissosity, without formation of axial plane schistosity.

3. Intense recumbent folding of the cumulate layering.

4. Disruption of folded cumulate layering by felsic vein like material resembling the felsic layers, in the layered part of the marginal amphibolite zone.

5. Boudinage of and formation of gneissosity in the dykes in the metagabbro and in the amphibolite zone.

6. The formation of potassic biotite - hornblende granitic rocks in and near the gneissic zone on the western margin of the metagabbro.

7. Formation of a biotite schistosity in the potassic granite rock.

8. The presence of potassium - poor hornblende granophyre in major planar joints within the metagabbro. The composition of the rocks suggests they represent final stage differentiates of the gabbro, or perhaps partial melts of the gabbro. They have crystallized in joints which postdate all folding of the metagabbro. Some are mylonitized.

9. The metagabbro and associated rocks show local mechanical deformation and very local mylonitization.

Two possible explanations of the observed features are presented in tables 14 and 15.

Table 14: Metamorphic and Deformation History of Vaddasgaisak Metagabbro - Most Favoured Interpretation

1. Intrusion of basaltic magma, some crystallizing as well layered cumulate gabbro, other sections crystallizing as non-layered and poorly layered gabbro. Contact metamorphism of Ankerlia Metagreywacke, some partial melting producing biotite - hornblende granitic magma, some of which intruded the margin of the gabbro.

2. Deformation of the gabbro: formation of a gneissosity, extensive recrystallization of most of the gabbro at high temperature, low to moderate pressure, recrystallization of the lower margin of the gabbro at lower temperature and with higher water content, producing amphibolite. Extensive folding of cumulate layering may have occured at this stage. May have been minor melting in the amphibolite zone, to produce felsic veins cutting folded layering.

3. Intrusion and crystallization of basic dykes in the metagabbro and in the amphibolite zone.

4. Deformation: folding of the gneissosity in the metagabbro, perhaps further recrystallization and minor hornblende alteration; incomplete recrystallization of the dykes, including boudinage and formation of a gneissosity in some dykes.

5. Large - scale joints formed in the metagabbro and pegmatitic hornblende granophyre crystallized in some joints. Water from crystallization of the granophyres produced strong hornblende alteration of the metagabbro next to the joints.

6. Lower temperature deformation produced local mylonitization in and adjacent to the metagabbro, and in the late stage granophyres.

Table 15: Metamorphic and Deformation History of Vaddasgaisak Metagabbro - Alternative Interpretation

1. Intrusion of basaltic magma, crystallization of gabbro. Contact metamorphism and partial melting of Ankerlia Metagreywacke.

2. Intrusion of basic dykes into the gabbro.

3. Deformation of the gabbro and dykes. Gneissosity developed very well in the gabbro, less well developed in dykes. Boudinage of dykes, folding of cumulate layering in gabbro, recrystallization of gabbro, but only partial recrystallization of dykes. Extensive formation of hornblende in amphibolite zone and in dykes, but less in metagabbro, as a result of differences in water content. Minor partial melting in amphibolite zone, producing felsic veins cutting folded layering.

4. Folding of gneissic layering in metagabbro, possibly resulting from continuation of the same deformation.

5. Large-scale joints in the metagabbro, pegmatitic hornblende granophyre etc as in table 14.

6. Low temperature mylonitic deformation.

RELATIONSHIPS BETWEEN THE METAGABBRO AND THE ENCLOSING ROCKS

The gneissic zone along the western margin of the Metagabbro appears to contain contact metamorphosed and partially melted Ankerlia Metagreywacke and some finely recrystallized metagabbro. Small amounts of potassic granitic rock within the adjacent Metagabbro are best explained as partial melts of the relatively potassic Ankerlia Metagreywacke. These features indicate that the Metagabbro developed more or less in site from an intruded magma.

Relatively intense folding within the gneissic zone may indicate some movement of the Metagabbro relative to the Ankerlia Metagreywacke, or may have resulted from competency contrasts during deformation of both rocks. The folding appears to have boudinaged some of the probably anatectic granitic segregations.

Apart from the apparent mixture of metagabbro and metasediment in the gneissic zone, no xenoliths of country rock were observed in the Metagabbro.

The contact between the amphibolite zone of the Metagabbro and the Loftani Greenstone, along the eastern and northern margins, is a zone of strong schistosity. There are no obvious contact metamorphic effects on the Loftani Greenstone. Both the Greenstone and the amphibolite become more schistose as the contact is approached, and become very similar in appearance. The contact appears to be a zone of relative movement, but it seems unlikely to be a major thrust, because the contact between Loftani Greenstone and Ankerlia Metagreywacke does not appear to be a thrust (west and south of the Metagabbro), and no thrust has been identified on a regional scale in this position (K. B. Zwaan, pers.comm. 1982).

Can the deformations of the Metagabbro be correlated with the deformations of the country rocks? This question cannot be answered with confidence without detailed structural analysis, which is not available. However some general similarities were noticed. In the Metagabbro most folds are relatively flat-lying with axial planes parallel to layering. In the metasediments, schistosity, folding and boudinage are mostly oriented parallel to bedding. In both the Metagabbro and metasediments there are some more open folds with axial planes non-parallel to layering.

CHEMISTRY

Whole rock analyses were made on 48 specimens from Vaddas, Rieppe and Moskodalen. Results are presented in appendix 3. The samples are from various parts of the Metagabbro, including the amphibolite zone and dykes within the Metagabbro, from both the upper and lower Loftani Greenstone, from the felsic intrusives, from the Ankerlia Metagreywacke and dykes/sills in the Metagreywacke. There are also 2 analyses of arkose from the Loddevagge Meta-Arkose and one analysis of Skardalen Quartzite.

The major elements and most trace elements were analysed at NGU using XRF methods. The rare earth elements were analysed at Sentralinstitutt for Industriell Forskning (SI in Oslo).

Sampling

Because of the very limited time for this project the sampling was carried out before the mapping was completed and many of the samples were not checked in thin section before analysis. A few samples show mylonitization (description, appendix 2). One group of samples (with VR-numbers) was selected from rock samples collected by Lindahl in the early 1970s. The VR-samples were of various sizes, but generally smaller than the other (BS) samples. The BS-samples were generally about 1½-2 kg in weight, with most weathered joints etc, trimmed off.

Diagrams

A number of chemical variation diagrams are presented. Some are standard discriminant diagrams designed to show whether the rocks are ocean floor, island arc etc. Others are simple plots of minor elements against SiO_2.

The object of the project was to determine whether the Vaddasgaisak Metagabbro is an ophiolite (or ophiolite fragment) or not. Therefore data from known ophiolites is presented for comparison. The diagrams show data from Coleman (1977): analyses of basalts, dykes, cumulate gabbros and felsites from known ophiolites. (Note: cumulate and non-cumulate ultramafic data is not included.)

The rocks of the Lyngen Peninsula are thought to be ophiolite (R. Boyd, pers.comm. 1982). Data from Lyngen gabbros, two amphibolites (thought to be metabasalt, R. Boyd, pers.comm. 1982), and some felsites are presented for comparison with Vaddas. The analyses are from Munday (1970) and Minsaas (1981).

The Seiland igneous province has a whole range of non-ophiolite gabbroic rocks, some of which are syn-tectonic. It is possible that the Vaddasgaisak Metagabbro was also a syn-tectonic, non-ophiolite gabbro. Therefore data from the tholeiitic Hasvik Gabbro is presented for comparison (Robins & Gardner 1974).

The diagrams are not all presented in an ideal manner, but time did not permit improvements. The Vaddas data is not presented on a volatile-free basis, therefore there are some minor problems in comparison with other data. Volatiles comprise less than 0,5% of most gabbro analyses and less than 2% of the greenstones and dykes. Volatile-free calculations would not change most of the other elements very much. SiO_2 would be most affected, with an increase of about 1% SiO_2 in the greenstones.

Miyashiro Diagrams

Diagrams showing FeO (totalt Fe)/MgO plotted against TiO_2, FeO (total Fe), and SiO_2 were used by Miyashiro (1975) to distinguish between basalts formed in various tectonic environments. The Vaddas data shows very definite abyssal tholeiite trends on FeO/MgO vs FeO and FeO/MgO vs TiO_2 diagrams. There is no obvious trend on the FeO/MgO vs SiO_2 diagram, although there is a spread from tholeiitic to calc-alkaline. One exeption is the "sediment" data. The "sediments" plotted are Ankerlia Metagreywacke, and they plot in the calc-alkaline or island arc fields. The mineralogy of these rocks indicates a more or less intermediate igneous composition similar to andesite. The possibility that they represent detritus derived from andesitic island arc volcanism should be further investigated (see also data in Armitage 1976).

The "ophiolite" data shows a spread from island arc (line M) to abyssal tholeiite (line A) on the FeO/MgO vs TiO_2 and FeO diagrams, and a spread from tholeiitic to calc-alkaline on FeO/MgO vs SiO_2. In the data used there appears to be a definite island arc component.

The Lyngen data show a trend parallel to the abyssal tholeiite line on FeO/MgO vs FeO, but more MgO rich. Most of the data is from gabbros, however, and the diagrams are designed for basalts. Nevertheless the Lyngen gabbros differ a little from Vaddas gabbro and from Coleman's ophiolite gabbros.

On the FeO/MgO vs TiO_2 diagram the Lyngen gabbros define a low TiO_2 trend similar to the calc-alkaline trend (line Am), which is also apparent in some of the ophiolite data. The amphibolites (metabasalts) from Lyngen in contrast contain more than 2,5% TiO_2 and do not plot on the diagram.

In summary, the Vaddas basic rocks resemble abyssal tholeiites (ocean floor basalts). The "ophiolites" spread from abyssal tholeiites to island arcs. The Lyngen gabbros follow low TiO_2, low FeO/MgO trends, not the same as Vaddas and not particularly good ophiolite trends. The Hasvik data show no clear trend.

$Na_2O + K_2O$ against SiO_2

The Vaddas basic rocks are clearly sub-alkaline, with gabbros, dykes and greenstones grouping very closely.

The ophiolite data spreads much more. The cumulate gabbros are lower in Na_2O and K_2O than the Vaddas gabbroic rocks. Many of the ophiolite dykes and greenstones are higher in Na_2O and K_2O than the Vaddas dykes and greenstones, and spread well into the alkaline field.

The Lyngen gabbros are sub-alkaline and closer to ophiolite gabbros. The amphibolites (meta-basalts) are alkaline.

The Hasvik gabbros are mostly sub-alkaline, but there is no clear trend.

AFM Diagrams

The Vaddas basic rocks group very tightly and define a linear trend from MgO rich to FeO rich. The trend is just within the tholeiitic field of Irvine and Baragar (1971), and is within the ophiolite field. The Vaddas felsite data cluster towards the Na_2O and K_2O corner, and are not continuous with the trend defined by the basic rocks.

The ophiolite data defines a wide, more or less continuous belt very close to Irvine and Baragar's line separting tholeiitic and calc-alkaline. There is a continuous line from cumulate gabbro to felsite. The cumulate gabbros are separate from the greenstones/dykes unlike the Vaddas data, and are less alkaline than the Vaddas gabbroic rocks.

The Lyñgen basic rocks define a more tholeiitic trend than most of the ophiolite data. The felsites are more magnesian than the ophiolite felsites. The Lyngen gabbros define a much greater spread of FeO and MgO than the Vaddas data.

The Hasvik gabbros define a broad tholeiitic trend, more alkaline than Lyngen, but similar to ophiolites.

Ti - Y - Zr Diagram

Only the Vaddas data has Y values. The Vaddas data is located mostly in field B of Pearce & Cann (1973), but there is overlap into fields A and C. The diagram indicates that the rocks are not within-plate basalts, are mostly likely ocean floor basalts, but could also be islands arc tholeiites or calc-alkaline.

The gabbros show only a little difference from dykes and greenstones.

Ti - Zr Diagram

Almost all the Vaddas greenstone and dyke data plot in the ocean floor basalt field of Pearce & Cann (1973). The gabbros follow the same trend, but with generally lower Ti & Zr.

The Lyngen gabbros are similar to some Vaddas gabbro data. This part of the diagram is for low-K tholeiites, but the fields are designed for basalts, not gabbros.

Minor Element Data-Vaddas

Minor element data from Vaddas is plotted against SiO_2 on several diagrams. Also plotted is Coleman's (1977) average value for ophiolite gabbros (point G) and ophiolite dykes and pillow lavas (point B). It should be noted that the Vaddas data is not volatile-free, and would shift by up to 1% more SiO_2 if recalculated on a volatile-free basis. This does not significantly affect the conclusions.

In comparison with the ophiolite average values,

1. the Vaddas rocks are very low in Ni and Co,

2. the Vaddas greenstones/dykes are low in V,

3. the Vaddas Cr and Sr values are approximately normal for ophiolites,

4. the Vaddas Ba is a little high, with a few very high values,

5. the Vaddas Cu is higher than average for ophiolites,

6. the Zr values range from average ophiolite, to four times as high as ophiolites. The gabbros are closer to average ophiolite than the greenstones/dykes.

It is noticeable that on most of the diagrams the Vaddas data define a single group or a single trend, as in the discriminant diagrams.

Minor Element Data - Lyngen

Much of the Lyngen data is similar to that from Vaddas, although the Lyngen data is less homogeneous than Vaddas. Lyngen shows similar deviations from Coleman's average ophiolite values, as Vaddas: - low to very low Ni and Co, slightly low Cr, high Ba & Cu, and some high Zr values (only the amphibolites, ie metabasalts).

Summary of Chemical Data

1. FeO/MgO vs FeO, and FeO/MgO vs TiO_2 diagrams indicate that the Vaddas basic rocks have ocean floor basalts chemistry.

2. The Na_2O + K_2O vs SiO_2 diagram indicates the Vaddas basic rocks are sub-alkaline.

3. On the AFM diagram the Vaddas basic rocks are tholeiitic.

4. On the Ti - Y - Zr diagram the Vaddas rocks plot mostly in the ocean floor field.

5. The Vaddas greenstones and dykes plot in the ocean floor field on the Ti vs Zr diagram.

6. The ophiolite data do not show such clear oceanic basalt trends, but show some island arc and calc-alkaline trends in addition to oceanic basalt trends.

7. The Lyngen data plot differently from Vaddas on the discrimination diagrams, and show different trends from much of the ophiolite data.

8. The Vaddas data cluster much more closely than the ophiolite, Lyngen or Hasvik data. At Vaddas there is little difference between gabbros, dykes and greenstones, although the most basic end of the group tends to be gabbro. The ophiolite data shows a clear difference between gabbro and basaltic rocks on some diagrams. The Lyngen gabbro is clearly different from the Lyngen amphibolites.

9. In minor elements, Vaddas and Lyngen are both lower in Ni & Co than average ophiolites. The V values in Vaddas greenstones/dykes are low, and Cr is slightly low in

Lyngen and perhaps Vaddas. Sr is similar in Vaddas, Lyngen and ophiolites. Ba and Cu are high in Vaddas and Lyngen. Some Vaddas rocks and the Lyngen amphibolites are high to very high in Zr compared with average ophiolites.

Conclusions from Chemical Data

The discriminant diagrams show that the Vaddas rocks have the chemistry of ocean floor tholeiites. The Vaddas basic rocks occupy part of a larger field shown by ophiolites, on diagrams involving FeO, MgO, TiO_2, SiO_2, Na_2O, K_2O, and could be ophiolitic.

However, there are some differences between the Vaddas rocks and Coleman's (1977) selected ophiolite analyses. The lower Ni, Co and V, and higher Ba and Zr at Vaddas may indicate a more highly differentiated (olivine depleted) magma than is normal for ophiolites, or perhaps a deeper source of the basaltic magma. However these minor element values are the same as those in the Lyngen gabbro, which is considered to be an ophiolite.

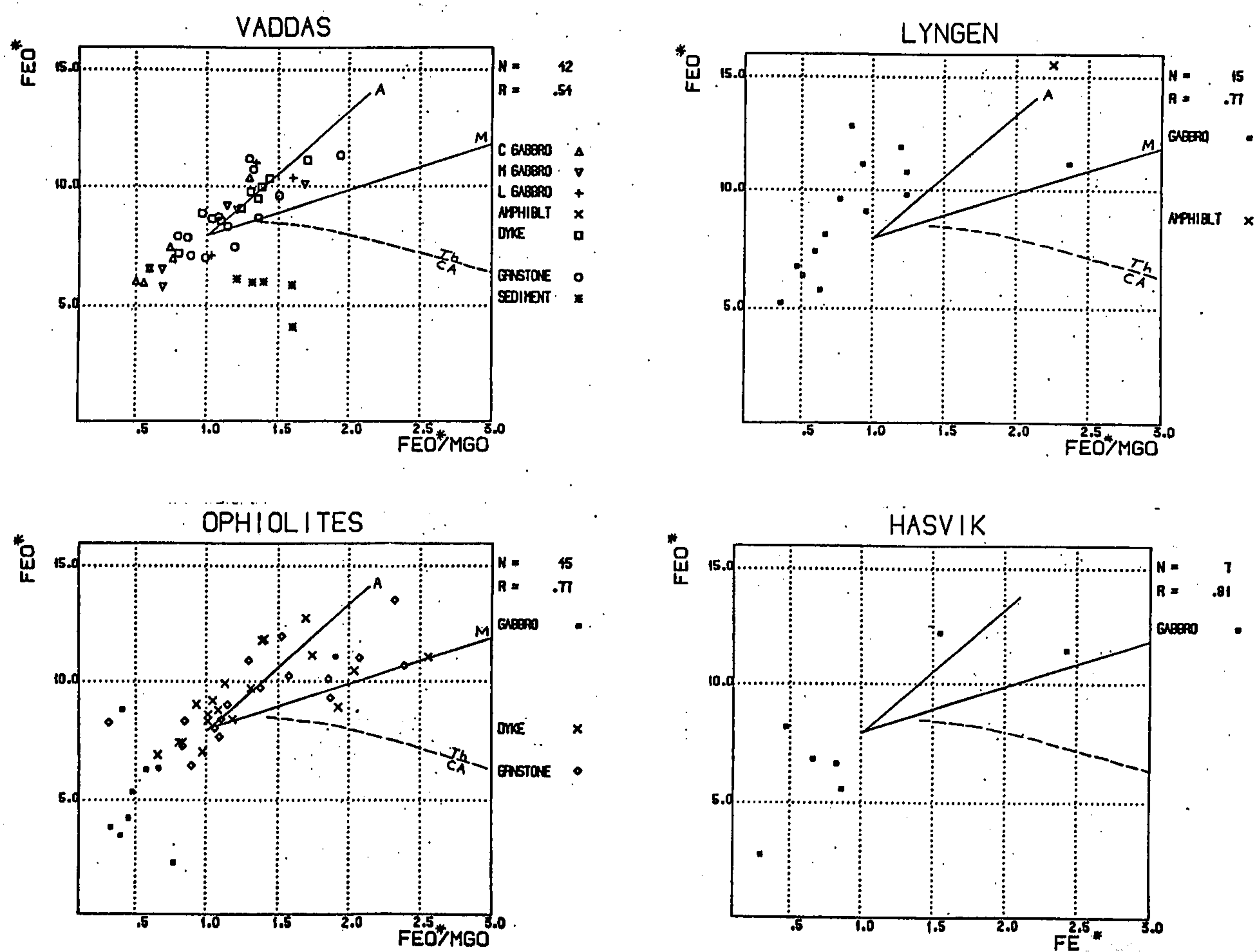
The Vaddas data tend to group much more tightly than the ophiolite data, with less difference between gabbro and basaltic dyke/greenstone. In the ophiolite system there appears to be either separate magmas forming the gabbros and basalts, or a well-developed and systematic fractionation system leading to distinct differences between gabbro and basalt.

At Vaddas the gabbro, amphibolite, dykes and greenstone have formed from one type of magma. The magma may have been fractionated before any of the Vaddas rocks crystallized. Further fractionation probably occured during crystallization, leading to progressive increase in such components as FeO/MgO, TiO_2 and Zr, both within the gabbro and within the basaltic rocks. However, there is considerable overlap in composition of gabbro and basalt.

Despite the later age of the dykes, they are chemically indistinguishable from the greenstones.

The gabbros, dykes and greenstones either formed from the same magma (implying the gabbro and dykes were not formed later than the greenstone), or from exactly the same type of magma. The gabbros and dykes were undoubtedly formed in the same tectonic conditions as the greenstones.

The Ankerlia Metagreywacke shows some island arc characteristics and should be further investigated.



VADDAS
FEO*
FEO*/MGO
N = 42
R = .54
C GABBRO
M GABBRO
L GABBRO
AMPHIBLT
DYKE
GRNSTONE
SEDIMENT
A
M
Th
CA
LYNGEN
FEO*
FEO*/MGO
N = 15
R = .77
GABBRO
AMPHIBLT
OPHIOLITES
FEO*
FEO*/MGO
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DYKE
GRNSTONE
HASVIK
FEO*
FE*
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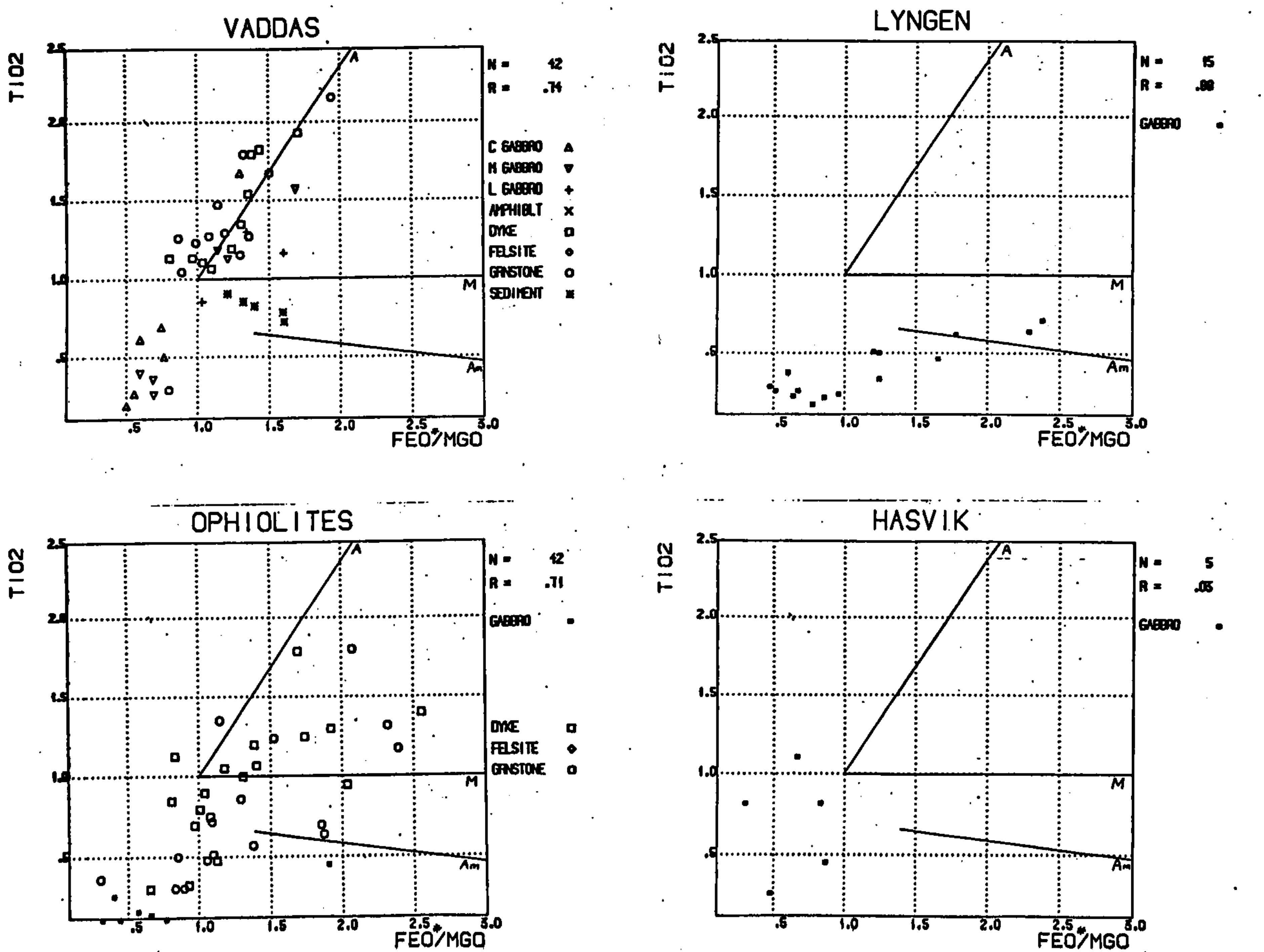
R = .81
GABBRO



VADDAS
TIO2
FEO*/MGO
N = 42
R = .74
C GABBRO
M GABBRO
L GABBRO
AMPHIBLT
DYKE
FELSITE
GRNSTONE
SEDIMENT
A
M
Am
LYNGEN
TIO2
FEO*/MGO
N = 15
R = .88
GABBRO
A
M
Am
OPHIOLITES
TIO2
FEO*/MGO
N = 42
R = .71
GABBRO
DYKE
FELSITE
GRNSTONE
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M
Am
HASVIK
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FEO*/MGO
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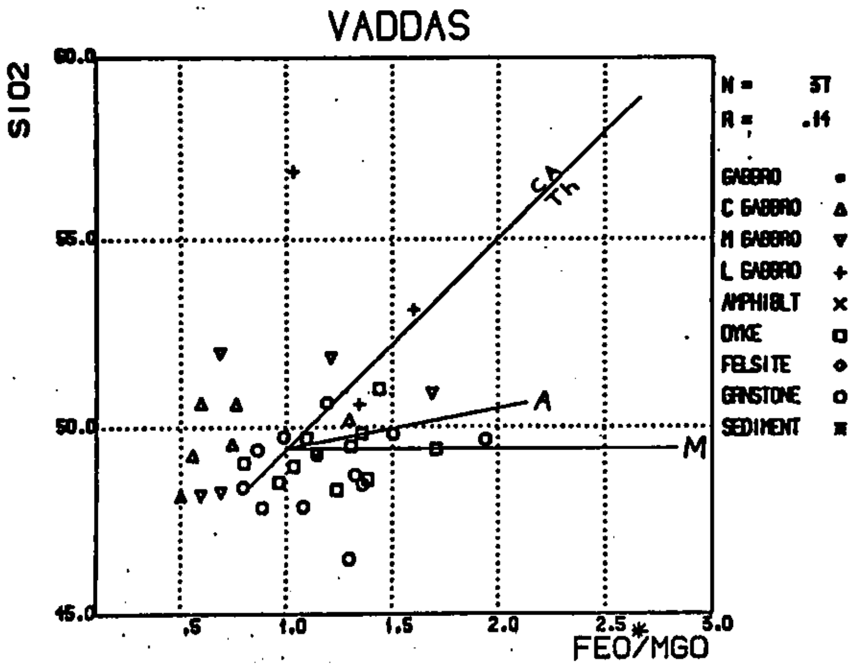
R = .05
GABBRO
A
M
Am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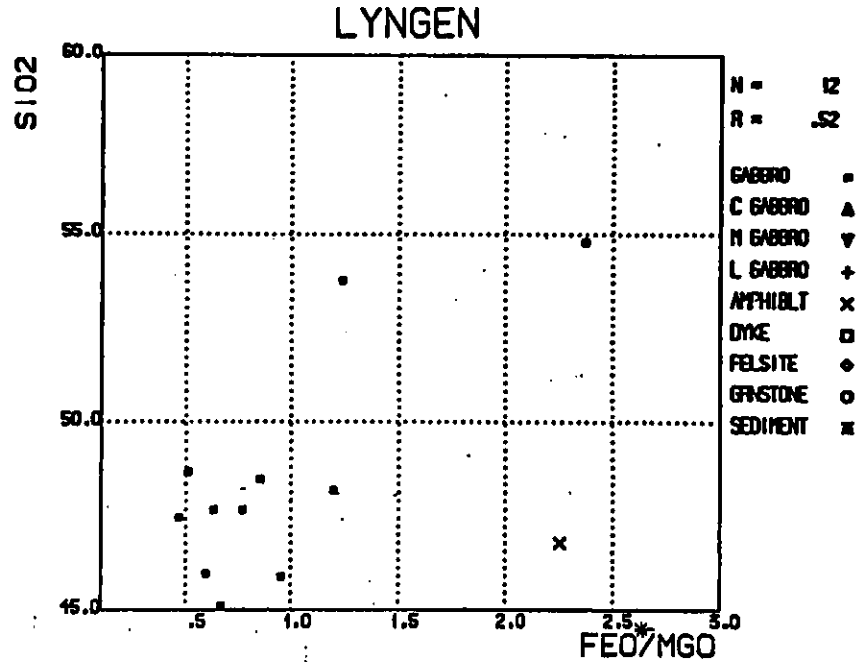
R = .14
GABBRO
C GABBRO
M GABBRO
L GABBRO
AMPHIBLT
DYKE
FELSITE
GRNSTONE
SEDIMENT
CA
Th
A
M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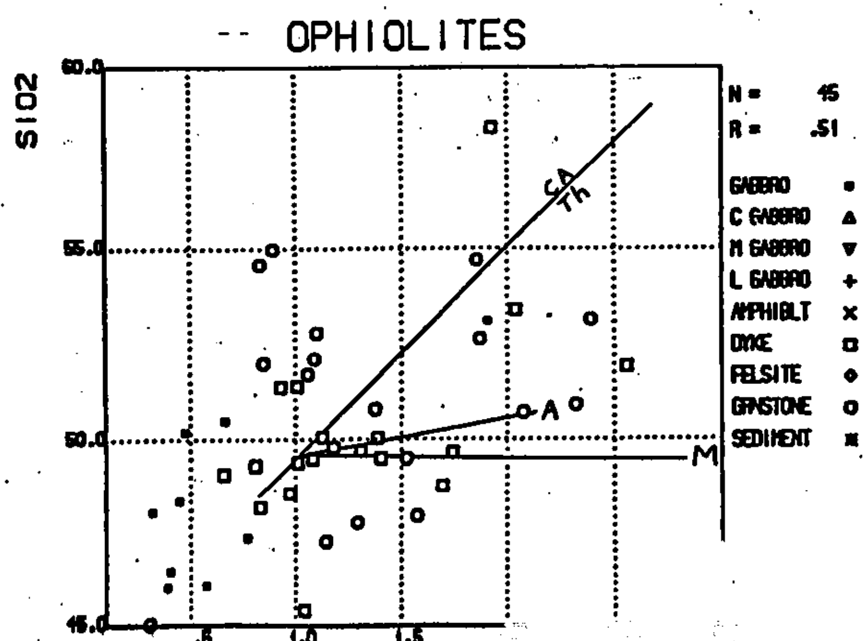
SIO2
FEO/MGO
N = 12
R = .52
GABBRO
C GABBRO
M GABBRO
L GABBRO
AMPHIBLT
DYKE
FELSITE
GRNSTONE
SEDIMENT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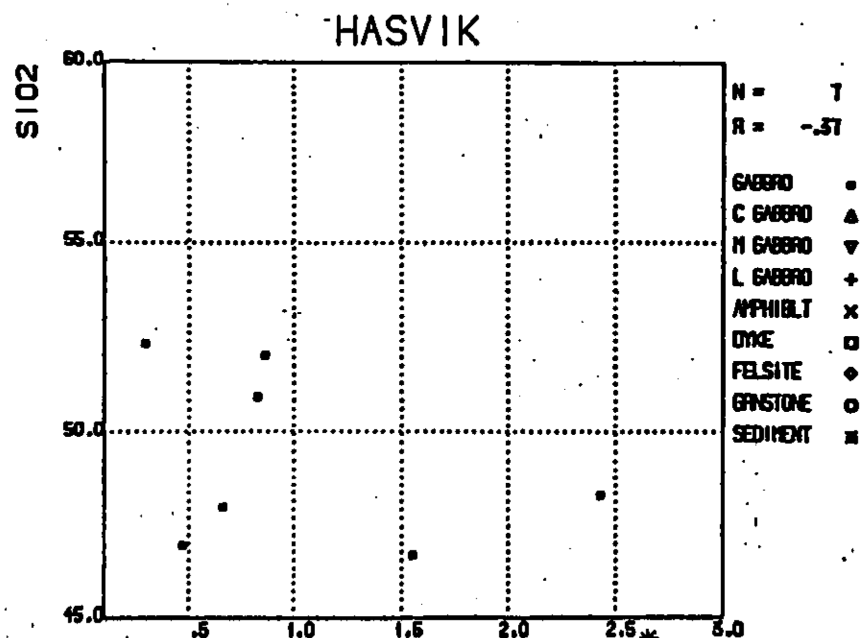
L GABBRO
AMPHIBLT
DYKE
FELSITE
GRNSTONE
SEDIMENT
CA
Th
A
M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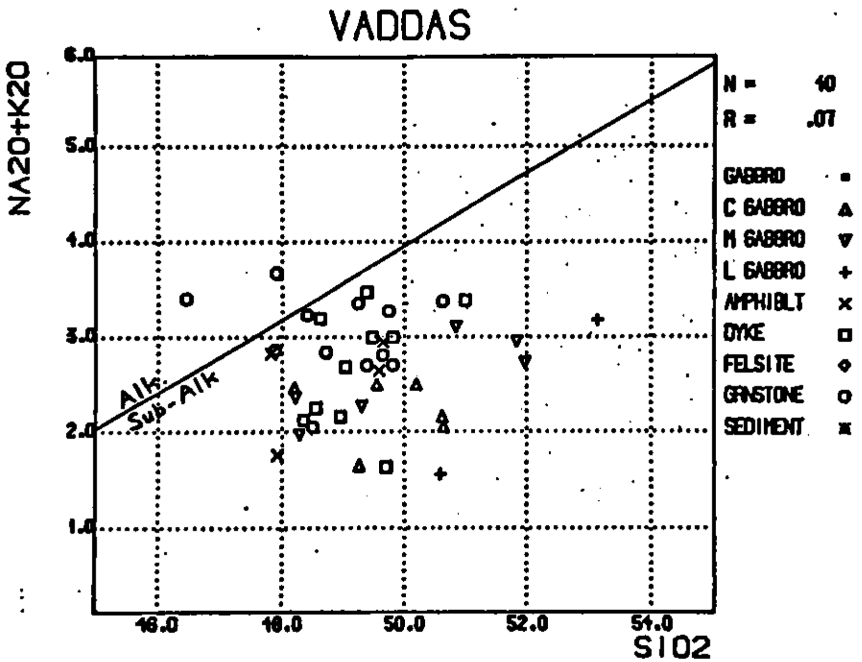
GRNSTONE
SEDIMENT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SIO2
Alk
Sub-Alk
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AMPHIBLT
DYKE
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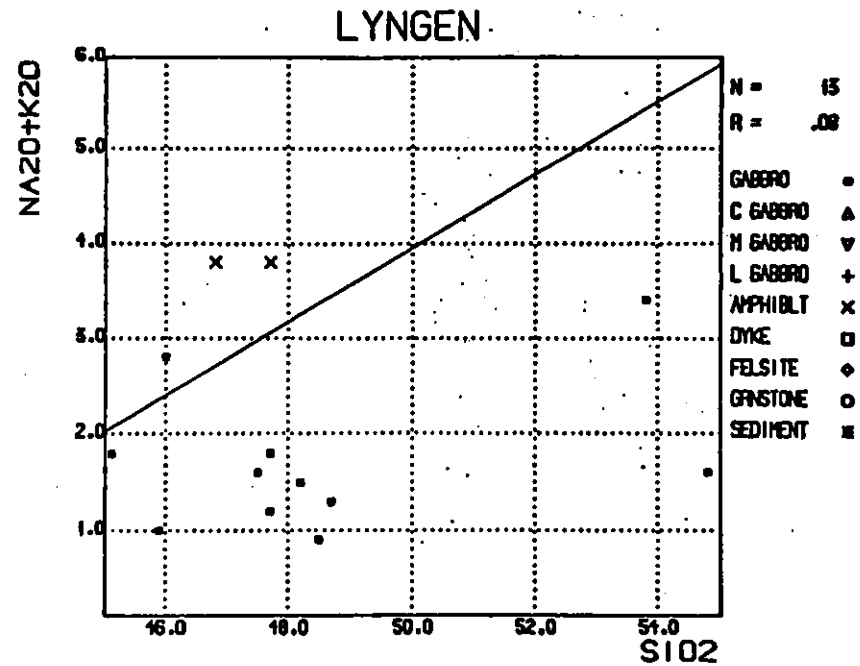
GRNSTONE
SEDIMENT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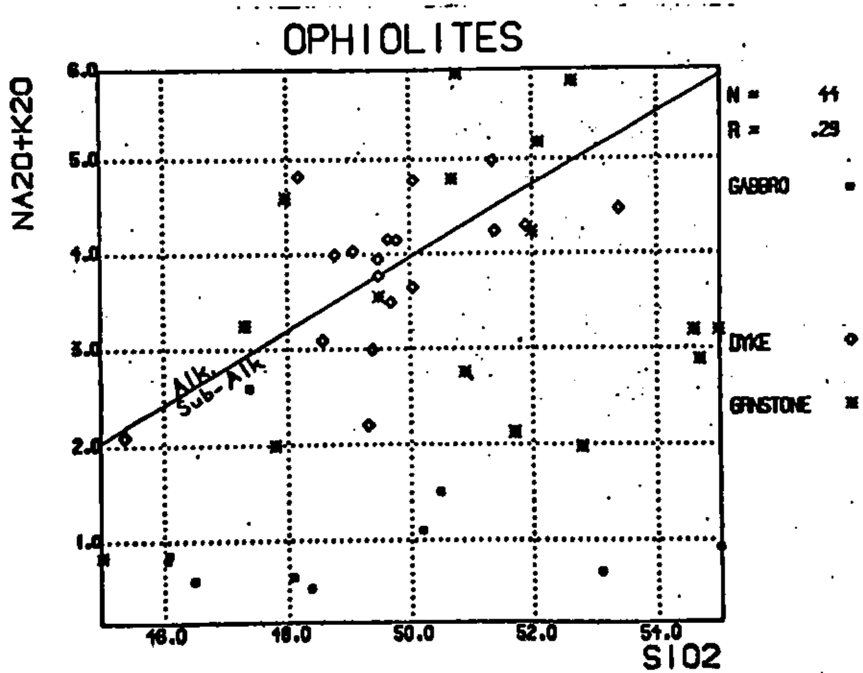
DYKE
FELSITE
GRNSTONE
SEDIMENT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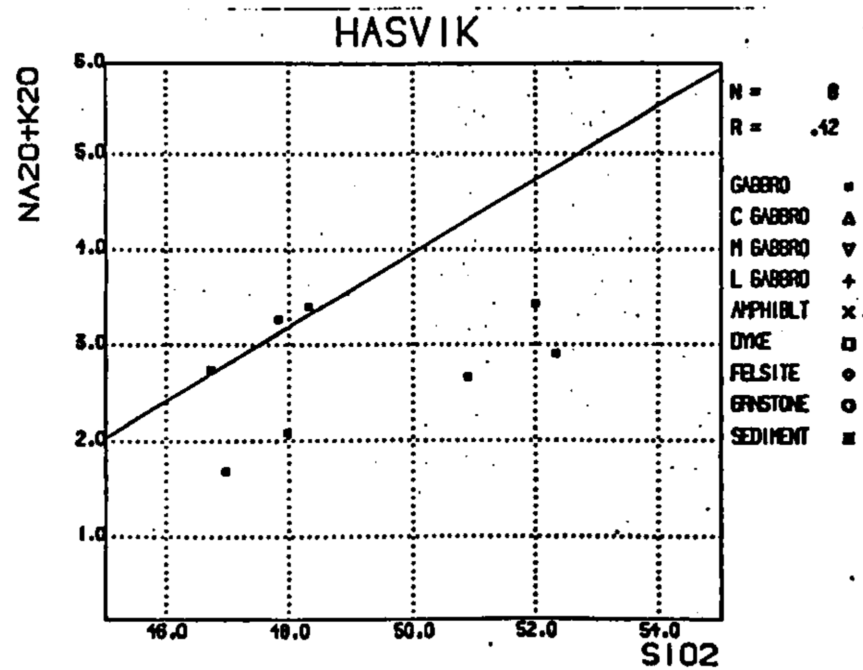
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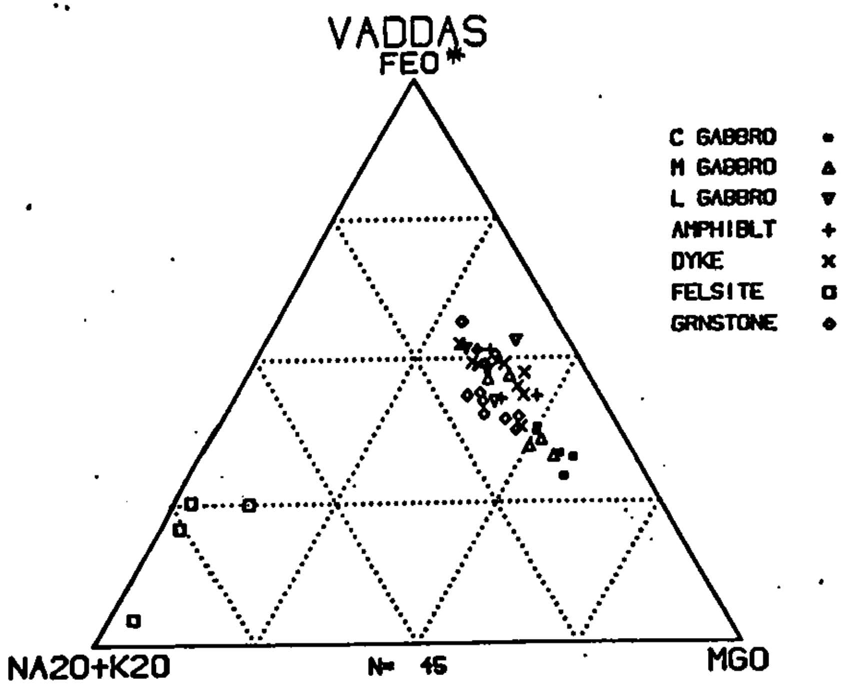
SEDIMENT


VADDAS
FEO*
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L GABBRO
AMPHIBLT
DYKE
FELSITE
GRNSTONE
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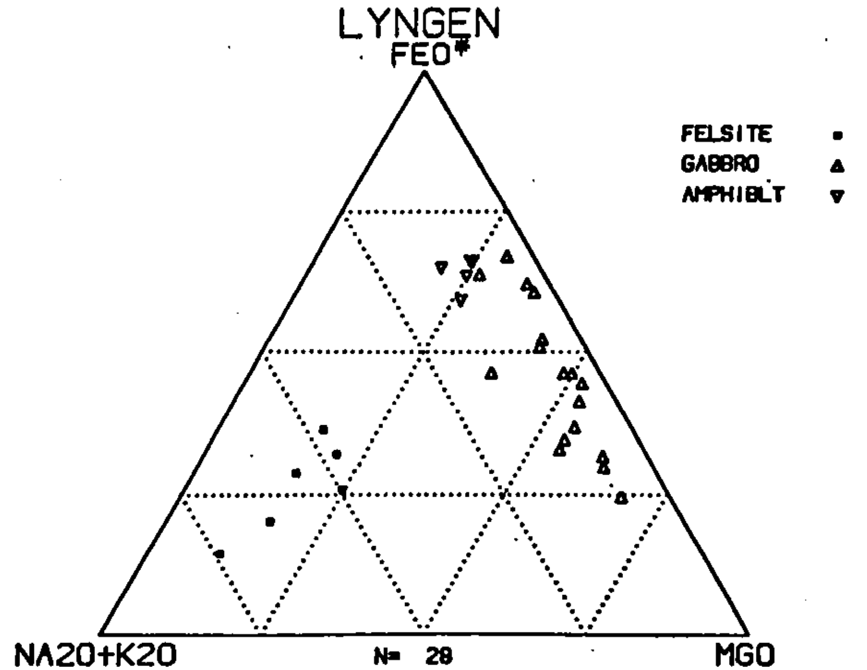
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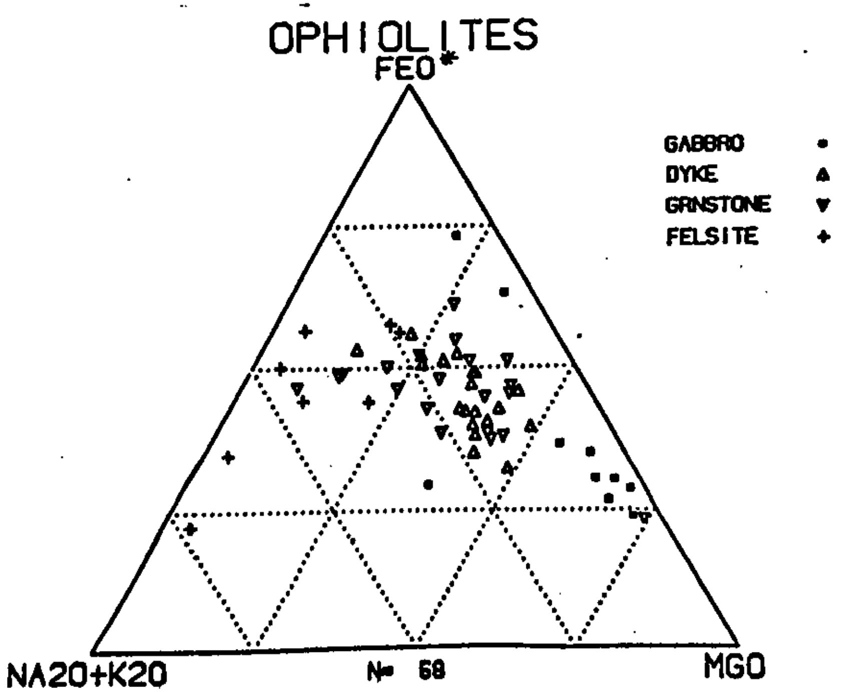
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GABBRO
DYKE
GRNSTONE
FELSITE
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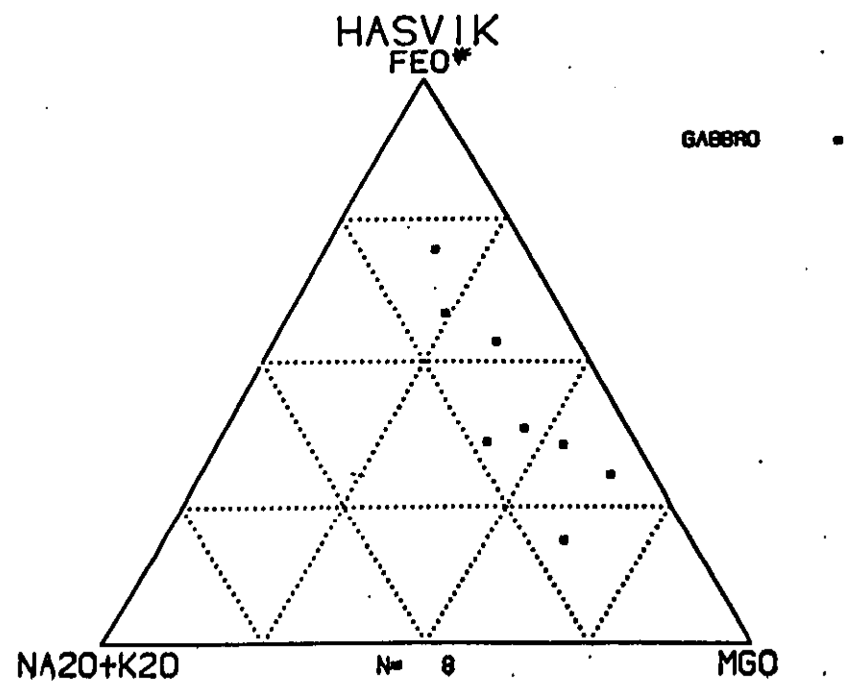
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FEO*
GABBRO
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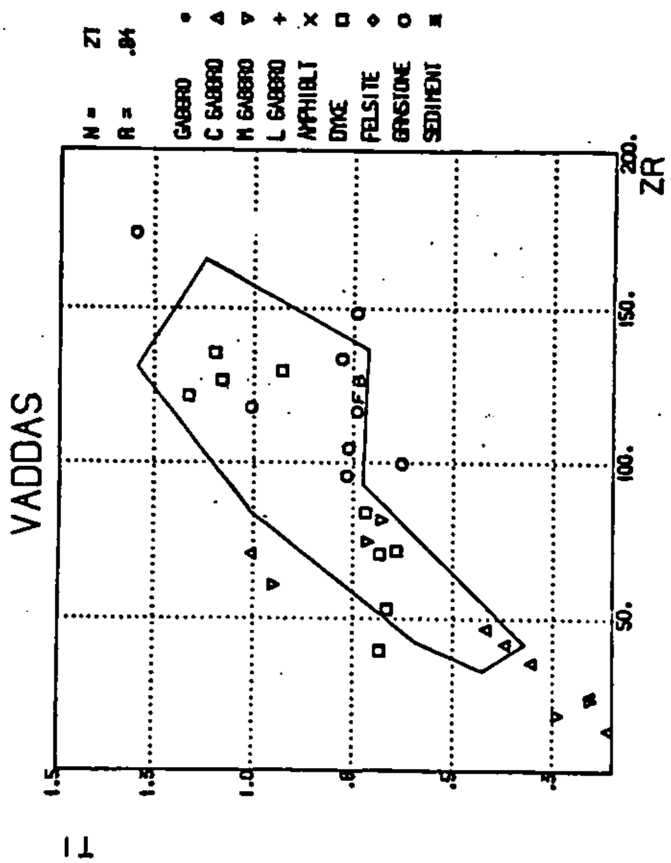
MGO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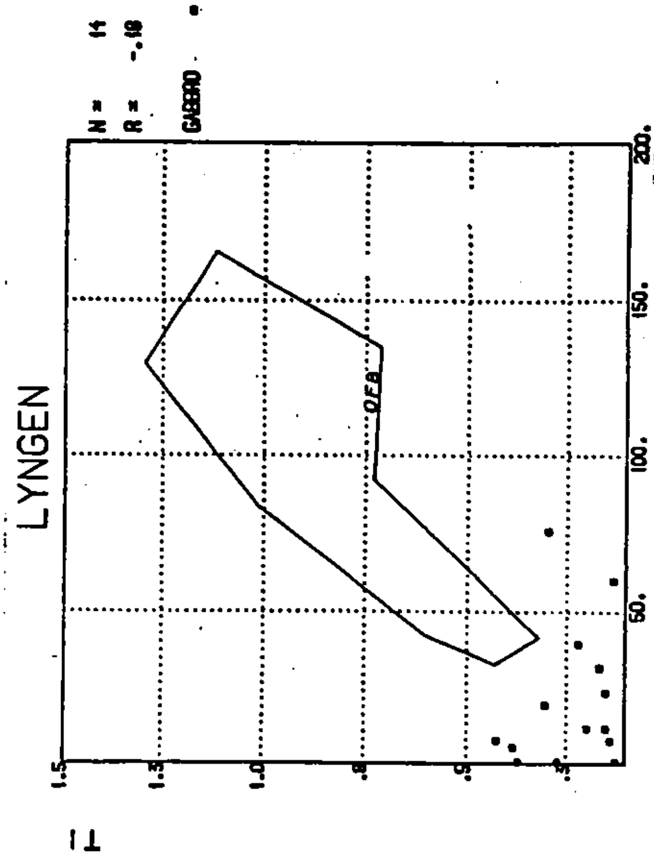
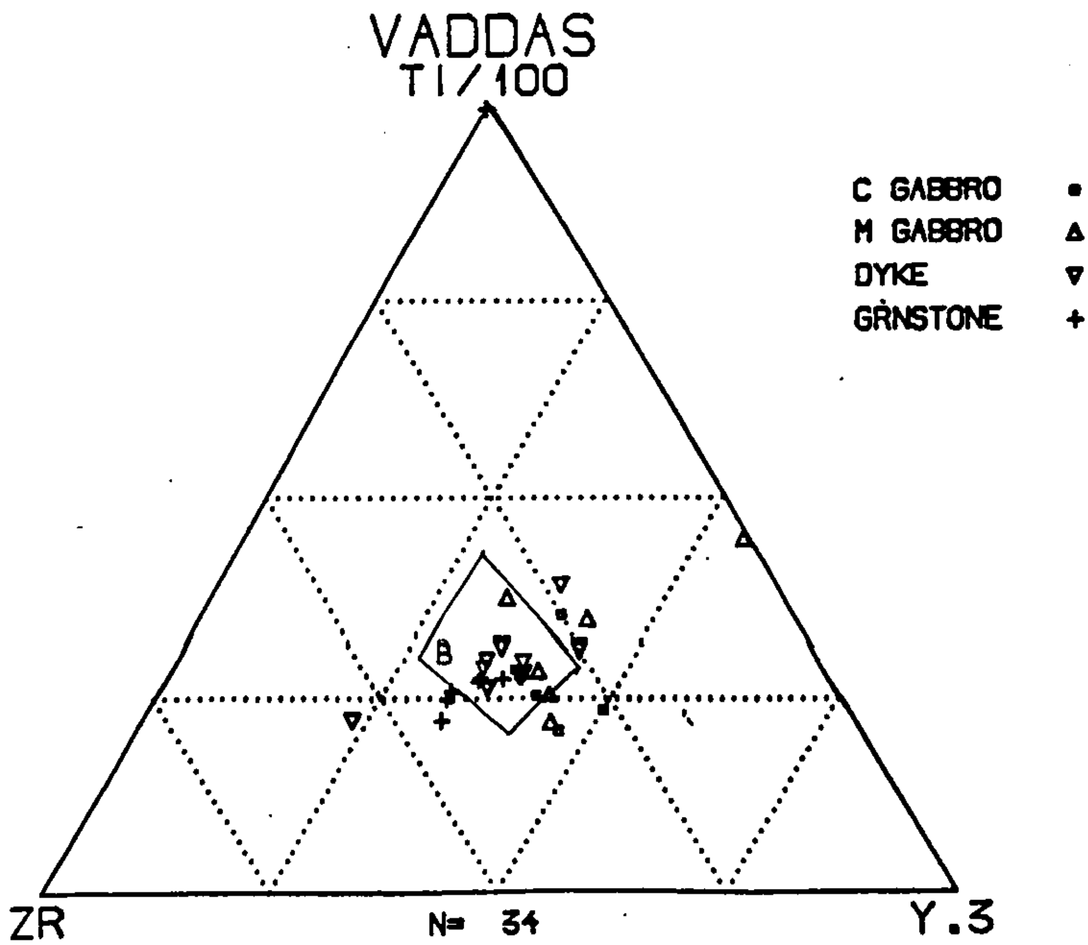
ZR
TI
OFB
GABBRO
C GABBRO
M GABBRO
L GABBRO
AMPHIBLT
DYKE
FELSITE
GRNSTONE
SEDIMENT


LYNGEN
TI
OFB
GABBRO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DYKE
GRNSTONE
B
ZR
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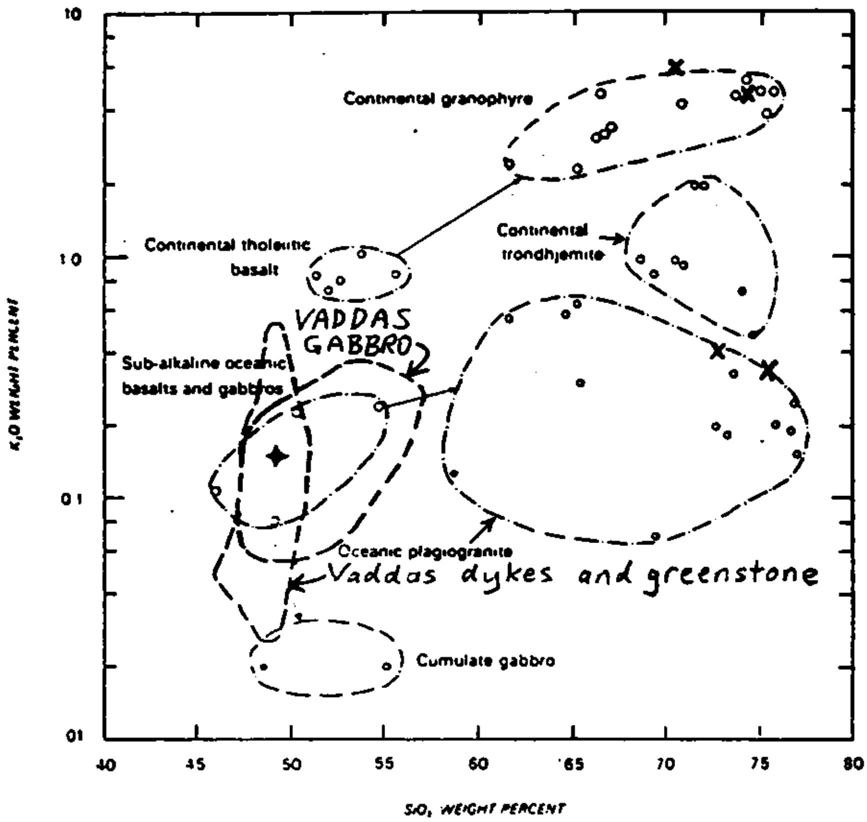
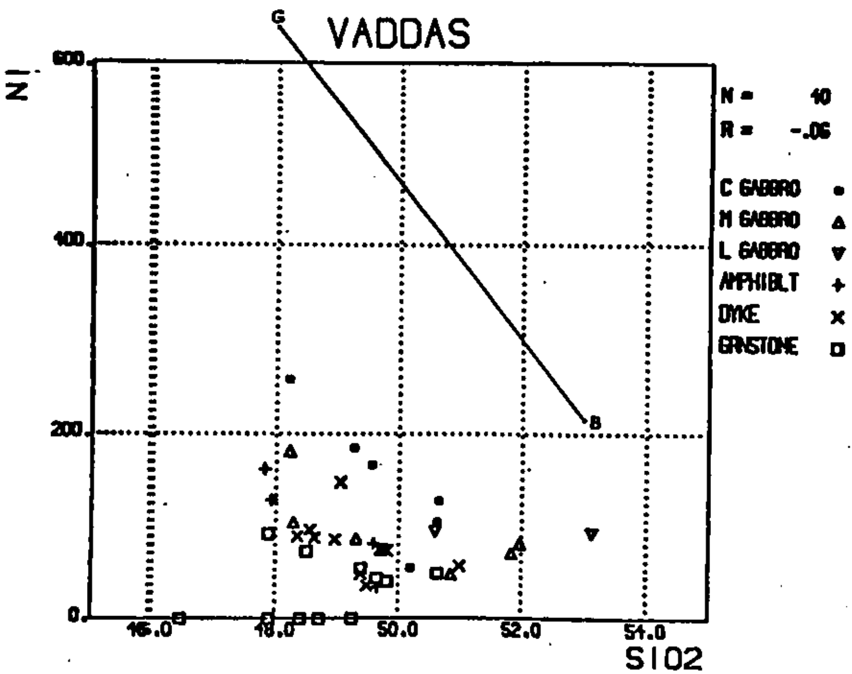


Semilog plot of SiO_2 versus K_2O illustrating the difference in K_2O in oceanic plagiogranites as compared with equivalent rock types

X – plots from Vaddasgaisak and Moskodalen felsites

Diagram from Coleman (1977), p53.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M GABBRO
L GABBRO
AMPHIBLT
DYKE
GRNSTONE
G
B
600
400
200
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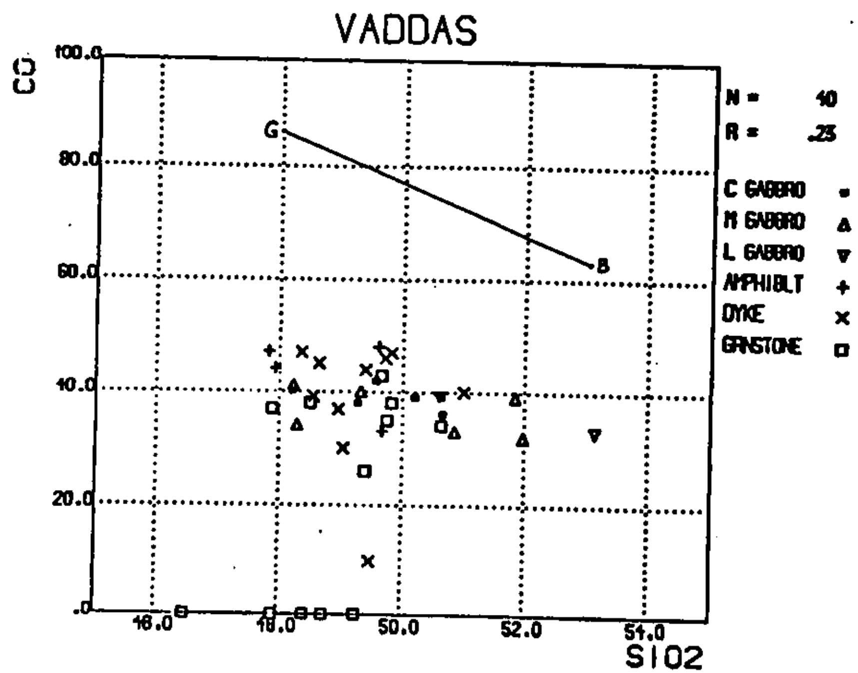
52.0
54.0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CO
SIO2
N = 40
R = .23
C GABBRO
M GABBRO
L GABBRO
AMPHIBLT
DYKE
GRNSTONE
G
B
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80.0
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20.0
.0
46.0
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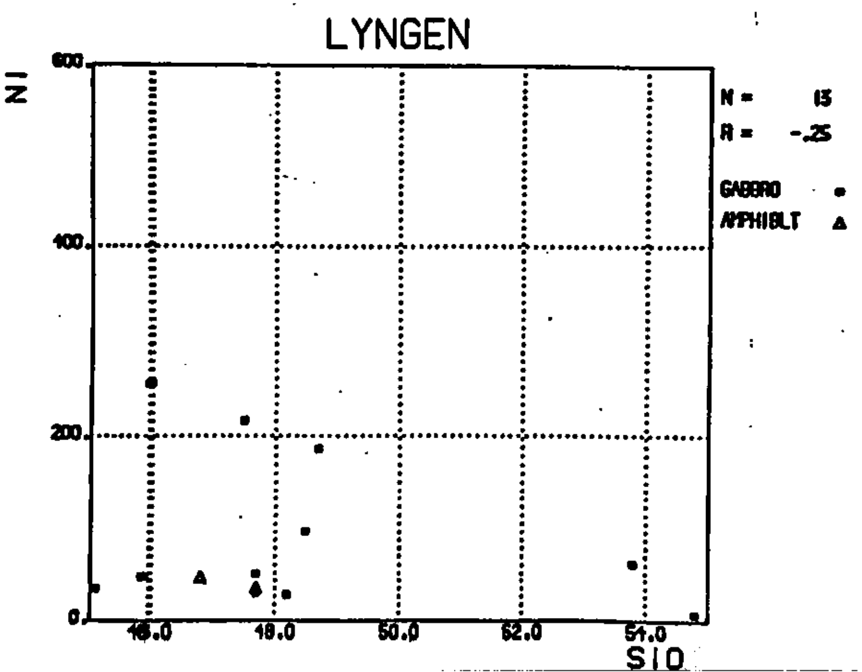
50.0
52.0
54.0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SIO
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400
200
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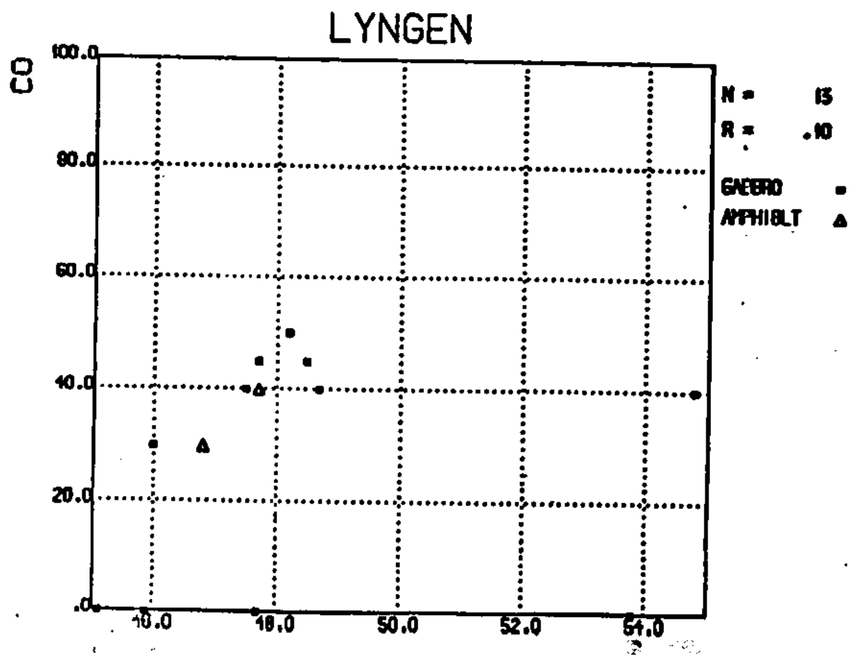
52.0
54.0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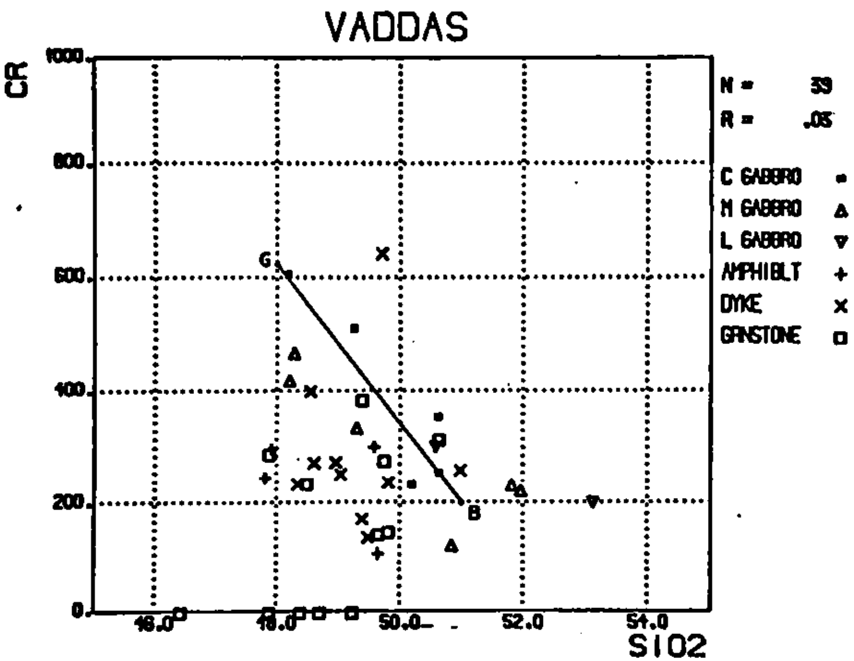
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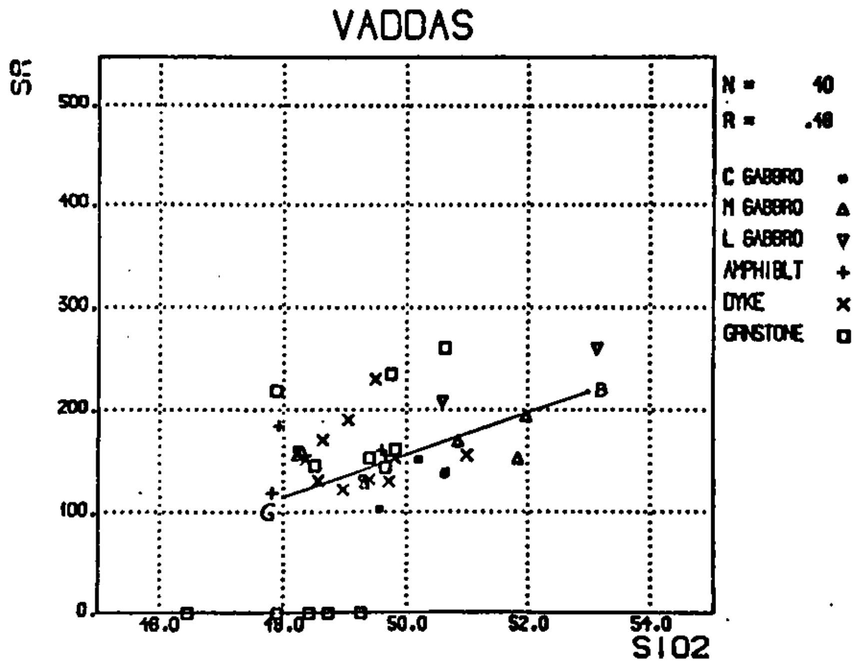
AMPHIBLT
DYKE
GRNSTONE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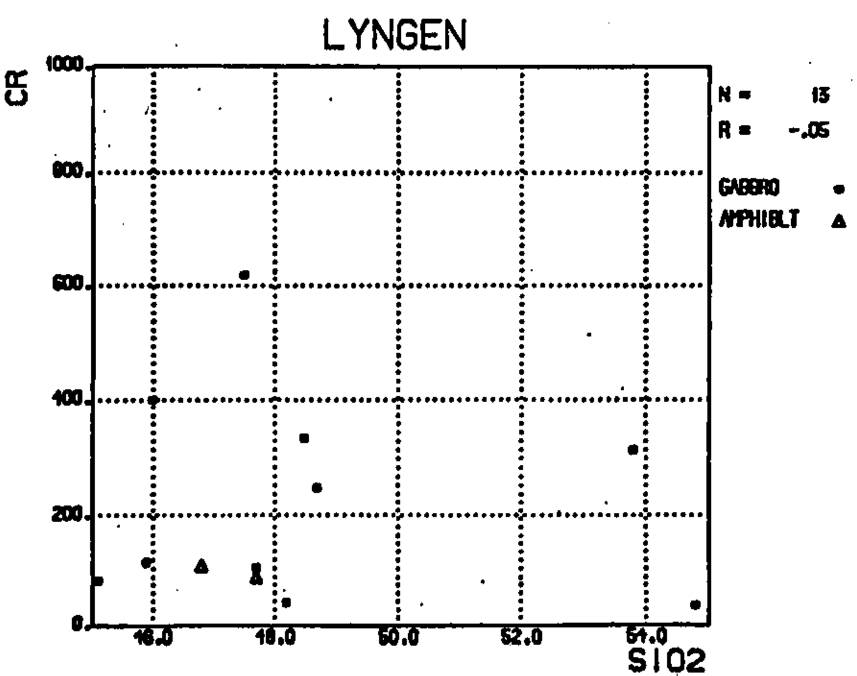
AMPHIBLT
DYKE
GRNSTONE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CR
SIO2
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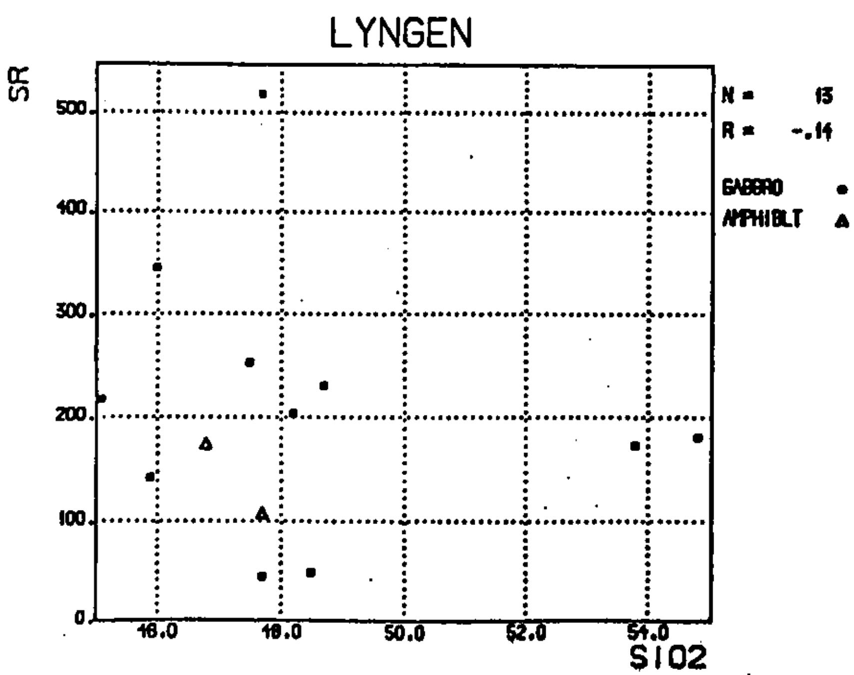
GABBRO
AMPHIBLT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SIO2
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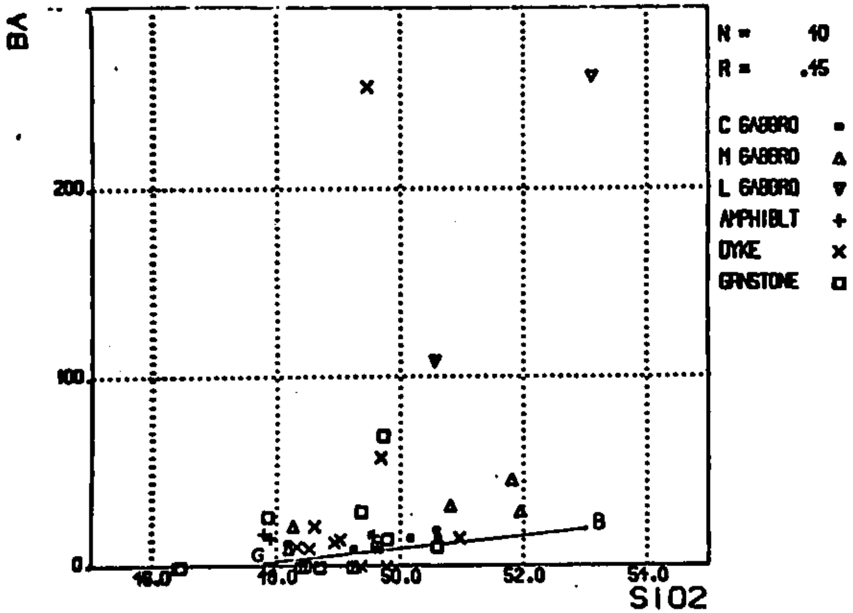
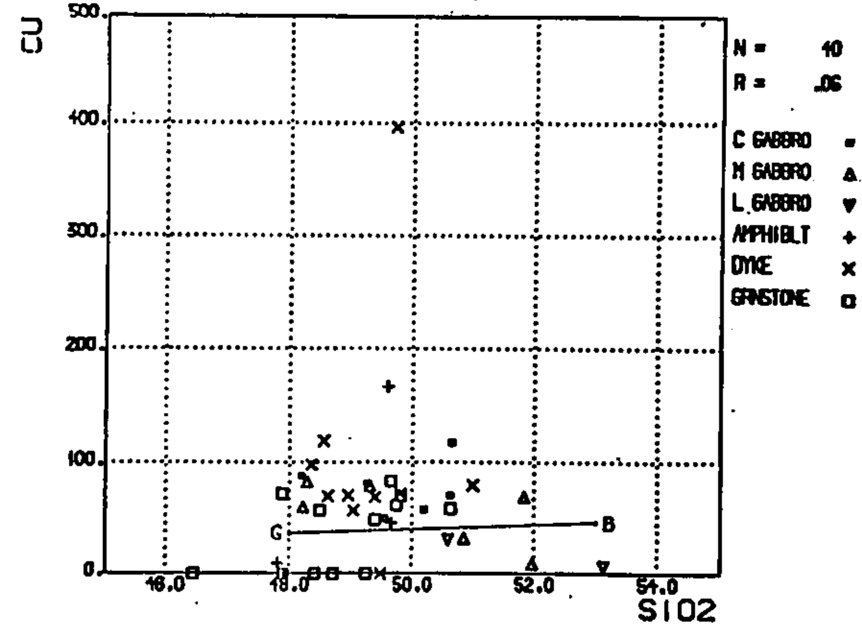
GABBRO
AMPHIBLT



VADDAS



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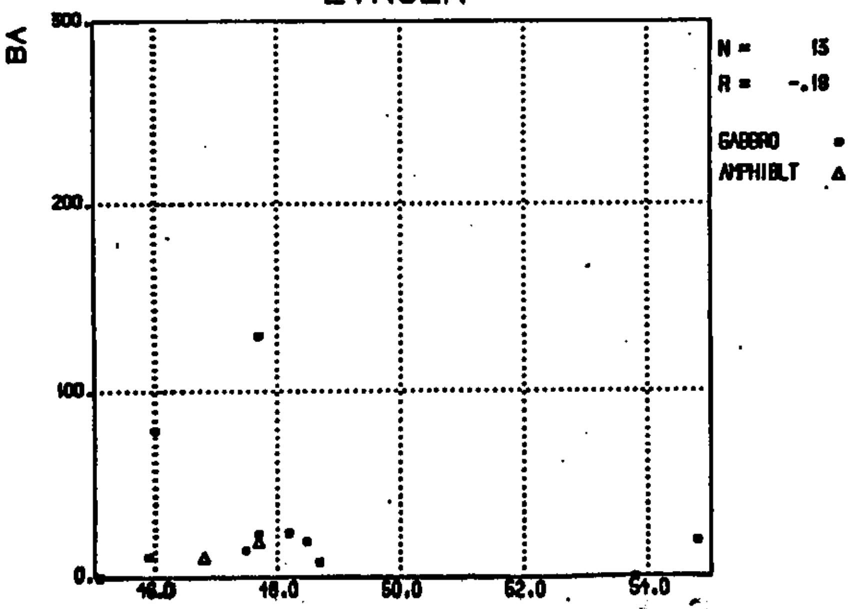

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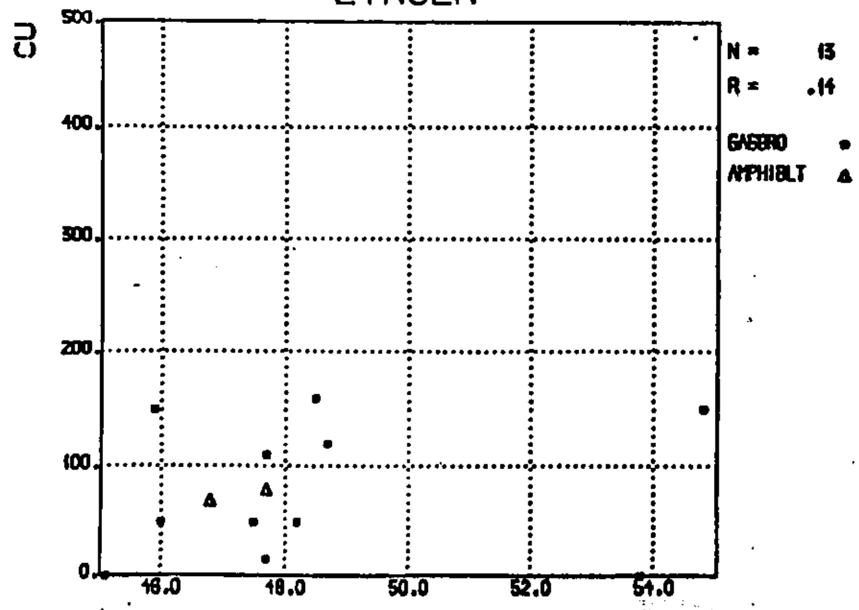
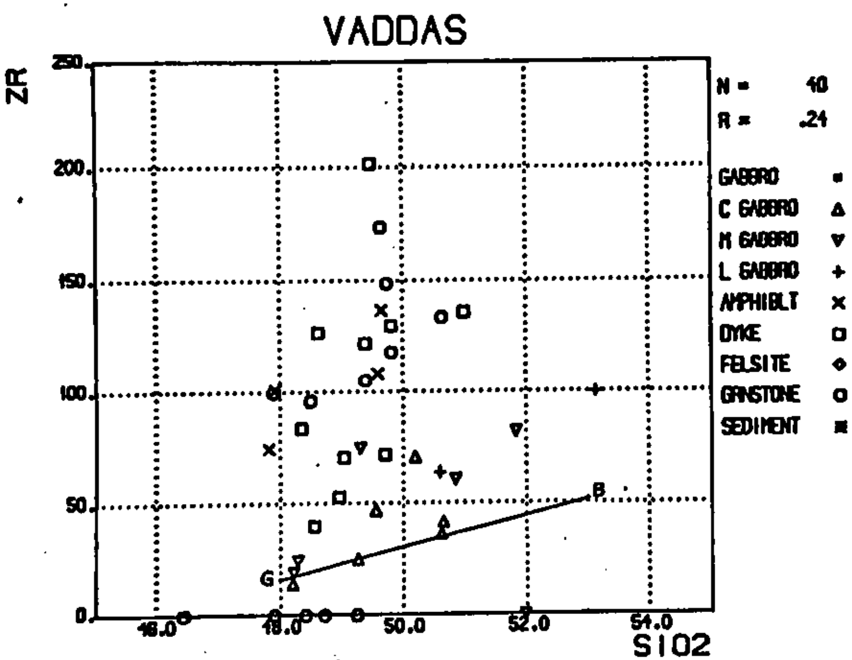
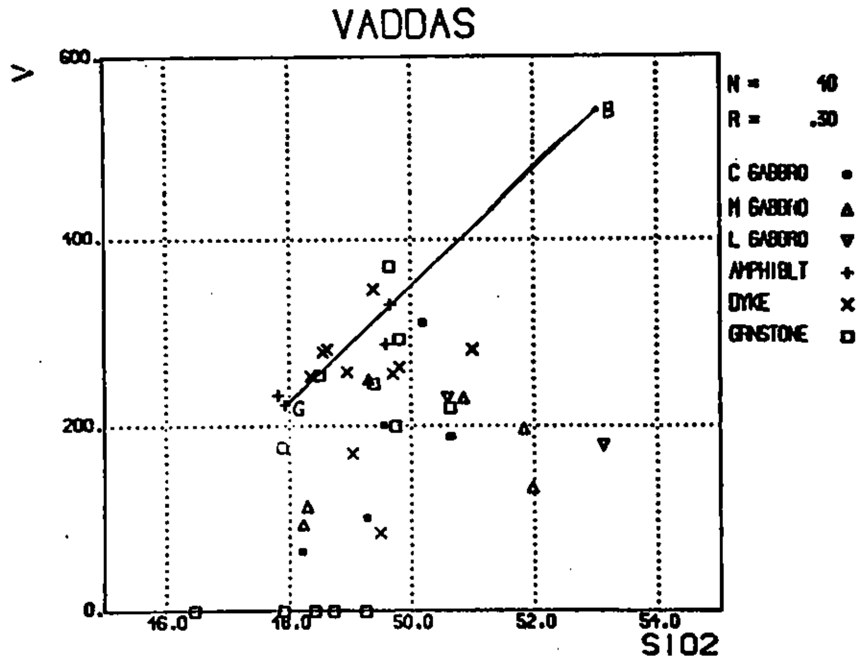



VADDAS
ZR
250.
200.
150.
100.
50.
0.
46.0
48.0
50.0
52.0
54.0
SIO2
N = 40
R = .24
GABBRO
C GABBRO
M GABBRO
L GABBRO
AMPHIBLT
DYKE
FELSITE
GRNSTONE
SEDIMENT
G
B


VADDAS
V
600.
400.
200.
0.
46.0
48.0
50.0
52.0
54.0
SIO2
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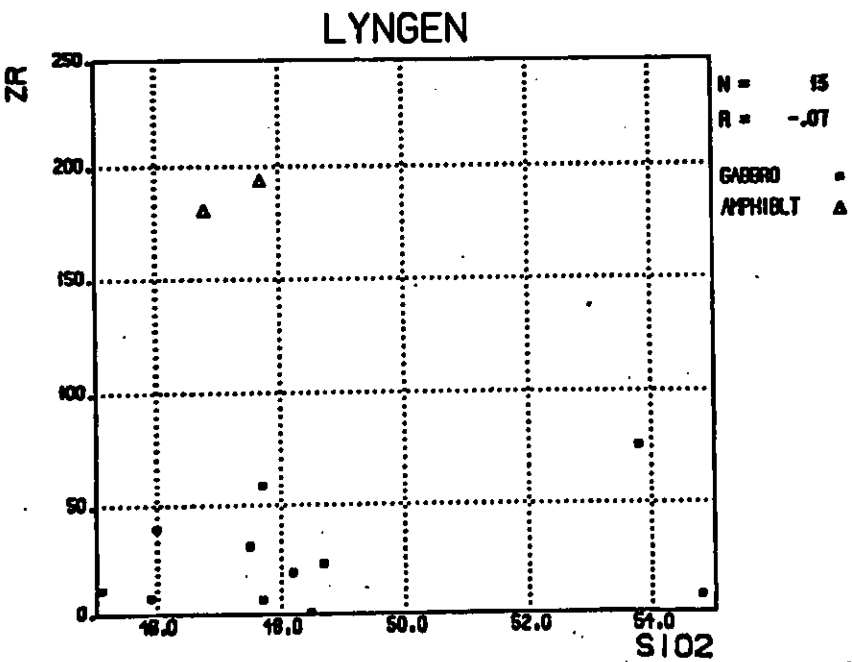
R = .30
C GABBRO
M GABBRO
L GABBRO
AMPHIBLT
DYKE
GRNSTONE
G
B


LYNGEN
ZR
250.
200.
150.
100.
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0.
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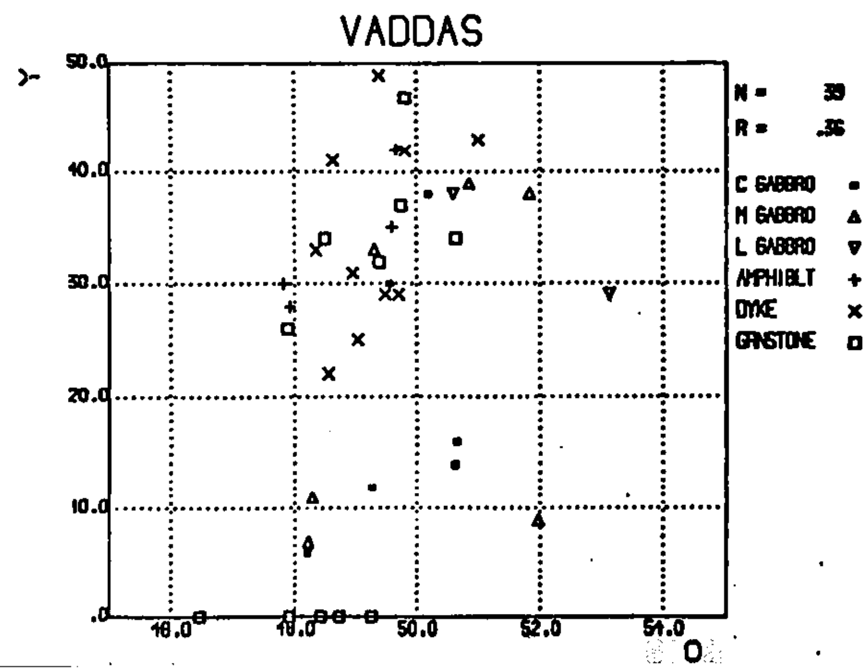
48.0
50.0
52.0
54.0
SIO2
N = 15
R = -.07
GABBRO
AMPHIBLT


VADDAS
Y
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20.0
10.0
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46.0
48.0
50.0
52.0
54.0
N = 39
R = .36
C GABBRO
M GABBRO
L GABBRO
AMPHIBLT
DYKE
GRNSTONE

EVIDENCE FOR AND AGAINST AN OPHIOLITE ENVIRONMENT

According to the most generally accepted definition (from GSA Penrose Conference, reported in Coleman 1977), an ophiolite is a distinctive assemblage of mafic to ultramafic rocks. In a completely developed ophiolite the rock types occur in the following sequence, from the bottom to the top:

1. Ultramafic complex usually with a metamorphic tectonic fabric

2. Gabbroic complex usually with cumulus textures, and commonly containing cumulus ultramafics

3. Mafic sheeted dyke complex

4. Mafic volcanic complex, commonly pillowed

Other rock types commonly associated (table 16) are: deep-ocean sediments (ribbon chert, shale, minor limestone), podiform chromite, sodic felsic intrusive and extrusive rocks, and copper-bearing pyrite deposits.

The ophiolite association is inferred to represent ancient oceanic crust and upper mantle, obducted onto adjacent continental rocks. During the process of obduction it is very common for ophiolites to become fragmented, various parts being thrust against non-ophiolite-rocks.

At Vaddas there is not a complete ophiolite sequence. The question is whether any of the rocks there were once part of an ophiolite. If not, what was their environment of formation? For simplicity the evidence for and against an ophiolite origin is discussed below in point form.

1. Some possible components of an ophiolite are present (see table 16), but not all of them have the normal features.

(a) Ultramafic rocks and podiform chromite are missing.

(b) Cumulate and non-cumulate gabbros are present.

(c) Some felsic rocks present may be oceanic plagiogranites, others are definitely not.

(d) There are basic dykes and sills in the gabbro and in the Ankerlia Metagreywacke. Ideally in an ophiolite the dykes should be in gabbro and greenstone and there should be a sheeted dyke complex with virtually 100% dykes. The dyke

Table 16: Components of an Ideal Ophiolite Sequence

Sequence	Associated
Deep-ocean sediments[2] Pillow basalt[2]	Pyritic copper deposits[2]
Sheeted dyke complex[2] Cumulate and non cumulate gabbros[1]	Minor oceanic plagiogranites[1]
Cumulate ultramafic rocks Tectonized non-cumulate ultramafic rocks	Minor podiform chromite bodies

Note 1: present at Vaddas
Note 2: something similar present at Vaddas

density only reaches about 50% at Vaddas, although there is a possibility that it was greater in the amphibolite zone.

(e) There are pillow basalts at Vaddas, in the Loftani Greenstone, but well-developed pillows are rare. Mostly there are only fracture patterns which may be pillows structure. with no obvious rim zonation. It seems likely that the basalts which now appear as Loftani Greenstone, were not deposited at oceanic depths.

(f) Typical black shale-chert deep-water sediments are not present. Only the Ankerlia Metagreywacke could represent a deep-water sediment. If this takes the place of normal ophiolite sediments the ophiolite would have to have developed near a source of sandy sediment with a possible volcanic component, e.g. near an island arc.

(g) Pyritic mineralization containing minor copper, is commonly developed in the pillow basalt zone of ophiolites. In the Vaddas area there is extensive pyrrhotite rich copper mineralization at the top of the greenstones and in the Ankerlia Metagreywacke. The abundance of pyrrhotite instead of pyrite might not be significant.

2. Although not part of an ophiolite, it seems to be very common (particularly in Norway) to find coarse sediments, including conglomerate and breccia unconformably overlying an ophiolite. This is the result of erosion which follows obduction. At Vaddas there is no such unconformity, nor is there a conglomerate containing ophiolite debris.

3. The geological relationships of the possible ophiolite components at Vaddas make an ophiolite interpretation difficult. It is tempting to suggest that the observed sequence of: greenstone - amphibolite - gabbro, represents an overturned gabbro - dyke - basalt section of an ophiolite. However at Vaddas there is no indication that these rocks are overturned. The Vaddas Group below the greenstones appears to be right-way-up, and the greenstones appear to conformably overlie this sequence. The contact between the Loftani Greenstone and underlying Vaddas Group does not appear to be a thrust. The Loftani Greenstone was probably extruded over shallow-water Vaddas Group sediments (Lindahl 1974).

The gabbro is thought to have been intruded more or less in situ as a magma, although there is extensive shearing of the contact with the Loftani Greenstone. The contact with the Ankerlia Metagreywacke shows intense folding, but metamorphic and melting effects indicate that it is essentially an intrusive contact.

There is no regional evidence for thrust emplacement of the greenstones or gabbro.

The extent of the dyke/sill complex in the Ankerlia Metagreywacke has not yet been mapped on a regional scale. Its shape and extent, and relationship with other dyke swarms and amphibolites in the region may provide information on the relationship of the Ankerlia Metagreywacke to the Metagabbro and to the underlying sequence.

4. The Vaddasgaisak Metagabbro is only one of a number of gabbroic bodies in the area. Other gabbros nearby appear to be intruded at various stratigraphic positions, mostly higher in the Ankerlia Metagreywacke (K. B. Zwaan 1975 & pers.comm. 1982). They are considered intrusive and not thrust into place.

5. Chemically the Vaddasgaisak Metagabbro, the Loftani Greenstone and the dykes have many characteristics of ocean-floor tholeiites. They correspond broadly with the compositions of some ophiolite basalts and dykes, and with the most basaltic (i.e. least basic) part of the ophiolite gabbros. There is less difference between the composition of the gabbros and the basaltic rocks (dykes, greenstones) at Vaddas, than there is in typical ophiolites. The Vaddas rocks may have formed from simple oceanic tholeiite magmas intruding continental shelf and island arc sediments, and not as part of an ophiolite sequence, or real oceanic crust.

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APPENDIX 1: Mineralogy of Samples Collected by Vogt (1927) and Lindahl (1974)

The estimated percentages of minerals in thin sections of samples collected by Vogt (1927) and Lindahl (1974) from the Vaddas area are presented in the following tables. The samples are grouped according to the mapped rock unit from which they came. The names and numbers used for the rock units are taken from Lindahl (1974)*. Lindahl decided in which of the rock units Vogt's samples were located. The rock units are grouped into similar lithological types so that comparisons can be made.

The percentages of minerals were mostly estimated by Lindahl, with only minor modifications by myself. The estimates are only approximate. I have checked the mineralogies of Lindahl's samles (VR-numbers), but only a few of Vogt's samples (Va-numbers). Most of the plagioclase compositions were determined by me, using standard flat stage optical methods. Consequently accuracy is limited.

List of Abbreviations used:

Qtz - quartz
K-spar - K-feldspar
Plag - plagioclase
(An) - Anorthite content of plagioclase
Opx - orthopyroxene
Oliv - olivine
Amp, Amph - amphibole
Carb - carbonate
Gar - garnet
Ep - epidote
Cz - clinozoisite
Zo - zoisite
Musc - muscovite
Biot - biotite
Chlor - chlorite
Cpx - clinopyroxene
Opaq - opaque minerals
Sph - sphene (titanite)
Zir - zircon
Ap - apatite
Rut - rutile
Tour - tourmaline
Staur - staurolite
Ky - kyanite

* for correlation of Lindahl's (1974) informal stratigraphic names with proposed formal names, see table 13, in text p. 72.

Table 1: Estimated modal mineral content of the metasediments from the SPARAGMITE AND SPARAGMITIC SCHIST rock unit (Ba 1), Lilleelv Group.*

Sample	Qtz	K-spar	Plag (An)	Musc	Biot	Gar	Ep/cz	Opaq	Zirc	Other
Va 155	20	60-70	-	-		x	-	-	x	Amphibole
Va 156	30	?	50	- 15 -		x	x	-	-	-
Va 157	65	30	-	-	x	-	-	x	x	-
Va 158	25	65	-	- 5 -		x	-	x	-	-
Va 159	45	45	-	- 10 -		-	-	-	-	-
Va 193	35	-	45	-	15	x	x	-	-	-
Va 210	30	30		-	15	15	x	x	-	-
VR 134	40	48	-	10	2	-	x	x	x	Apatite
VR 137	40	35		3	7	-	5	-	x	-
VR 467	45	45		5	x	-	2	-	x	-
VR 549	30	70	(40)	x	x	x	x	-	x	Apatite
VR 598	40	20	20(25?)	10	10	x	2	-	x	Sphene
516-1195	x	x	x	x	x	-	x	x	-	-

* (= Napojåkka Group. Samples are from Loddevagge Meta-Arkose).

Table 2: Estimated modal mineral content of metasediments from the two quartzite units, Vaddas Group

RUSTY QUARTZITE (Ba 9)
(= Rieppesjåkka Quartzite Member)

Sample	Qtz	K-spar	Plag	(An)	Musc	Biot	Chlor	Ep/cz	Carb	Opaq	Sph	Zirc	Other
Va 145	15	?	?		– 30 –		–	–	45	–	–	–	Amp. 10
Va 211	70	–	x		–	5	x	–	10	x	–	x	Amp. 5
VR 156	45	–	–		–	5	30	–	–	x	x	–	Zo. 15
VR 157	75	–	10	(5)	5	5	–	x	3	x	–	x	–
VR 416	30	–	–		25	25	–	–	–	10	–	x	Gar. 10
VR 458	80	–	12	(5)	3	3	x	–	–	x	x	x	–
VR 535	85	–	12	(0-5)	2	–	x	–	–	x	x	–	–
VR 591	80	–	20	(5)	x	–	–	–	–	x	x	x	–
516-1205	75	–	20		x	2	–	–	–	x	x	x	–

VADDAS QUARTZITE (Ba 15)
(= Skardalen Quartzite Member)

Sample	Qtz	K-spar	Plag	(An)	Musc	Biot	Chlor	Ep/cz	Carb	Opaq	Sph	Zirc
VR 159	10	–	15	(0-2)	8	5	x	x	60	x	–	x
VR 401	85	x	10	(0-5)	2	x	x	–	x	x	x	–
VR 402	80	– 18 –		(0-5)	x	–	–	–	–	–	–	–
VR 412(a)	35	–	x		60	–	–	–	x	x	x	–
VR 461	95	–	–		5	–	–	x	–	–	x	–
VR 534	80	x	15	(0-5)	3	–	–	x	x	x	x	–
Va 161	45	20	20		x	7	–	x	–	–	–	x
Va 191	55	– 40 –			x	–	–	x	–	x	–	–

Table 3: Estimated modal mineral content of the schistose rock units in the Lilleelv Group

VADDAS SCHIST (Ba 3)
(= Luovosskaide Meta-Arkose)

Sample	Qtz	Plag	(An)	Musc	Biot	Gar	Ep/cz	Opaq	Sph	Zir	Tour	Other
Va 151	30	?		40	x	20	-	x	-	-	-	-
VR 113 (7115)	15	7		x	x	75	-	x	-	-	-	Carb.
VR 113 (7168)	75	x		-	25	-	-	x	-	-	-	Carb, Ap
VR 133	45	15	(-)	15	15	x	x	x	x	x	-	Carb.
VR 136	30	x		30	x	30	x	x	x	-	-	-
VR 597	60	20	(15-20)	5	15	x	x	-	x	-	-	-

GRAPHITE-MICA SCHIST (Ba 4)
(= Luovosskaide Meta-Arkose)

VR 132	35	15	(38?)	35	10	-	-	x	-	x	x	
VR 596	50	20	(5?)	-	15	3	-	x	x	x	-	Chlor, Ap

VADDAS SCHIST (Ba 5)
(= Luovosskaide Meta-Arkose)

Va 162	40	10		-	35	-	10	x	-	x	-	
Va 195	30	15		20	20	10	-	x	-	x	-	
VR 158	35	-		45	15	x	x	x	-	x	x	
VR 414	30	x		50	15	-	x	x	-	x	x	
VR 581	60	x		-	30	-	x	x	-	x	-	
	- 30 -			-	10	20	-	-	x	x	-	Amph 40
VR 600	315	5	(12?)	25	20	10	x	x	-	x	x	
VR604	50	-		20	20	5	-	x	-	x	x	

Table 4: Estimated modal mineral content of the calcium-poor mica schist units of the Vaddas Group

MICA SCHIST (Ba 11)
(= Oksfjorddalen Schist Member)

Sample	Qtz	Plag (An)	Musc	Biot	Chlor	Gar	Opaq	Sph	Zirc	Tour	Other
Va 212	- 30 -		-	40	5	5	10	-	5	x	
VR 154	30	-	10	25	8	x	x	-	x	x	Amp 15, Ep, Carb 8
VR 254	45	15 (sodic)	-	20	8	5	x	-	x	x	Ap
VR 403	40	?	35	20	5	-	x	x	x	x	
VR 419	65	10 ?	10	15	x	-	x	x	x	x	
VR 459	35	-	30	30	-	5	x	-	x	x	

GARNET - MICA SCHIST (Ba 14)
(= Oksfjorddalen Schist Member)

VR 555	40		40	10	x	5	x	x	x	x	
VR 587	40	x	-	10	35	x	5	x	x	-	Ep 10, Amp, Carb
VR 593	35		35	15	-	5	x	x	-	x	Staur 5

Table 5: Estimated modal mineral content of mica schist units with abundant calcium minerals (calc - mica schists), Vaddas Group

AMPHIBOLE - CALC - MICA SCHIST (Ba 6)
(= Gæirajav'ri Marble)

Sample	Qtz	Plag	(An)	Musc	Biot	Chlor	Gar	Amp	Ep/cz	Zo	Carb	Opaq	Sph	Zirc	Tour	Other
Va 153	x	x		x	-	-	-	30	x	-	x	x	-	-	x	
VR 119	30	x?		-	30	-	-	30	-	-	5	x	-	x	-	
VR 123	35	5	(55+)	x	20	2	-	20	x	-	15	-	x	x	x	
VR 450	30	x	(35+)	-	35	7	-	20	-	-	5	-	x	x	-	Ap
VR 452	30	x		-	35	2	-	15	x	x	15	x	x	x	-	
VR 599	10	x	(66+)	-	20	x	-	45	-	x	20	x	x	x	-	
516-1202	20	-		-	25	5	-	25	-	5	15	x	x	x	-	

GARNET - MICA SCHIST (Ba 10)
(= Oksfjorddalen Schist Member)

Sample	Qtz	Plag	(An)	Musc	Biot	Chlor	Gar	Amp	Ep/cz	Zo	Carb	Opaq	Sph	Zirc	Tour	Other
VR 118	25	-		40	10	x	5	10	x	-	-	-	x	x	x	Ap?
VR 124	35	x		35	10	x	5	2	-	-	-	x	-	-	-	
VR 553	30	-		40	15	-	5	-	-	-	-	x	x	-	x	Staur 5
VR 585	35	-		30	20	x	5	10	-	-	-	x	x	x	x	Ap?

MICA SCHIST (Ba 18)
(Guolasjav'ri Formation)

Sample	Qtz	Plag	(An)	Musc	Biot	Chlor	Gar	Amp	Ep/cz	Zo	Carb	Opaq	Sph	Zirc	Tour	Other
Va 147	45	x		-	40	-	-	-	-	-	10	x	-	x	x	
Va 152	x	-		x	x	x	x	x	x	-	-	x	-	x	x	
VR 60	85	-		7	7	-	-	-	-	-	-	x	-	x	-	Rut?
VR 160	30	-		25	30	x	-	-	4	-	10	x	-	x	x	
VR 359	35	-		20	25	1	10	5	-	-	1	-	-	-	x	Rut?
VR 365	20	-		50	15	-	10	-	-	-	-	x	-	x	x	Staur
VR 409	40	-		-	20	-	-	10	x	-	25	x	-	x	x	Ap
VR 411	60	-		10	25	-	-	-	x	-	x	x	-	x	-	Ap?
VR 462	65	-		x	15	x	-	-	x	-	15	x	-	x	x	
VR 495	20	-		45	15	x	15	-	-	-	-	x	x	x	x	Ap?
VR 500	60	x		x	20	x	x	x	-	x	15	x	x	-	x	Ap?
VR 532	40	x		x	35	-	-	-	7	-	15	x	-	x	-	

Table 5 (continued)

MICA SCHIST (Ba 20)

(= Guolasjav'ri Formation)

Sample	Qtz	Plag	(An)	Musc	Biot	Chlor	Gar	Amp	Ep/cz	Zo	Carb	Opaq	Sph	Zirc	Tour	Other
VR 448	45	10	(50)	–	25	–	–	–	–	x	15	x	–	x	x	
VR 488	25	–		20	15	–	20	–	–	–	–	x	x	x	x	Ky 10 Staur 1
VR 490	35	5	(32?)	x	45	–	5	x	–	–	5	5	–	x	–	

MICA SCHIST (Brown) (Ba 23)

(= Ak'kejav'ri Calc-Biotite Schist)

Va 150	70	–		5	10	–	–	–	x	–	5	x	–	–	–	
VR 1	50	x		x	25	x	–	–	5	–	18	x	–	x	x	
VR 2	40	–		x	25	x	20	–	–	–	15	x	–	x	–	
VR 3	45	–		–	10	–	–	15	–	–	25	x	–	x	–	
VR 23	60	–		5	8	–	–	–	x	–	25	x	x	x	–	
VR 125	60	x	(43+)	–	15	–	–	8	x	–	12	–	x	x	–	
VR 148	25	–		–	50	–	–	–	10	–	10	x	–	–	–	
VR 251	60	x		10	20	–	–	–	–	5	–	x	x	x	x	
VR 252	60	–		–	x	12	–	10	x	–	15	x	x	x	–	
VR 528	60	–		15	20	x	–	–	–	–	8	x	x	x	x	Ap?
VR 557	45	x	(67?)	5	20	x	–	–	10	–	15	x	x	x	x	

Table 6: Estimated modal mineral content of samples from impure carbonate units, Vaddas Group

MARBLE/CALC-SCHIST/CALC-MICA SCHIST (Ba 16)
(= Guolasjav'ri Formation)

Sample	Qtz	Plag	(An)	Musc	Biot	Chlor	Ep/cz	Carb	Opaq	Sph	Zirc	Tour	Other
Va 142	15	x		8	–	–	–	75	x	x	–	–	
VR 457	10	–		20	x	–	x	65	5	–	–	x	
VR 521	40	x		20	–	–	x	40	x	x	–	x	
VR 533	30	5	(36+)	20	–	–	x	40	x	x	–	x	

PALE MARBLE UNIT (Ba 17)
(= Guolasjav'ri Formation)

Sample	Qtz	Plag	(An)	Musc	Biot	Chlor	Ep/cz	Carb	Opaq	Sph	Zirc	Tour	Other
VR 116	10	x		15	10	–	x	60	x	x	–	x	
VR 588	80	5		5	–	–	–	10	x	–	–	–	

PALE MARBLE UNIT (Ba 19) * denotes pebble from conglomerate
(= Guolasjav'ri Formation)

Sample	Qtz	Plag	(An)	Musc	Biot	Chlor	Ep/cz	Carb	Opaq	Sph	Zirc	Tour	Other
Va 160	65	5	(sodic)	x	–	–	?	25	x	x	–	–	Rut?
Va 190	20	10	(55)	–	10	5	10	30	x	–	–	–	Zo?
Va 209	85	5	(sodic?)	x	x	–	–	8	x	x	x	–	
Va 214	20	10		–	15	x	–	20	5	x	–	–	
516-1194	5	2		x	–	–	–	93	–	x	–	–	
VR 165	40	?		8	–	–	–	50	x	x	–	–	
VR 188	80	–		4	4	–	–	12	–	x	x	–	
VR 407	5	3		x	–	x	–	90	x	x	–	–	
VR 408	12	?		5	–	–	5	75	x	–	x	–	
VR 463 (7767) *	70	25	(0-2)	–	–	–	–	–	–	x	x	–	
	50	–		10	–	–	–	40	x	x	x	–	
VR 463 (7768)	25	x	(sodic)	5	–	–	–	70	x	x	x	–	
VR 498	5	–		8	–	–	–	85	x	?	–	–	
VR 506	2	–		x	x	x	–	97	x	–	–	–	
VR 524 * (7774)	70	25	(0-2)	x	–	–	–	–	x	x	x	–	
VR 524 (7773) *	75	20	(0-2)	–	–	–	–	x	–	x	x	–	
*	x	–		–	–	–	–	95	x	x	–	–	
	50	x		x	–	–	–	50	–	–	–	–	

Table 7: Estimated modal mineral content of samples from nearly pure marble units, Vaddas Group

GREY MARBLE (Ba 7)
(= Gæirajav'ri Marble)

Sample	Qtz	Plag	(An)	Musc	Biot	Chlor	Zo	Carb	Opaq	Sph	Other
VR 117	10	2	(35+)	4	4	-	-	80	-	x	Amp, Zirc
VR 155	2	-		2	-	-	-	95	x	-	
VR 162	2	-		2	-	-	-	95	x	-	
VR 415	2	x		x	-	-	-	95	2	-	
VR 548	7	?		x	-	x	-	90	x	-	
VR 583	5	-		2	-	-	-	90	x	-	

GREY MARBLE (Ba 12)
(= Oksfjorddalen Schist Member)

VR 112	3	-		5	-	-	x	90	x	-	
VR 255	5	-		5	-	-	8	80	x	-	Ep
VR 469	5	-		x	-	-	-	90	x	-	
VR 592	7	-		3	-	-	-	90	x	-	

Table 8: Estimated modal mineral content of samples from the Oksfjord Schist

OKSFJORD SCHIST (Ba 29)
(= Ankerlia Metagreywacke)

Sample	Qtz	Plag	(An)	Biot	Chlor	Amp	Ep/cz	Carb	Opaq	Sph	Zirc	Other
Va 164	30	35	(62)	5	-	5	20	-	x	x	x	
Va 166	35	15	(60?)									
Va 165	40	20	(40)	10	-	15	x	x	x	x	x	Cpx 10
Va 167												
Va 188	50	20	(45?)	10	-	15	5	-	x	x	x	
Va 189	60	5	(32?)	-	-	30	5	x	-	x	-	
Va 192	25	25		40	-	5	-	-	x	x	x	Tour
516-1339	35	15		25	-	10	10	-	x	-	x	
VR 426	65	x		-	x	25	10	x	x	x	-	Ap
	50	x	(sodic)	40	x	x	-	-	x	x	x	Gar 8
VR 541	65	x	(33?)	25	x	5	-	5	x	x	x	
VR 542	5	85	(55)	-	-	x	x	-	x	8	-	Note 1

Note 1: VR 542 contains skeletal poikiloblasts of scapolite

Note 2: Minor K-feldspar may be present in a few samples, but none was positively identified

Table 9: Estimated modal mineral content of a sample of

RAPPESVARRE GNEISSIC GRANITE (Ba 30)

Sample	Qtz	K-fels	Plag	(An)	Musc	Biot	Chlor	Opaq	Sph	Zirc
VR 278	25	45	15	(0-2)	10	5	x	x	x	x

Table 9: Estimated modal mineral content of samples from the

LOWER GREENSTONE (Ba 21)
(= lower Loftani Greenstone)

Sample	Qtz	Plag	(An)	Chl	Amp	Ep/cz	Carb	Opaq	Sph	Other
Va 15	?	30		x	60	2	5	x	x	
Va 25	–	25		–	55	15	–	x	x	
VR 161	–	35	(65)	–	60	x	x	x	x	
VR 250	–	35	(50)	5	50	8	1	x	1	
VR 491	?	25	(50)	–	70	x	s	x	x	
VR 510	x	30?	(36)	–	45	20	–	x	x	
VR 525	–	25	(50)	x	65	x	x	x	x	
VR 530	?	25	(sodic)	x	70	–	x	x	x	

Table 10: Estimated modal mineral content of samples from the

UPPER GREENSTONE (Ba 24)
(= upper Loftani Greenstone)

Va 19	–	15		–	70	10	–	x	x	
Va 22	–	10		–	75	15	–	–	x	
Va 37	x	15		–	65	15	x	–	x	
Va 44	–	15	(29)	–	70	15	–	–	–	
Va 46	–	20		5	65	5	–	x	x	
Va 89	–	15		–	70	15	–	x	x	
Va 113	–	20	(30)	–	70	5	x	x	x	
Va 134	–	20	(40)	–	60	15	–	–	–	
Va 144	35	–		–	–	–	–	–	–	Gar 5, Mica 50
Va 176	–	35	(40)	–	45	20	–	x	–	
Va 177	–	25	(40)	–	60	12	–	x	x	
516-1208	–	30	(40)	–	65	–	–	5	–	
VR 63	?	25	(35)	5	65	–	–	x	x	Biot
VR 127	?	20	(50?)	x	70	5	x	–	x	
VR 164	–	40	(60)	x	50	x	–	x	x	
VR 303	–	20	(35?)	45	5	–	–	x	–	Gar 25
VR 309A	x	35		50	5	–	–	x	x	
VR 309B/C	–	30	(65)	x	60	x	x	x	x	
VR 329	x	–		x	80	15	–	x	x	
VR 334	–	30	(54)	5	60	–	–	3	x	

Table 10: UPPER GREENSTONE (Ba 24) - continued)

Sample	Qtz	Plag	(An)	Chl	Amp	Ep/cz	Carb	Opaq	Sph	Other
V4 339	-	25	(55)	-	60	10	x	-	5	
VR 344	30	10		40	15	-	x	s	x	
VR 346	-	18	(55)	-	65	15	-	-	2	
VR 352	-	25	(48?)	10	65	-	-	x	-	
VR 381	x	30	(60)	25	30	-	x	8	-	Biot
VR 406	x	25	(70?)	-	65	10	-	-	-	
VR 424	20?	20?	(45)	-	60	-	-	x	x	
VR 603	10	20	(68)	-	65	5	-	x	x	

Table 11: Estimated modal mineral content of samples from the

"CONTACT METAMORPHIC" SERIES (Ba 25)
(mostly = Gryta Amphibolite)

Sample	Qtz	Plag	(An)	Bio	Amp	Ep/cz	Opaq	Sph	Zir	Ap	Other
Va 14, Va 16	x	45	(60)	x	50	x	x	-	-	-	
Va 18, Va 180	-	50	(55)	-	50	-	x	-	-	x	Tour
Va 34	40	50		-	8	x	x	-	-	-	
Va 36	-	15		-	70	-	x	-	-	-	Zois 10
Va 42	x	45	(55)	2	40	10	3	x	-	-	
Va 91	-	60	(65)	-	35	-	x	-	-	-	
Va 106, Va 130	-	60		-	25	-	x	x	-	5	Chl 5
Va 107	-	40	(50)	-	60	-	x	-	-	-	
Va 110	-	25		10	60	5	x	x	x	-	
Va 111	30	60		x	10	-	-	x	-	-	Chl
Va 135	-	40		-	45	x	x	5	-	-	Pyx 5
Va 136	-	45		-	50	5	x	x	x	-	
Va 202	-	30		-	65	5	x	x	-	x	
VR 114	35	15	(45?)	5	20	15	-	x	x	-	Cpx 5
VR 120	30?	10?		25	20?	10	-	5	x	-	Musc
VR 128 (6126)	10?	20		-	60	2	-	8	-	-	
VR 128 (6127)	30?	30?	(35?)	-	30	-	-	2	-	-	
VR 258	-	40	(70)	-	55	5	x	-	-	x	
VR 260	-	55	(45)	-	25	-	x	-	-	x	Cpx 15
VR 276	-	20	(50)	-	60	15	x	5	-	-	
VR 318	?	60	(45)	-	25	-	x	x	x	-	
516-1215	x	65		-	30	5	x	-	-	-	
	-	45	(60)	-	50	5	x	-	-	-	
516-1322	x	33		-	25	20	x	-	x	-	Chl 20, Gar
516-1325	-	80		2	15	-	x	3	x	x	
	-	20		5	60	8	x	5	x	x	

Table 12: Estimated modal mineral content of samples from the

GABBRO GNEISS (Ba 27)
(= part Vaddasgaisak Metagabbro)

Sample	Plag	(An)	Biot	Cpx	Opx	Amp	Ep/cz	Opaq	Sph	Ap	Other
Va 5	45		–	15	15(?)	5	–	–	x	–	
Va 7	50		–	15	15(?)	15	–	x	–	–	
Va 100 } Va 8 }	60		–	25	5	8	–	x	x	–	
Va 9	65		–	20	12	–	–	3	x	–	
Va 17	35	(50)	–	15	–	40	–	x	–	x	
Va 20	55	(43)	–	15	–	30	–	x	–	–	
Va 87 } Va 29 }	50		–	10	–	40	–	–	–	–	
Va 78	40		–	30	8	20	–	x	–	x	
Va 83	50		–	45	3	20	–	3	–	x	
Va 84	5		–	–	–	30	–	–	–	–	Gar 65
Va 88	50		–	15	3	30	–	x	–	–	
Va 98	98		–	–	–	1	x	x	–	–	
Va 99	25		–	–	–	80	x	x	–	–	Carb
Va 123	38		–	–	–	60	–	2	–	–	
Va 101	50		–	30	10	5	–	5	–	–	
Va 104	50		–	30	5	8	–	5	–	–	
Va 105	45		–	– 20 –		35	–	–	–	–	
Va 112	40		5	– 20 –		35	–	–	–	–	
Va 124	50		–	35	5	5	–	5	–	–	
Va 133	50		–	– 30 –		15	–	–	–	–	
Va 168	50		5	20	–	–	5	–	–	–	Qtz 20
Va 169	70		15	15	?	–	–	x	–	5	
Va 182	50		–	– 30 –		10	–	5	–	5	
Va 183	60		–	25	10	x	–	x	–	–	
Va 184	65		10	10	–	15	–	–	–	–	
Va 204	65		–	– 15 –		20	–	–	–	–	
Va 205	50		30	– 20 –		–	–	x	–	–	
Va 206	45		–	– 30 –		20	–	5	–	–	
VR 105	70	(62)	–	–	15	10	–	5	x	x	
VR 108 }		(65)									Oliv
VR 107 }	70	(70)	–	30	x	x	–	x	–	–	
VR 109	65	(55)	–	30	–	–	–	5	–	–	

Table 12: GABBRO GNEISS (Ba 27) - Continued

Sample	Plag	(An)	Biot	Cpx	Opx	Amp	Ep/cz	Opaq	Sph	Ap	Other
VR 256	45	(70+)	–	30	8	8	–	x	–	–	Oliv 5
VR 257	65	(75+)	–	20	5	5	–	x	–	–	Oliv 5
VR 261	40	(70)	–	– 5 –		50	2	x	x	–	Carb 3
VR 262	60	(50)	–	25	10	–	–	5	–	x	
VR 265	x		–	30	–	x	–	–	–	x	Qtz 60?
VR 273	60	(66)	–	20	–	10	–	s	–	–	Chl 5
VR 275	45	(45)	5	30	–	15	5	–	x	–	Chl
VR 428	60	(60)	–	– 38 –		–	–	2	–	–	
VR 438	45	(12)	x	–	–	–	x	5	–	–	Qtz 40, Musc
VR 441	40	(75)	–	15	5	30	–	5	–	x	

Table 13: Estimated modal mineral content of samples from the

OLIVINE GABBRO (Ba 28)
(= part Vaddasgaisak Metagabbro)

Sample	Plag	(An)	Cpx	Opx	Oliv	Amp	Opaq	Spinel	Ap	Other
Va 1	65		15	8	10	2	–	–	–	
Va 2	65		15	3	10	7	–	–	–	
Va 3										
Va 96	65	(78–68)	20	5	10	x	x	–	–	
Va 122										
Va 4	50		20	15	5	8	x	–	–	
Va 6	45		25	10	10	8	x	x	–	
Va 80	60		20	3	2	10	4	–	–	
Va 86	65		10	–	15	10	x	–	–	
Va 92	70		10	5	5	5	2	x	–	
Va 97	40		40	5	10	5	x	–	–	
Va 125	60		20	5	10	2	x	–	–	
Va 132	60		15	5	10	8	x	–	–	
Va 181	45		40	5	x	5	5	–	–	
Va ?	x	(75–66)	–	x	–	x	–	x	–	
VR 110	60	(70–75)	20	5	10	5	–	x	–	
VR 167	75	(70)	10	–	5	5	x	–	–	
VR 259	60	(55)	35	10	x	–	x	–	–	
VR 263	65	(65)	20	5	8	x	x	–	–	
VR 264	55	(55)	20	10	5	2	5	–	1	
VR 266	55	(60–66)	35	10	x	5	5	–	x	
VR 431	60	(65)	– 20 –		10	x	–	x	x	
VR 432	60	(70)	– 30 –		10	–	–	–	–	
VR 439	45	(70–75)	– 30 –		15	3	5	–	x	
	55		– 30 –		3	x	5	–	5	
VR 560	60	(70)	– 25 –		10	x	x	–	–	
516-1205	55		25	5	10	x	–	–	–	Biot

APPENDIX 2 Description of samples collected in this study

BS-2 Hornblende-Biotite Altered Gabbro

Hand-specimen: Basaltic rock with a large proportion of square phenocrysts from loose block in Moscodalen.

Thin section: Very large, highly twinned plagioclase crystals, interlocking. Also some large clinophyroscene crystals altering to hornblende, plus one large olivine crystal heavily altered to opaques along fractures. Coarse hornblende and biotite plus minor sphene present. There is no fine matrix. Plagioclase shows alteration.

Interpretation: The rock is an altered gabbro retaining its igneous texture and much igneous mineralogy. It may have been part of a large gabbro body or a slow-cooling dyke.

BS-3 Porphyritic Basic Dyke with Recrystallized Matrix

Hand-specimen: Deformed fine grained basic rock with scattered feldspar phenocrysts.

Thin section: Zoned and largely sericitized plagioclase phenocrysts in a metamorphic textured matrix of fine grained, sub-poligonal plagioclase, hornblende and minor sphene. One large apatite grain in an aggregate of plagioclase grains.

Interpretation: Dyke rock containing relict plagioclase phenocrysts, but with matrix entirely recrystallized to an amphibolite facies assemblage and texture.

BS-10 Amphibole-clinozoisite Altered Amphibolite

Hand-specimen: Partly amphibolized pyroscene meta-gabbro - medium grained, non-layered.

Thin section: Hornblende - plagioclase amphibolite with much vermicular clinozoisite, minor colourless amphibole and very minor opagne and sphene. The colourness amphibole is associated with clinozoisite.

Interpretation: Hornblende - plagioclase amphibolite with near-equilibriesm texture, showing later partial alteration to pale amphibole - clinozoisite - sphene. Brownish surface colouring of rock is due to clinozoisite and pale amphibole, not pyroxene.

BS-11 Mechanically Deformed Olivine Metagabbro

Hand-specimen: Coarse olivine metagabbro, non-layered.

Thin section: Desequilibrium texture with relatively coarse, equigranular plagioclase and clinopyroxene, some deformed, finer grained olivine, clinopyroxene, plagioclase and hornblende, forming rims of partial rims around the coarser grains, and interstitial aggregats.

Interpretation: Appears to be a high grade metamorphic texture, partially mechanically deformed, with little chemical alteration of the minerals involved.

BS-13 Gneissic Metabasalt (Greenstone)

Hand-specimen: Gneissic amphibolite with layering and parallel schistosity.

Thin section: Rock has an igneous texture - interlocking plagioclase and pale amphibole. Abundant clinozoisite and minor sphene and opaques present.

Interpretation: Plagioclase may be relict igneous. Amphibole, clinozoisite sphene are metamorphic. Texture indicates the rock was completely crystalline, possible a dyke, but more likely greenstone.

BS-20 Metamorhically Recrystallized Porphyritic Basaltic Dyke

Hand-specimen: Recrystallized porphyritic basalt, probably a dyke rock, within metasediments.

Thin section: Relict plagioclase phenocrysts with recrystallized margins, in a matrix of relatively fine grained opaque grains and sphene. Appears to be two colours of sphene - orange-brown and colourless, the coloured one may be another mineral, some amphibole is very poikiloblastic.

Interpretation: Basaltic dyke rock heavily altered by metamorphism (amphibolite grade).

BS-21 Metasediment (Ankerlia Metagreywache)

Hand-specimen: Bedded metasediment (Oksfjord Schists).

Thin section: Fine grained rock with strong schistosity. Consists of plagioclase and probable quartz with abundant biotite and clinozoisite. Very minor opaques and sphene form alteration of opaque.

Interpretation: Fine sandy metasediment possibly with a basic igneous component, metamorphosed to probable amphibolite grade.

BS-25 Partly recrystallized Porphyritic Basalt (Dyke?)

Hand-specimen: Igneous textured rock, thin plagioclase phenocrysts to 1 cm, in a matrix with fine, interlocking laths.

Thin section: Phenocrysts of plagioclase and interlocking matrix laths of plagioclase and amphibole - relict igneous texture. Much recrystallization of amphibole and some plagioclase.

Interpretation: Probable dyke rock partly recrystallized under metamorphic condition.

BS-27 Metagabbro or Metasediment from Gneissic Zone

Hand-specimen: Rock with brown surface weathering suggesting pyroxene, but fresh surface appears amphibole rich, perhaps with an igneous texture.

Thin section: Relatively fine grained metamorphic rock with irregular grainshape and grainsize. Consists of plagioclase (much untwinned), dark greenish amphibole (some poikiloblastic), clinopyroxene, and minor biotite. Much of the clinopyroxene is poikiloblastic - may be metamorphic in origin. Very minor fibrous mineral - resembles fibrolite.

BS-28 Metasediment (Ankerlia Metagreywacke)

Hand-specimen: Outcrop of brown rock with subtle to well-defined layering - could be layered cumulate metagabbro, or possibly layered metasediment.

Thin section: Minerals present - abundant plagioclase, quartz, hornblende, clinopyroxene, biotite. Clinopyroxene is mostly poikiloblastic. Equigranular metamorphic texture in plagioclase and quartz, but morphic minerals are less regular, especially biotite.

Interpretation: Appears to be a metasediment (Ankerlia Metagreywacke) which has been metamorphosed to a grade where the assemblage quartz + plagioclase + hornblende + clinopyroxene + biotite is stable.

BS-36A Granular Amphibolite

Hand-specimen: Massive, medium grained, equigranular amphibolite.

Thin section: Polygonal to slightly elongate plagioclase and hornblende with minor finer opaques. Weak preferred grain orientation. Very minor zerion.

Interpretation: Equilibrium texture in a high grade metamorphic amphibolite.

BS-36B Granluar Amphibolite

Hand-specimen: Massive, medium grained, granular amphibolite.

Thin section: Polygonal, lesser elongate, hornblende and plagioclase with scattered fine opaque.

Interpretation: Equilibrium texture in a high grade metamorphic amphibolite.

BS-39 Olivine Metagabbro

Hand-specimen: Coarse grained olivine meta-gabbro.

Thin section: Polygonal to sub-polygonal plagioclase rich meta-gabbro, with abundant clinopyroxene and olivine and possible minor orthopyroxene. Clinopyroxene occurs as grains of similar size to plagioclase and as grain aggregates. Olivine grains are generally small. Minor opaque and minor hornblende. Plagioclase and olivine are in contact with no corona texture.

Interpretation: High temperature recrystallization of an olivine gabbro to produce olivine metagabbro. One zone of later mechanical deformation. Only very minor hornblende alteration.

BS-40 Gneissic Olivine Metagabbro

Hand-specimen: Massive olivine meta-gabbro, coarse grained.

Thin section: Gneissic texture defined by lenticular aggregates of mafic minerals - clinopyroxene plus minor olivine and hornblende. Some apparent elongation and deformation of plagioclase grains, and some recrystallization to sub-grain aggregates. Olivine forms small grains and aggregates of small grains. A few shapes resemble igneous laths, but generally the mafic aggregates and plagioclase aggregates have no particular shape.

Interpretation: Gneissic olivine meta-gabbro. Lenticular mineral aggregates may have developed from deformation and recrystallization of original coarse igneous grains.

BS-44 Layered Felsic Olivine Metagabbro

Hand-specimen: Layered felsic pyroxene metagabbro.

Thin section: Plagioclase - clinopyroxene - olivine metagabbro, with minor opaque minerals. Layering is mainly defined by variations in proportion of clinopyroxene. Clinopyroxene is finely twinned. Texture inequigranular - many small olivine grains, many plagioclase grains show curved twins or extra sets of twins.

Interpretation: Felsic plagioclase - clinopyroxene - olivine metagabbro, with high grade metamorphic texture modified by later mechanical deformation.

BS-44 Layered Felsic Olivine Metagabbro

Hand-specimen: Fine to medium grained felsic rock from interlayered and boudinaged felsic and mafic zone.

Thin section: Fine grained, mylonitic texture (ribbon quartz and fine recrystallization) in rock consisting of quartz, K-feldspar (microcline) (not stained check against analysis), minor blue-green hornblende, very minor opaques with sphene rims. Much fine sericitic alteration of untwinned feldspar. Also substantial amount of altered clinopyroxene - larger grains than the hornblende.

Interpretation: Mylonitized and metamorphically altered pyroxene granite.

BS-45A Hornblende Altered Microdolerite Dyke

Hand-specimen: Granular amphibolite which is interlayered with felsic rock, in boudinage structures.

Thin section: Rock has an igneous texture, very much resembling that in dyke rock BS-98B, from Moscodalen. Interlocking plagioclase laths, showing much recrystallization. Between plagioclase laths there are slightly small sub-equant clinopyroxene grains, with very much alteration to hornblende and fine opaque grains, some sericitization of plagioclase.

Interpretation: Probably a micro-dolerite dyke rock partly altered by amphibolite facies metamorphism, and partly recrystallized.

BS-48 Layered Biotite-Bearing Felsic Metagabbro

Hand-specimen: Felsic metagabbro.

Thin section: Felsic rock with some very thin mafic layers. Felsic part is sub-polygonal plagioclase grains with smaller polygonal clinopyroxene, minor opaques, and very minor biotite. One layer is relatively rich (about 10%) in biotite. Mafic layers are pyroxene rich, with a little biotite and opaques. Most of the pyroxene in the rock is clinopyroxene, a little is orthopyroxene.

Interpretation: Felsic recrystallized metagabbro with minor thin pyroxene rich layers. Contains minor biotite, probably of igneous origin.

BS-49A Fine Metagabbro

Hand-specimen: Apparently intrusive medium-fine grained metagabbro, adjacement to medium to coarse metagabbro. The rock has a polygonal grain texture.

Thin section: Very well developed polygonal, equigranular metamorphic texture, relatively fine grained. Main minerals are plagioclase and clinopyroxene. Minor hornblende is present as an alteration product of clinopyroxene, and small opaque grains are relatively abundant.

Interpretation: The rock appears to be just a finer grained metagabbro. Either it is not a dyke rock, or the original textures have

BS-49B Recrystallized Gabbro

Hand-specimen: Coarse meta-gabbro with schistosity, truncated b finer meta-gabbro (BS-49A).

Thin section: Plagioclase - clinopyroxene meta-gabbro with minor hornblende and opaque minerals. Rock characterized by aggregates of clinopyroxene sub-grains and plagioclase sub-grains. Some aggregates have lath-like shapes, probably representing igneous crystal shapes.

Interpretation: Fine grained metagabbro developed from polygonal recrystallization of coarser grained igneous-textured gabbro. Gneissosity formed by rotation and recrystallization of coarse igneous grains.

BS-51 Recrystallized and Altered Hornblende Granodiorite

Hand-specimen: (near Høgfjellvatnet mine) Felsic rock forming the matrix of an intrusive breccia - mostly fine grained feldspar, minor mafic minerals.

Thin section: Quartz - feldspar rock with minor sphene, clinozoisite, blue-green hornblende, chlorite and very minor zircon. Quartz is recrystallized to sub-grains. Feldspar is very altered (sericitic). Feldspar is plagioclase, some untwinned. One large mafic aggregate (1 x 1,5 mm) consists of sphene, opaque with sphene rim, hornblende, interlayered biotite/muscovite, sub-radial chlorite, minor quartz, and possible clinozoisite. This may be an altered basic rock fragment. A large feldspar - hornblende aggregate may also be a rock fragment.

Interpretation: Partly recrystallized, altered and weathered granitic rock, with small basic rock fragments.

BS-52 Carbonite - K-Feldspar Bearing Quartzite

Hand-specimen: Pale rock, metasedimentary, either feldspar rich or carbonate rich.

Thin section: Quartzite with polygonal to elongate quartz grains, minor carbonate, muscovite, scattered opaques (probably pyrite) and many small grains of untwinned K-feldspar between the quartz grains.

Interpretation: Carbonate - K-feldspar bearing quartzite originally either a sand or a cherty chemical sediment.

BS-58 Layered Hornblende Metagabbro

Hand-specimen: Layered gabbro or amphibolite, medium grained, appears to have cumulate layering and perhaps gneissic layering.

Thin section: Relatively fine grained rock consisting mainly of plagioclase, amphibole and clinopyroxene. Has a fine-scale gneissic layering and a coarser mineralogical layering which may be original igneous cumulate layering.
Abundant vermicular intergrowths on the margin of plagioclase grains

and as separate grains - mostly clinozoisite.
Cumulate layering is now defined by variation in the ratio of plagioclase to mafic minerals, and by abundance of opaque minerals.
Types of layers:

1. Plag - minor hb - minor cpx
2. Hb - cpx - minor plag
3. Hb - cpx - plag
4. Plag - minor hb
5. Plag - minor cpx - minor hb - minor opaques
6. Hb - plag - minor cpx - minor opaques

Interpretation: Layered plagioclase - clinopyroxene metagabbro with metamorphic gneissosity and partial conversion of pyroxene to amphibole.

BS-59 Recrystallized Hornblende Gabbro

Hand-specimen: Igneous textured rock with interlocking plagioclase laths 2-4 mm long, in a dark matrix (laths about equal in volum to matrix). May be a dyke intruding the metagabbro.

Thin section: Coarse, interlocking plagioclase laths with interstitial, fairly coarse, equigranular amphibole grains and minor opaque minerals. Minor growth of fine amphibole in plagioclase.

Interpretation: Gabbroic texture; probably a gabbro in which original pyroxene has been altered to amphibole under medium or high grade metamorphic conditions. (May be original amphibole, recrystallized.) Probably not a dyke.

BS-60 Amphibole - Clinozoisite Altered Metagabbro

Hand-specimen: Coarse gabbro with no obvious olivine, and non-layered. Coarse schistosity present. Could be amphibole and feldspar rock.

Thin section: Plagioclase - amphibole - clinozoisite rock. Schistosity defined by preferred orientation of lath - like plagioclase grains. Areas of pale amphibole within darker greenish amphibole, may indicate progressive replacement of an earlier mineral. Some vermicular clinozoisite rims on plagioclase.

Interpretation: Probably amphibole - clinozoisite altered and deformed metagabbro.

BS-62 Metabasal (Lower Greenstone)

Hand-specimen: Coarse greenstone with felted texture - probably metamorphic (Lower Greenstone).

Thin section: Interlocking elongate plagioclase and hornblende, with some areas of fine recrystallization. Sphene is a common minor mineral and lesser opaques are present.

Interpretation: Metabasalt with amphibolite facies metamorphic texture, perhaps reflecting an original interlocking lath - like igneous texture.

BS-68 Recrystallized Porphyritic Basic Dyke

Hand-specimen: Dyke - like rock. medium to fine grained. Forms boudin - like lens in very coarse olivine metagabbro.

Thin section: Scattered plagioclase phenocrysts in a fine grained matrix of polygonal to sub-polygonal plagioclase, clinopyroxene, hornblende and minor opaque grains. Hornblende appears to be in equilibrium with other minerals. Minor opaques exsolution in clinopyroxene. Some plagioclase grains crowded with clinozoisite inclusions.

Interpretation: Dyke rock with matrix recrystallized under amphibolite facies conditions.

BS-70 Olivine Metagabbro

Hand-specimen: Medium grained olivine gabbro, not layered.

Thin section: Some large plagioclase aggregates and a few large grains of plagioclase, plus smaller aggregates of clinopyroxene - olivine and single grains of plag, cpx, olivine. Olivine commonly fine grained and interstitial. Hornblende and opaques very minor.

Interpretation: Olivine metagabbro.

BS-72 Coarse Metabasalt (Lower Greenstone)

Hand-specimen: Lower Greenstone - coarse, felted texture.

Thin section: Coarse, ragged to fibrous pale amphibole, some lath-like plagioclase, abundant clinozoisite, minor sphene.

Interpretation: Texture dominated by metamorphic amphibole and clinozoisite growth, but may be some relict igneous plagioclase laths. May have been a finely crystalline basalt.

BS-74 Porphyritic, Fine Grained Metabasalt (Upper Greenstone)

Hand-specimen: Upper Greenstone, fine to medium grained, with plagioclase phenocrysts, somewhat schistose.

Thin section: Well developed schistosity defined by fine matrix. Plagioclase phenocrysts, extensively altered to clinozoisite, and rotated into schistosity. Matrix is fine pale hornblende, plagioclase, clinozoisite and minor sphene.

Interpretation: Porphyritic basalt metamorphosed to lower amphibolite facies and deformed to produce strong schistosity.

BS-75 Felsic Amphibolite

Hand-specimen: Grey layer from grey and brown layered cumulate gabbro.

Thin section: Relatively fine grained rock consisting of polygonal plagioclase grains and smaller less regular amphibole grains, the whole rock dusted with very fine opaque grains.

Interpretation: Totally recrystallized metagabbro, probably with amphibole derived from complete alteration of pyroxene.

BS-75A Amphibolite

Hand-specimen: Brown layer from layered grey and brown metagabbro.

Thin section: Relatively fine grained rock with subpoligonal to elongate grains, defining a well-developed schistosity. Minerals are hornblende, plagioclase and abundant, minor finer grained sphene. Much yellow staining of grain margins.

Interpretation: Totally amphibole altered and recrystallized metagabbro, or perhaps recrystallized plagioclase - amphibole metagabbro. The abundant sphene tends to indicate that the present mineralogy is metamorphic.

BS-78 Recrystallized Porphyritic Basic Dyke

Hand-specimen: Dyke with feldspar phenocrysts, intrudes medium to coarse pyroxene gabbro.

Thin section: Strongly zoned plagioclase phenocrysts with small hornblende inclusions, and some mechanical deformation, in a matrix of sub-polygonal to elongate hornblende, plagioclase and minor fine opaques. Strong preferred orientation.

Interpretation: Dyke rock with relict plagioclase phenocrysts and matrix recrystallized under amphibolite facies conditions.

BS-82 Gneissic Olivine Metagabbro with Metallic Mineral

Hand-specimen: Rusty coarse olivine gabbro, may contain a high proportion of an opaque metallic mineral.

Thin section: Aggregates of plagioclase and of mafic minerals define a strong preferred orientation (- genissosity). Grainshapes within the aggregates are polygonal to sub-polygonal. Major mafic mineral is clinophyroxene, with minor opaque minerals, olivine and hornblende. The opaque mineral forms patches, mostly associated with mafic minerals. It has similar grainsize and grainshape to the mafic minerals, and appears to have been recrystallized in the same manner. Boundaries between opaque grains and grains of plagioclase and clinopyroxene are characterized coronas of a nearly colourless mineral, probably pale amphibole.

Interpretation: Totally recrystallized olivine meta-gabbro containing a high percentage of a metallic mineral. The rock preserves original coarser grain textures and gneissic structure.

BS-83 Schistose Metabasalt (Upper Greenstone)

Hand-specimen: Upper Greenstone - fine to medium grained greenstone with felted igneous or metamorphic texture.

Thin section: Strongly schistose rock with preferred orientation of abundant lath like plagioclase and relatively long amphibole grains. Some plagioclase grains appear to be small relict phenocrysts - partly altered and deformed. Also much fine grained recrystallized plagioclase. Abundant minor opaque minerals and scattered sphene.

Interpretation: Meta-basalt showing amphibolite facies metamorphic effects and strong deformation effects.

BS-85A Recrystallized Olivine Gabbro Dyke

Hand-specimen: From centre of dyke of medium grained olivine gabbro intrusive into coarse meta-gabbro, with much relict igneous texture, and recrystallization of igneous grains to metamorphic aggregates. Plagioclase - clinopyroxene - minor olivine - minor opaques. Opaques mostly rimmed by hornblende; opaque alteration along fractures in olivine, minor fine opaques in chleripyroxene cleavages. Abundant pale blue-green amphibole alteration along and near a planar fracture through the rock. Some plagioclase may be relict igneous - many bent crystals, and a couple of possible phenocrysts. Minor yellow serpentine(?) after olivine.

Interpretation: Probably a dyke rock, partly recrystallized, but difficult to distinguish from meta-gabbros in the main intrusion. Olivine meta-gabbro.

BS-85B Recrystallized Porphyritic Basic Dyke (with Olivine)

Hand-specimen: Margin of dyke intruding coarse to very coarse olivine gabbro.

Thin section: A few large and smaller plagioclase phenocrysts in a recrystallized matrix of plagioclase, clinopyroxene, hornblende, altered olivine and minor opaque. Olivine is altered to yellowish, fine serpentine(?) or chlorite(?). Hornblende is probably in equilibrium with plagioclase and clinopyroxene.

Interpretation: Porpyritic microdolerite dyke, largely recrystallized under amphibolite facies conditions.

BS-85C Recrystallized Prophyritic Basic Dyke (with Olivine)

Hand-specimen: As for BS-85B.

Thin section: Plagioclase phenocrysts and recrystallized phenocrysts in a matrix of sub-polygonal fine grained plagioclase, clinopyroxene, hornblende and opaques with minor aggregates of chlorite, possibly replacing olivine.

Interpretation: As for BS-85B.

BS-87 Olivine Metagabbro

Hand-specimen: Coarse olivine, metagabbro - very yellow weathered surface, indicating relatively high olivine content.

Thin section: Large mafic aggregates (mostly clinopyroxene) in a matrix of plagioclase with minor olivine. All is recrystallized to polygonal or sub-polygonal aggregates. Minor hornblende alteration.

Interpretation: Olivine metagabbro with recrystallized, metamorphic texture.

BS-88 Slightly Altered Olivine Metagabbro

Hand-specimen: Very coarse olivine gabbro showing original grainage and texture; all plagioclase finely recrystallized.

Thin section: Coarse monomineralllic aggregates (to 7 mm or more) of clinopyroxene in a matrix of recrystallized plagioclase and olivine. Minor hornblende alteration of pyroxene. Minor orange-brown chloritic alteration of olivine - with development of fine opaques along fractures and rims.
Strange greenish exsolution(?) and ensolution of opaque rhombs in clinopyroxene. Fibrous chlorite occupies whole grain positions within some clinopyroxene aggregates.
Rare reaction coronas of clinopyroxene(?) between olivine and plagioclase.
Olivine aggregates include grains of plagioclase - igneous olivine may have been interstitial, or at last poikilitic.

Interpretation: Recrystallized very coarse olivine metagabbro with minor hornblende - chlorite alteration.

BS-90 Metagabbro

Hand-specimen: Medium grained olivine metagabbro, layered.

Thin section: Polygonal, equigranular plagioclase and clinopyroxene, with fine opaque grains and possibly some orthopyroxene. No olivine. Minor hornblende including rims around some opaque grains.

Interpretation: Plagioclase - clinopyroxene metagabbro, recrystallized. No olivine, not layered on this section scale.

BS-98A Hornblende - Altered Basaltic Dyke

Hand-specimen: From near the margin of the later two basaltic dykes, intruding felsite, Moskodalen.

Thin section: A few small plagioclase phenocrysts in a matrix of interlocking plagioclase laths, with interstitial slightly smaller clinopyroxene grains and opaques. Moderate amount of hornblende and opaque alteration of clinopyroxene.

Interpretation: Partly altered micro-dolerite dyke rock.

BS-98B Hornblende Altered Microdolerite Dyke

Hand-specimen: Dyke rock with a basaltic texture - earlier of two intersecting dykes within a felsite host (Moskodalen).

Thin section: Essentially igneous texture, with interlocking plagioclase laths and interstitial mafic minerals. The mafic minerals appear to be complex intergrowths of hornblende and clinopyroxene, perhaps partial replacements of clinopyroxene by hornblende. Some of the mafic intergrowths appear to be graphic. Some of the plagioclase is dusted by fine needle-shaped inclusions.

Interpretation: A micro-dolerite dyke rock, possibly partly altered during metamorphism.

BS-98C Graphic Texture Hornblende - Biotite Microgranodiorite

Hand-specimen: Felsic intrusive rock, host to basic dykes.

Thin section: Mostly graphic intergrowths of plagioclase and quartz, with minor microcline, some perthitic. Minor blue-green hornblende, very minor opaques with sphene alteration. Very minor biotite. Much fine alteration of plagioclase. Some compositional variation in plagioclase, indicated by alteration density.

Interpretation: Graphic-textured, micro-granodiorite containing hornblende and minor biotite, partly altered.

BS-98D Clinozoisite - Hornblende Altered Porphyritic Basic Dyke

Hand-specimen: (Moskodalen) Basaltic dyke from within Ankerlia Metagreywacke.

Thin section: Altered igneous texture. A few plagioclase phenocrysts in a matrix of interlocking plagioclase laths and pale amphibole of similar grainsize. Plagioclase heavily altered to clinozoisite and sericite. Margins of plagioclase laths modified by amphibole growth. Sphene rims on opaque grains.

Interpretation: Microdolerite dyke altered by lower amphibolite facies or greenschist facies metamorphism.

BS-98E Metasediment (Ankerlia Metagreywacke)

Hand-specimen: Pale, fine grained sandy or silty metasediment, host for basic dyke, BS-98D.

Thin section: Inequigranular rock with relatively coarse quartz (some strained, recrystallized), some plagioclase of similar size, and finer clinozoisite, hornblende, minor biotite, opaque (and sphene alteration).

Interpretation: Metasediment with possible relict detrital plagioclase and quartz grains.

BS-101 Scapolite-bearing Metasediment (Ankerlia Metagreywacke)

Hand-specimen: Cream-white porphyroblasts in biotite rich metasediment. Could be epidote group mineral or scapolite.

Thin section: Small poikiloblasts have following properties: low relief, refractive index similar to quartz, one good clearage, extinction angle about 14^0, colourless, birefringence about 0,020. Mineral is not epidote group, probably scapolite.
Other minerals; plagioclase, quartz(?), biotite, clinopyroxene, hornblende, sphene, zircon.

Interpretation: Metasediment, metamorphosed to approximately upper amphibolite facies, perhaps affected by contact metamorphism.

BS-109 Layered Olivine Metagabbro

Hand-specimen: Medium grained meta-gabbro, probably contains olivine.

Thin section: Grades layering with oblique gneissosity. Grading defined by grainsize of mafic grains and percentage of mafic grains. Minor plagioclase rich layer with biotite at base of one graded layer. Mineralogy: plagioclase, clinopyroxene, orthopyroxene, minor opaques, hornblende, biotite, opatite, possibly olivine.
Hornblende rims around opaques are common.

Interpretation: Metagabbro showing cumulate graded layering and imposed gneissosity. Biotite may have been an igneous mineral.

BS-111 Metasediment (Ankerlia Metagreywache) from Gneissic Zone

Hand-specimen: Intensely folded gneissic rock; looks like a biotite bearing metasediment, but could be altered gabbro.

Thin section: Biotite rich rock, probably metasediment. Layered to lenticular rock, mafic rich and mafic poor areas.
Minerals: relatively coarse plagioclase, aggregates of plagioclase, lesser quartz (generally finer), coarse clinopyroxene (some poikiloblastic), possible minor orthopyroxene, minor hornblende.

Interpretation: Metasediment metamorphosed to probable upper amphibolite facies.

BS-112 Mylonitized Metagabbro

Hand-specimen: Medium grained meta-gabbro, folded in ontcrop. NW margin of gabbro body.

Thin section: Partly mylonized rock consisting of hornblende, clinopyroxene partly altered to hornblende, plagioclase, quartz.

Interpretation: Probably a deformed meta-gabbro, but the high quartz content is strange (under this is untwinned plagioclase).

BS-114 Metagabbro rich in Hornblende, Opaque Mineral Apatite

Hand-specimen: Meta-gabbro with concentration of a metallic mineral (weakly magnetic).

Thin section: Hornblende rich rock with large opaque grains and large apatite grains (both opaque and apatite abundant). Aggregates of recrystallized plagioclase, some crowded with inclusions.

Interpretation: Meta-gabbro rich in an opaque mineral and apatite, and heavily altered to blue-green hornblende.

BS-116 Clinopyroxene rich Layers in Olivine Metagabbro

Hand-specimen: Very pyroxene rich layers in coarse olivine meta-gabbro.

Thin section: Pyroxene rich layer is mostly clinopyroxene (some with green spinel? exsolution), may be minor orthopyroxene. Rock is plagioclase, clinopyroxene, olivine, minor chlorite/opaque aggregates after olivine(?); orthopyroxene(?).

Interpretation: Cumulate pyroxene layers in olivine meta-gabbro.

BS-117 Hornblende Metagabbro

Hand-specimen: Massive to gneissic medium grained amphibolite.

Thin section: Plagioclase - hornblende - clinopyroxene rock with minor opaques and apatite. Plagioclase forms aggregates, may be after original coarser grains. Texture is subpolygonal to irregular.

Interpretation: Metagabbro partly altered to amphibolite.

BS-120 Partly Recrystallized Very Coarse Olivine Metagabbro

Hand-specimen: Very coarse meta-gabbro, non-layered.

Thin section: Very large clinopyroxenes with exsolved orthopyroxene and green spinel. Minor hornblende and opaque within the clinopyroxene. Original very coarse plagioclase is recrystallized to aggregates of coarse, polygonal plagioclase. Some plagioclase aggregates outline probable igneous crystal shapes. Some moderately coarse hornblende and opaques. A few grains (olivine?) replaced by yellow serpentine(?). Minor graphic intergrowth of clinopyroxene and opaque mineral.

Interpretation: Very coarse olivine gabbro, partly recrystallized to coarse olivine meta-gabbro. Minor later alteration.

BS-121 Recrystallized Troctolite or Olivine Metagabbro

Hand-specimen: Very rusty meta-gabbro, coarse grained, non layered.

Thin section: Olivine rich rock (ca. 50%). Olivine - plagioclase - clinopyroxene - hornblende - opaque. Plagioclase occurs as elongate aggregates, defining a gneissic layering.

Interpretation: Olivine rich meta-gabbro.

BS-127 Hornblende - Altered Doleritic Dyke

Hand-specimen: Thick dyke transgressing sediments at a high angle.

Thin section: A few plagioclase phenocrysts in a matrix of fairly coarse interlocking plagioclase laths and clinopyroxene heavily altered to hornblende. Minor opaques.

Interpretation: Dolerite dyke with pyroxene heavily altered to hornblende.

BS-128 Mylonitized Basic Rock (Metasediment?)

Hand-specimen: Cherty rock from zone of sulphite mineralization.

Thin section: Very fine grained, inequigranular rock with strongly planar fabric.
Minerals: plagioclase, quartz(?), clinozoisite, amphibole, sphene.

Interpretation: Mylonitized metasediment or dyke rock.

BS-129 Hornblende - Altered Gabbro (Dyke?)

Hand-specimen: Gabbroic plagioclase - hornblende rock, may be a dyke.

Thin section: Igneous texture, dominated by coarse, interlocking plagioclase. Lesser clinopyroxene, with hornblende alteration, plus hornblende grains and opaques with thich hornblende rims. Exsolution of some opaques and some green spinel(?) from clinopyroxene.

Interpretation: Partly hornblende - altered gabbro. May be a dyke rock.

BS-131 Quartz bearing Metagabbro

Hand-specimen: Yellowish fine grained rock, either metasediment or meta-gabbro.

Thin section: No biotite. Plagioclase, possibly quartz, clinopyroxene, minor sphene, hornblende, clinozoisite.

Interpretation: Probably a meta-gabbro.

BS-132 Partly Recrystallized and Altered Olivine Gabbro

Hand-specimen: Coarse to medium gabbro with lath texture.

Thin section: Much lath-shaped plagioclase and aggregates of plagioclase (grains in aggregates are polygonal); well developed grains of clinopyroxene, hornblende, minor opaques. Minor yellow serpentine(?) after olivine(?). Some very good polygonal clinopyroxene aggregates.

Hornblende generally separate grains, in equilibrium with clinopyroxene.

Interpretation: Gabbro partly recrystallized to a plagioclase - clinopyroxene - hornblende rock. Olivine may have been stable at the time of recrystallization and was altered later.

APPENDIX 3: Chemical Analyses

Following are chemical analyses carried out as part of the current project. Analyses of Loftani Greenstone presented by Lindahl (1974) were also used in the diagrams in the chemistry section of this report.

Analyses were carried out by XRF methods at NGU, except for rare earths which were determined by neutron activation, at Sentralinstitutt for Industriell Forskning.

Lower limits of detection were:

SiO_2	Al_2O_3	TiO_2	MgO	CaO	Na_2O	K_2O	MnO	P_2O_2
.01%	.01	.01	.01	.01	.1	.01	.01	.01

Nb	Zr	Y	Sp	Rb	Zn	Cu	Ni	Cr	V
5 ppm	5	5	5	5	5	5	5	5	5

Ba	U	Th	Pb	Co
10 ppm	10	10	10	5

		SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MgO	CaO	Na_2O	K_2O	MnO	P_2O_5					
		Nb	Zr	Y	Sr	Rb	Zn	Cu	Ni	Cr	V	Ba	U	Th	Pb	Co
BS-20	D	48.65	15.61	11.08	1.50	7.19	10.52	2.80	.40	.17	.20					
		9	127	41	171	9	94	70	89	274	283	22	0	0	0	45
BS-21	S	60.86	13.58	6.65	.83	4.28	3.19	2.30	2.07	.07	.19					
		14	230	36	175	90	49	5	66	151	112	378	0	12	0	21
BS-35	F	72.41	14.22	1.80	.48	.76	3.97	3.70	.42	.03	.03					
		9	137	12	244	17	16	5	5	5	14	129	0	39	0	6
BS-36A	A	49.68	14.79	11.90	1.82	7.08	10.41	2.90	.05	.22	.17					
		6	137	42	156	0	103	46	34	109	331	11	0	0	0	33
BS-36B	A	49.61	14.86	12.22	1.44	7.73	10.64	2.60	.04	.24	.14					
		6	108	35	161	0	117	167	82	302	239	17	0	0	0	48
BS-39	C	48.22	19.07	6.70	.19	11.93	12.37	2.40	.07	.09	.03					
		0	14	6	162	0	37	68	258	608	65	13	0	0	0	40
BS-40	C	49.28	17.74	6.62	.27	10.61	13.15	1.60	.06	.10	.02					
		0	25	12	134	0	38	81	185	512	102	10	0	0	0	38
BS-44	L	50.61	14.86	12.22	1.31	8.16	11.64	1.40	.17	.14	.14					
		10	64	38	209	0	51	31	96	301	231	109	0	0	0	39
BS-45	F	70.37	13.36	2.88	.39	.43	1.34	3.30	6.06	.03	.05					
		10	433	50	103	136	26	9	3	0	21	608	0	23	0	0
BS-45A	D	51.01	15.05	11.48	1.83	7.17	11.36	3.00	.39	.20	.15					
		0	136	43	156	12	104	80	58	260	283	16	0	0	0	40
BS-48	L	56.84	14.31	7.87	.86	6.36	9.61	2.40	.29	.06	.19					
		9	121	29	223	8	45	0	91	184	142	190	0	0	0	21
BS-49A	M	49.32	15.61	10.22	1.19	8.06	12.36	2.20	.07	.16	.10					
		0	75	33	129	0	68	79	98	335	251	0	0	0	0	40
BS-49B	M	51.85	15.00	10.03	1.13	7.43	11.16	2.70	.26	.17	.19					
		8	82	38	153	7	75	69	72	232	197	47	0	0	0	39
BS-51	F	76.56	12.90	.30	.18	.23	2.43	4.30	.36	.01	.01					
		8	169	26	149	6	20	0	0	0	9	82	0	34	0	0
VR-108	C	50.66	14.81	7.27	.62	10.89	13.93	2.00	.06	.13	.05					
		0	42	16	140	0	41	118	129	255	190	16	0	0	0	36
VR-109	L	53.14	15.50	11.51	1.17	6.45	8.65	2.80	.38	.07	.28					
		10	100	29	261	0	32	7	94	200	180	262	0	0	0	33
VR-110	M	48.23	19.65	7.25	.40	10.87	12.11	2.30	.06	.11	.04					
		0	19	7	157	0	46	60	182	419	95	10	0	0	0	41
VR-128A	S	61.29	14.38	6.62	.86	4.52	7.91	3.70	.09	.08	.18					
		13	197	35	325	0	34	0	66	147	124	48	0	11	0	17
VR-128B	S	57.65	15.29	6.78	.91	5.04	8.07	4.20	.14	.09	.17					
		11	179	33	315	5	34	10	82	142	156	71	0	12	0	27
VR-164	G	49.41	17.26	8.72	1.27	9.08	10.17	2.60	.11	.26	.12					
		5	105	32	153	0	73	49	55	393	246	30	0	0	12	26
VR-256	C	50.63	15.75	7.73	.51	9.13	13.79	2.10	.06	.14	.04					
		0	36	14	138	0	43	71	107	354	189	20	0	0	0	39
VR-258	A	47.93	17.18	9.24	1.19	9.01	12.66	1.70	.06	.15	.12					
		0	101	28	165	0	44	0	130	297	223	16	0	0	0	44
VR-259	M	51.99	16.93	7.21	.36	9.40	9.90	2.60	.13	.14	.02					
		0	0	9	195	0	46	9	82	222	135	30	0	0	0	32
VR-264	C	50.20	14.73	11.55	1.68	9.01	12.21	2.40	.10	.19	.14					
		5	71	33	152	0	76	58	56	234	312	16	0	0	0	39
VR-439B	M	50.87	15.42	11.22	1.58	5.97	11.68	3.00	.11	.21	.27					
		0	61	39	170	0	74	32	49	120	231	33	0	0	0	35
VR-538	D	49.06	18.18	7.97	1.14	8.95	11.48	2.60	.09	.13	.13					
		0	71	25	191	0	66	57	149	252	171	15	0	0	0	30
BS-56	S	62.80	13.19	6.48	.79	3.65	7.20	2.40	1.56	.07	.16					
		12	197	33	144	45	35	0	56	151	111	369	0	13	0	17
BS-59	D	49.72	14.57	9.50	1.07	7.75	13.16	1.50	.14	.15	.08					
		0	72	29	131	0	50	397	76	542	257	59	0	0	0	46

BS-60	A	47.83	17.30	9.01	1.13	7.91	12.26	2.60	.23	.13	.11					
		5	75	30	119	8	42	10	163	245	233	18	0	0	0	47
BS-62	G	50.65	16.24	8.25	1.30	6.21	12.14	3.20	.18	.12	.14					
		7	134	34	262	0	62	59	50	312	220	11	0	0	0	34
BS-64	G	49.82	14.22	10.68	1.68	6.37	12.05	2.60	.11	.19	.16					
		5	118	47	162	0	95	70	41	144	294	15	0	0	0	38
BS-68	D	48.57	14.60	9.85	1.14	9.16	13.21	2.20	.05	.15	.02					
		0	40	22	132	0	46	120	98	400	280	10	0	0	0	39
BS-70	M	48.30	18.47	6.39	.26	8.29	13.65	1.90	.08	.10	.01					
		0	24	11	160	0	35	53	106	468	114	22	0	0	0	34
BS-72	G	47.89	18.59	7.86	1.05	7.96	11.46	2.70	.17	.12	.12					
		7	100	26	220	0	57	72	93	287	177	27	0	0	0	37
BS-73	G	49.76	18.24	7.75	1.24	7.03	10.75	3.10	.18	.10	.15					
		0	149	37	236	0	57	62	76	274	200	70	0	0	0	35
BS-74	G	48.51	16.17	9.65	1.28	6.38	12.72	1.90	.16	.15	.12					
		0	96	34	146	0	71	57	74	233	255	0	0	0	0	38
BS-78	D	48.37	16.90	10.11	1.20	7.33	12.30	2.10	.03	.17	.11					
		0	84	33	152	0	79	99	90	234	254	11	10	10	10	47
BS-83	G	49.66	14.08	12.60	2.17	5.33	10.54	2.50	.31	.13	.22					
		7	174	54	144	6	106	84	44	140	372	11	10	10	10	43
BS-85A	D	48.97	15.56	9.59	1.11	8.33	13.24	2.10	.06	.14	.04					
		0	53	31	123	0	46	71	87	273	259	13	10	10	10	37
BS-85D	C	49.57	12.91	6.26	.70	10.02	13.94	2.40	.10	.14	.07					
		0	47	30	104	0	33	50	137	1100	201	17	10	10	10	42
BS-98A	D	49.83	14.69	10.56	1.55	6.99	11.38	2.80	.20	.12	.15					
		0	130	42	153	0	79	72	75	236	264	0	10	10	10	47
BS-98B	D	49.40	13.70	12.36	1.94	6.51	11.19	3.20	.28	.20	.20					
		0	122	49	135	11	106	69	49	170	347	0	10	10	10	44
BS-98C	F	73.37	12.74	3.23	.34	.34	1.80	3.70	4.52	.04	.05					
		17	449	138	146	62	41	10	8	0	10	793	10	18	10	16
BS-98D	D	49.50	15.10	10.88	1.36	7.49	11.53	2.50	.50	.13	.11					
		12	202	29	231	22	28	0	36	136	85	256	10	10	10	10
BS-98E	S	67.42	11.56	4.56	.73	2.56	7.63	3.00	.96	.07	.17					
		0	84	32	155	19	96	73	94	288	278	46	10	10	10	42

RARE EARTH ANALYSES

Resultater (ppm).

	La	Ce	Sm	Eu	Tb	Yb	Lu
BS 20	7,8	20	4,2	1,7	1,0	3,4	0,56
35	82	190	3,4	0,93	0,32	0,98	0,16
36	6,5	18	4,1	1,6	1,2	3,6	0,61
39	0,90	3,0	0,41	0,44	0,16	0,44	0,056
44	8,7	14	4,2	1,5	0,85	4,1	0,60
48	21,3	44	4,9	1,5	0,73	2,4	0,42
49A	3,0	10,3	2,8	1,1	0,64	2,2	0,38
49B	8,9	23	4,6	1,6	0,98	4,7	0,63
60	3,2	9,8	2,5	1,0	0,56	3,0	0,45
70	1,2	4,7	0,82	0,57	0,19	1,1	0,18
73	7,6	20	3,5	1,3	0,91	2,9	0,45
78	5,3	13,2	3,1	1,2	0,76	3,1	0,41
83	9,7	22	5,6	1,9	1,3	4,9	0,74
85A	2,1	6,5	2,5	1,1	0,64	2,6	0,38
85D	2,4	8,3	2,1	0,94	0,50	2,1	0,38

Analysed Samples

		Code
BS 20	Basic dyke in metasediments	D
21	Metasediment (Ankerlia Metagreywacke)	S
35	Quartz - feldspar - hornblende - biotite granophyre (felsite)	F
36A	Equigranular amphibolite	A
36B	Equigranular amphibolite	A
39	Coarse olivine metagabbro	C
40	Gneissic olivine metagabbro	C
44	Felsic olivine metagabbro	L
45	Mylonitized and altered pyroxene granite (felsite)	F
45A	Basic dyke in felsite	D
48	Felsic metagabbro, minor biotite	L
49A	Fine metagabbro	M
49B	Coarse to medium metagabbro recrystallized	M
51	Granitic rock, recrystallized, altered (felsite)	F
56	Metasediment (Ankerlia Metagreywacke)	S
59	Hornblende gabbro dyke	D
60	Altered coarse metagabbro, non-layered	A
62	Lower Greenstone (metabasalt)	G
64	Upper Greenstone (dark, medium grained schist, layered)	G
68	Basic dyke from coarse olivine metagabbro	D
70	Medium olivine metagabbro, non-layered	M
72	Lower Greenstone - amphibole - plag - clinozoisite	G
73	Lower Greenstone - fine, porphyritic	G
74	Upper Greenstone - porphyritic metabasalt	G
78	Basic dyke in medium to coarse metagabbro	D
83	Upper Greenstone, schistose	G
85A	Centre of basic dyke intruding coarse to very coarse olivine metagabbro	D
85D	Coarse metagabbro, non-layered	C
98A	Basic dyke intruding felsite	D
98B	Basic dyke intruding felsite	D
98C	Felsic intrusive	F
98D	Basic dyke intruding metasediments	D
98E	Metasediment (Ankerlia Metagreywacke)	S

		Code
VR 108	Gneissic metagabbro, some mechanical deformation	C
109	Metagabbro, minor alteration	L
110	Layered olivine metagabbro, minor alteration	M
128A	Finely layered amphibolite schist	S
128B	Very finely layered amphibolite schist	S
134	Meta-arkose	-
164	Upper Greenstone (amphibolite - plagioclase - opaque)	G
256	Coarse metagabbro	C
258	Coarse amphibolite, minor alteration	A
259	Gneissic olivine metagabbro	M
264	Medium olivine metagabbro	C
401	Skardalen Quartzite	-
439B	Olivine gabbro	M
538	Olivine gabbro, minor alteration, intrudes metasediments	D
549	Meta-arkose	-

APPENDIX 4: Sample Locations

Locations are listed for samples, photos etc from the present study (BS numbers) and some of the samples from Lindahl's (1974) study (VR numbers, and 516-, 555-numbers). The locations were transfered from field maps based on aerial photographs, to an enlarged topographic map. Accuracy of location is very variable.

The map references refer to the Nordreisa and Reisadalen 1: 50 000 maps (1734 IV and 1734 III).

Location	Map Reference	Location	Map Reference
BS 2	132-326	BS 62	2360-4045
3	194-446	64	2315-4060
10	2230-4315	65	2280-4130
11	2160-4330	68	2220-4120
13	2195-4450	70	2160-4110
18	1895-4345	72	2350-3990
20	1890-4350	73	2343-4040
21	1882-4360	74	2330-3994
25	1917-4310	75	2350-3982
27	1935-4310	77	2290-3994
28	1945-4310	78	2275-3994
29	1955-4310	82	2200-3962
35	1964-4265	83	2340-3880
36	2310-4220	84	2210-3895
39	2160-4330	85	2210-3900
40	2175-4330	87	2165-3935
44	2130-4320	88	2116-3950
45	1817-3936	90	2048-2936
48	1940-3970	91	2025-3980
49	1940-4050	92	2002-3980
51	191-327	98	132-333
52	2030-4495	101	1835-4215
56	2030-4480	104	2100-4218
58	2300-3890	106	1835-4795
59	227-388	109	2015-4253
60	2240-3880	111	2015-4400

Location	Map Reference
BS 112	2060-4440
113	2080-4395
114	2080-4305
116	2115-4295
117	2225-4360
119	2160-4355
120	2205-4240
121	2210-4220
122	2230-4210
123	2245-4200
125	1880-4215
126	1790-4060
127	1790-4030
128	1810-4010
129	1820-4010
131	1820-4005
132	1870-4072
133	2090-4500
134	2065-4495
135	2065-4500
136	1948-4218
137	2078-4290
138	2100-4305
139	2115-4295
140	2210-4205
VR 1, 2	2380-3810
23	2340-3990
60	2312-4422
105, 106	2065-4375
107	2112-4370
108	2122-4361
109	2122-4359
110	2135-4371
112	2332-3720
127	2115-3240
128	2095-3245

Location	Map Reference
VR 136	2350-3457
137	2355-3546
154	2409-4283
155	2460-4183
156	2456-4185
157	2459-4188
158	2448-4140
159	2415-4216
160	2395-4218
162	2329-4535
167	2286-4355
188	2365-3905
250	2176-4484
251	2196-4466
252	2379-3745
255	2412-3808
256	2162-4391
257	2177-4319
258	2212-4333
259	2159-3883
260	2248-3850
261	2205-3910
262	2173-3922
263	2130-3960
264	2105-4048
265	2066-4072
266	2063-4085
303	2277-3678
309	2300-3640
334	2260-3720
359	1596-4521
401	2225-4522
402	2363-4342
403	1875-4582
406	1900-4423
407	1872-4488
408	1873-4481
411	1870-4516
414	2442-3960

Location	Map Reference
VR 415	2438-3980
416	2435-3978
424	1639-4442
428	1996-4296
431	2091-4315
432	2162-4271
438	1985-4075
439	2020-4010
441	1890-4064
467	2450-3843
469	2413-3773
488	1510-4590
521	2388-3972
525	2370-3917
528	2363-3887
530	2290-3723
533	2316-3735
534	2328-3732
538	1782-3973
548	2430-3760
553	2321-3535
554	2319-3532
555	2320-3526
557	2313-3529
560	1965-3826
603	1280-4425
516-1194	2320-3708
1195	2362-3730
1205	2135-3775
1208	2268-3672
1215	2216-3603
1339	1825-4245
555- 55	2359-3917

Descriptions of Units

Oa – fine grained, finely planar bedded psammitic metasediment: quartz-plagioclase-hornblende-biotite-clinozoisite. Contains abundant doleritic dykes.

zg – intensely folded gneissic metasediment and/or metagabbro, felsic mobile material common.

f – felsic intrusions present; granitic to pegmatitic: quartz-feldspar-hornblende ± biotite.

g5 – medium grained metagabbro, non-layered to poorly layered.

g4 – medium grained metagabbro, mostly well-layered.

g3 – medium (to coarse) grained olivine-bearing metagabbro, mostly well-layered.

g2 – coarse to medium grained, olivine-bearing metagabbro, non-layered to diffusely layered.

g1d – zone of basic dykes in g1.

g1 – coarse to very coarse, olivine-bearing metagabbro, non-layered to weakly layered.

a – intermixed medium grained, equigranular amphibolite and porphyritic to gneissic amphibolite.

a1 – layered amphibolite, texturally similar to g4.

Ok – interbedded pelitic and psammitic metasediments: quartz-biotite-carbonate (–amphibole–clinozoisite–muscovite).

zs – fine grained hornblende rich schist, minor chloritic zones; may be derived from underlying greenstone or from overlying amphibolite.

xxxx – Fe-Cu sulphide layers, lenses and disseminations.

Olu – schistose greenstone, much diffusely layered and folded(zs); and massive porphyritic greenstone

Oll – fine to coarse grained greenstone (metabasalt), matted metamorphic textures, and relict plagioclase phenocrysts common, minor well-preserved pillow structures.

Vg – psammopelitic to pelitic schists (quartz-muscovite-biotite ± carbonate, amphibole, clinozoisite, garnet) interbedded with thin and thick units of marble and conglomerate.

Vgf – finely bedded yellowish quartz-muscovite bearing marble, grading locally to matrix-supported polymictic conglomerate.

Vgj – finely bedded yellowish quartz-muscovite bearing marble.

Vgr – clast-supported conglomerate; quartzite pebbles in micaceous matrix.

Vn – quartzite, micaceous schist, calc-mica schist, graphitic phyllite, minor marble.

Vns – massive, poorly bedded quartzite (containing minor plagioclase and mica). Grades southward into interbedded marble and quartzite.

Vno – pelitic schists (quartz-muscovite-biotite-garnet ± hornblende, chlorite, plagioclase, clinozoisite, staurolite) and relatively pure grey marble (with scattered zoisite crystals).
Vno1 Marble in Vno.

Vnr – interlayered poorly bedded quartzite (with minor plagioclase, mica and pyrite) and graphitic phyllite.

Væ – relatively pure grey marble, finely bedded; scattered zoisite crystals.

Nu – pelitic to psammitic schists: quartz-biotite-muscovite ± plagioclase, garnet. Includes minor graphitic schist and hornblende-bearing schist. Grades to underlying meta-arkose.

Nl – bedded meta-arkose: quartz-K-feldspar-plagioclase-muscovite-biotite ± garnet, clinozoisite.

Structural Units		Stratigraphic Units		
Reisa Nappe Complex	Vaddas Nappe	OKSFJORD GROUP	Ankerlia Metagreywacke Oa	gneissic zone zg / Vaddasgaisak Metagabbro g
				Gryta Amphibolite a
				schistose zone zs
			Ak'kejav'ri Calc-Biotite Schist Ok	upper Olu / Loftani Greenstone Ol / lower Oll
		VADDAS GROUP	Guolosjav'ri Formation Vg	Frokosthaugen Conglomeratic Marble Member Vgf
				Jiek'kejåkka Marble Member Vgj / Raššavagge Conglomerate Member Vgr
			Nitsimvarre Formation Vn	Skardalen Quartzite Member Vns
				Oksfjorddalen Schist Member Vno
				Rieppesjåkka Quartzite Member Vnr
			Gæirajavre Marble Væ	
Kalak Nappe Complex	Čorrovarre Nappe	NAPPO-JÅKKA GROUP	Luovosskaide Meta-Arkose Nu	
			Loddevagge Meta-Arkose Nl	

GEOLOGY OF THE VADDASGAISAK AREA.

Compiled by B. Stevens from mapping by I. Lindahl in 1970-1972, and B. Stevens in 1982. Note: considerable interpretation in places, see also field sheets.

Topographic base from Nordreisa, Reisadalen, Kvænangen and Kvænangsbotn 1:50,000 sheets.

N

0 1 km

USB 1982 GEOLOGICAL MAP VADDAS, NORDREISA, TROMS	MÅLESTOKK 1:20 000	MÅLT B.S. TEGN B.S. TRAC B.S. KFR B.S. I.L.	
NORGES GEOLOGISKE UNDERSØKELSE TRONDHEIM	TEGNING NR. 1900/47H-01	KARTBLAD 1734 I-IV	

Vaddas Area 1:20,000

Locations of samples, photos, etc.

.BS locations from study by Brian Stevens, 1982

.VR
.516-
.555 } locations of samples thin-sectioned for Lindahl (1974)

Note: some of Lindahl's samples occurred further south and west of the area shown here.

USB 1982 SAMPLING AND LOCALITY MAP VADDAS, NORDREISA, TROMS	MÅLESTOKK 1:20 000	MÅLT B.S. TEGN B.S. TRAC B.S. KFR. B.S. I.L.	
NORGES GEOLOGISKE UNDERSØKELSE TRONDHEIM	TEGNING NR. 1900/47H-02	KARTBLAD 1734 I-IV	