The geology of the Váddás area, Troms: a key to our understanding of the Upper Allochthon in the Caledonides of northern Norway

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The Váddás area in the North Norwegian Caledonides is underlain by the Čorrovárri Nappe, the uppermost unit of the Kalak Nappe Complex, and the overlying Váddás Nappe representing the lowermost unit of the Reisa Nappe Complex. Both nappes form part of the Upper Allochthon. Only the upper part of the Čorrovárri Nappe, the Nahpojohka Group, which at c.580 Ma was intruded by a rift-type, intracratonic to marginal basin, dolerite dyke swarm and related gabbro source rocks, has been studied in detail. It is proposed that the rocks of the Čorrovárri Nappe were deformed during a poorly understood Finnmarkian tectonometamorphic phase, involving subduction and exhumation at around 500 Ma, and were part of the margin of the Baltican continent. The Čorrovárri Nappe served as basement for the overlying stratigraphic sequence of the Váddás Nappe, although the contact now represents a major tectonic break.

The rocks of the Váddás Nappe constitute a unique, relatively undisturbed, right-way up stratigraphic and magmatic succession. Its depositional history is bipartite; firstly, a continental sequence with shallow-water sediments, ending with a non-tectonic hiatus of unknown duration. This continental succession is overlain unconformably by a transgressive Late Ordovician-Silurian succession dated by fossils, and believed to have been deposited on the thinned edge of Baltica. This was broadly coeval with the development of a short-lived transtensional or marginal basin, with conglomerates, lava flows and continental slope sediments intruded by tholeiitic gabbros.

The descriptions of the units contribute towards correlation between the Troms and western Finnmark regions and with the Seve-Köli Nappe Complex to the southwest in Sweden. Several workers have challenged the interpretation of the relatively undisturbed, right-way up stratigraphic succession of the Váddás Nappe. They see it as a tectonostratigraphic succession with thrusts and regional nappe-folds introducing elements of the underlying Čorrovárri Nappe. This controversy in the tectonostratigraphic history of both nappes is discussed in the light of the recently proposed palaeogeographical rotation history of Baltica.

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Introduction

Geography

The Váddás area is situated in the northern part of Troms County, 69º45' N and 21º35' E, approximately 20 km East of the village of Nordreisa (Fig. 1). The landscape was largely formed during the last glaciation, which culminated approximately 10,000 years ago. U-shaped valleys are partly filled with glaciofluvial material above the upper marine limit, whereas glaciofluvial and marine sediments occur below this (Sveian et al. 2003). V-shaped hanging valleys commonly form the side valleys of the main drainage system. The mountains extend to 1100–1300 m above sea level, many with plateaus on the tops, which in this region most likely were not covered by ice (or were covered temporarily by thin, cold-based ice) during the last glaciation. In the mapped Váddás area the valley floors are 100–250 m asl., and the Váddašgáissát plateau 1000–1300 m asl. Permafrost occurs in the highest elevated areas.

Historical review

Petersen (1870) compiled the first geological map of the area, mostly based on observations whilst travelling by boat along the coast and on a poor-quality topographic base map. Further important geological observations from the area were published by Helland (1899). Th. Vogt (1927) published the first relatively accurate map and description of the Váddás area, as a result of his involvement in the exploration activity for massive sulphide deposits during the period 1914–18. Prospecting for massive sulphides and base metals has taken place in this region from the 1890s to the middle of the 1970s (Lindahl 1974), but so far only mineralogical data from the ores have been published (Bjørlykke & Jarp 1949, Bjørlykke 1960, Lindahl 1975).

Extensive geological work was undertaken in the northern Troms region, in the 1960s and 1970s, mostly within the Caledonian Nappes. Information on the geology of the Váddás area includes theses by Pearson (1970) in the

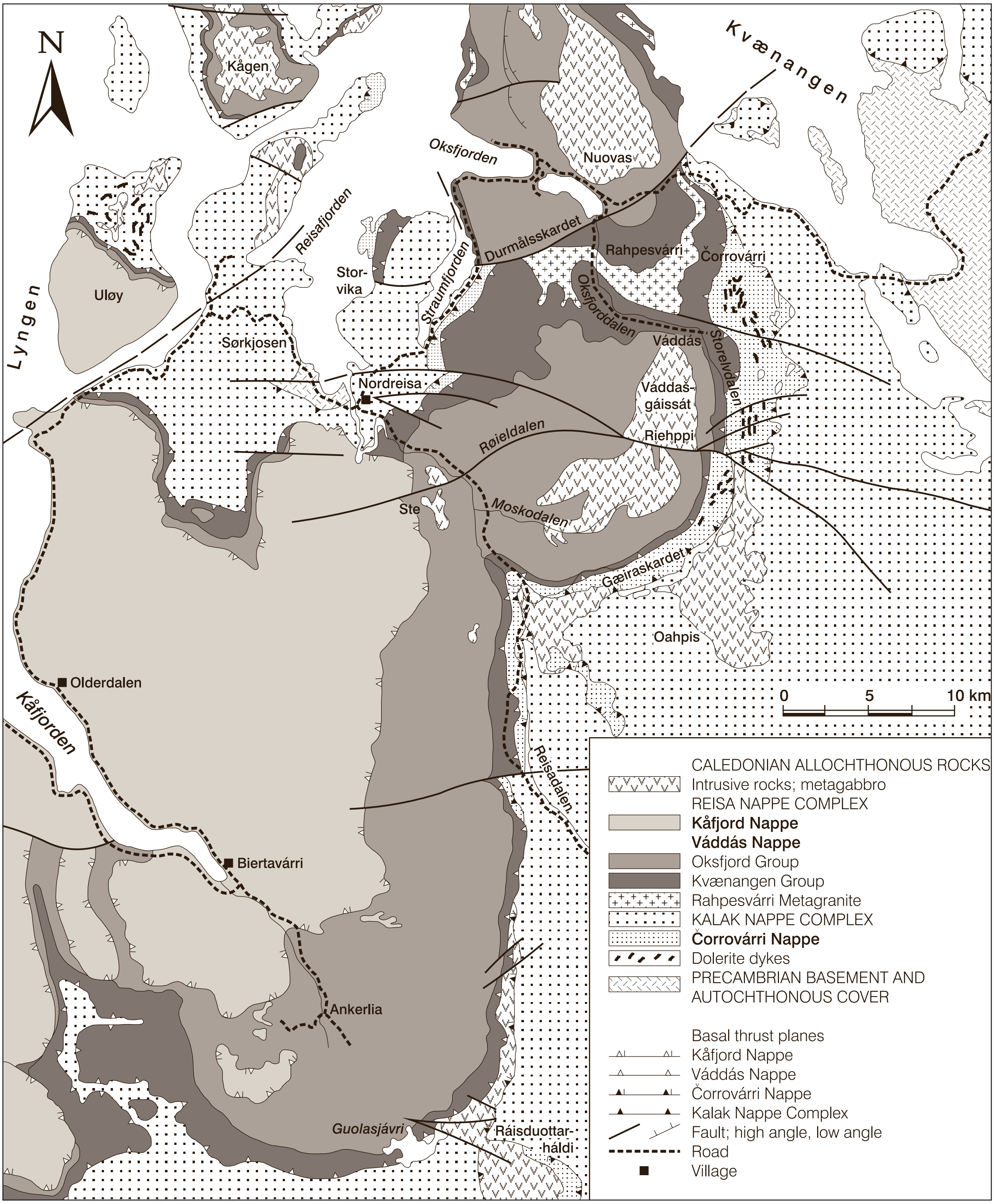


Fig. 1. Main geological features of the Váddás-Biertavárri region, northern Troms.

Straumfjord area, Strand (1971) just north of Váddás, Armitage (1972) west of Nordreisa, Kleine-Hering (1973) in the Moskodalen–Reisadalen area, Lindahl (1974) in the Váddás-Riehppi area, Wontka (1974) in Oksfjorddalen–Nordreisa area, and Zobel (1974) in Reisadalen. Quenardel (1977), Binns (1978) and Zwaan & Roberts (1978) undertook a first comprehensive correlation of the Caledonian nappe pile in West Finnmark and North Troms. A large number of unpublished reports are referred to by Lindahl (1974), including the following: Smith (1910), Sjøgren (1913), J.H.L. Vogt (1920), Th. Vogt (1952), Bjørlykke & Færden (1956), Barkey (1964), Lindahl (1969), Wontka (1971, 1972), Zobel (1971, 1972), Kleine-Hering (1972) and Kruse (1975). K.B. Zwaan of the Geological Survey of Norway (NGU) was responsible for the compilation of the 1:250.000 map-sheet Nordreisa (Zwaan 1988), and has, besides compilation, undertaken extensive mapping in the region (Zwaan et al. 1975, Bakke et al. 1975, Zwaan & Roberts 1978, Gautier et al. 1986, 1987). From 1985 to 1988, a detailed mapping and laboratory investigation on the rocks from the Čorrovárri area were carried out by Zwaan & van Roermund (1990). Their results are incorporated in this paper.

This paper is based partly on the thesis of Lindahl (1974): a detailed study of the sedimentary and volcanic rocks below and partly above the Váddás ore horizon. It is also based on work by Stevens (1982), undertaken while working for the Geological Survey of Norway on exchange from the Geological Survey of New South Wales. Stevens concentrated on the intrusive rocks. The stratigraphy of the area, as presented here, is the result of the cooperative work of the authors. A first manuscript draft was written in 1984. In late 1990, the area was revisited by the authors and sedimentologist V. Melezhik, confirming the right way up of the entire sequence of sedimentary rocks of the Kvænangen and Oksfjord Groups. In 2004 the manuscript was revised. K.B. Zwaan has rewritten the chapters: Abstract, Geology in Introduction and Summary of structure, metamorphism and tectonostratigraphy in the Váddás area, Age of sequence and regional correlation, and Conclusions.

Geology

The bedrock in the Váddás area is a part of the Caledonian nappe sequence, comprising the uppermost Čorrovárri Nappe of the Kalak Nappe Complex (KNC), and the lowermost Váddás Nappe of the Reisa Nappe Complex (RNC). In terms of Caledonide tectonostratigraphy, the KNC has been considered to form most of the Middle Allochthon and the RNC the Upper Allochthon (Roberts & Gee 1985). However, more recent compilatory work has favoured a lowermost Upper Allochthon position for the KNC and the correlative Seve Nappe Complex of Sweden (Andréasson et al. 1998, Siedlecka et al. 2004).

Only the upper part of the Čorrovárri Nappe, the Nahpojohka Group, has been studied in detail. It consists of monotonous, arkosic, semipelitic sedimentary rocks, locally carbonate-bearing, which are considered to be Neoproterozoic fluvial sediments laid down on the Fennoscandian Shield. At c.580 Ma they were intruded by a, rift-type, continental marginal basin, dolerite dyke swarm and related gabbro source rocks (Zwaan & van Roermund 1990, Roberts 1990). This rifting phase was earlier proposed for the correlative Seiland Igneous Province farther to the north (Krill & Zwaan 1987, Andréasson 1987). The nappe, with its mafic to ultramafic igneous rocks, extends to the southwest to the Ráisduottarháldi area where it wedges out beneath the Váddás Nappe (see Fig.1). In this area, the Čorrovárri Nappe contains the Halti Igneous Complex. The conflicting ages for this complex obtained in recent years cast doubt on the traditional view of a two-stage development of the Caledonian orogeny after the Vendian rift phase: i.e. an early Finnmarkian event at c. 500 Ma and a later Scandian event around 400 Ma. This topic is discussed in a final chapter, with an alternative interpretion that the Čorrovárri Nappe rocks could have formed the basement for the Váddás stratigraphic succession.

The Váddás Nappe constitutes a unique, relatively undisturbed right way up stratigraphic and magmatic succession. Its depositional history is bipartite. Firstly, a continental succession represented by metasedimentary rocks of the lower unit, the Kvænangen Group, was deposited in shallow-water and show large facies changes along strike, as well as changes in thickness and composition. A general trend is an increase in thickness from south to north. The contact between the two highest formations in the unit is characterised by a non-tectonic hiatus of unknown duration, forming a non-angular unconformity. It is overlain by a transgressive Late Ordovician–Silurian formation dated by fossils (Binns & Gayer 1980) which heralds a major shift in the depositional history. The upper unit, the Oksfjord Group, is dominated by pelitic metasediments, typically greywackes (Armitage 1972). It includes the Loftani Greenstone Member (partly pillow basalt) in the lowest part of the Oksfjord Group in the Váddás area. Here, the maximum thickness of the unit is 500 m, but it wedges out both to the northeast and to the southwest over a total distance of approximately 40 km. The lava flows wedge out laterally into conglomeratic marble of the Kvænangen Group. Pillowed mafic lava flows are described within the pelitic sedimentary succession (Padget 1955, P. Bøe pers. comm. 1973).

The major, volcanogenic, massive sulphide deposits in the Váddás district are located on top of the Loftani Greenstone Member. The deposits are Cu-Zn to Zn-Cu dominated, with a minor lead content. One major deposit, the Riehppi deposit, is located in a lower part of the greenstone. Smaller sulphide deposits with higher base-metal grades occur in the Váddás area in the greywacke succession above the greenstone, in a similar position to that of the deposits in the Biertavárri district (Vokes 1957). The upper part of the Oksfjord Group is a monotonous greywacke unit (the Ankerlia Formation), originally laid down as turbidites and reworked to contourites.

The Váddašgáissát Metagabbro (VM) intruded the Ankerlia Formation and varies from olivine gabbro to gabbro in composition, with magmatic layering and a granulitic metamorphic texture. Towards its borders it is gneissic and sheared. An extensive doleritic dyke swarm is found in the metagreywacke host rock around the VM. Slightly younger, but related K-rich felsites are also present. The greenstones, and the VM have the chemical composition of ocean floor tholeiites.

The general succession of shallow-water sedimentary rocks capped by lava flows and followed by continental slope deposits intruded by gabbros is typical for the Upper Allochthon in Troms county and for its southwestern correlatives, the Köli Nappe Complex, in Sweden (see compilation by Andréasson et al. 2003). Its correlation to the north with the upper part of the Sørøy-Seiland Nappe succession in Finnmark is disputed (Slagstad et al. in press). Pearson (1971) and Ramsay et al. (1985) challenged the undisturbed character of the succession and regarded it as a tectonostratigraphic sequence with thrusts and regional fold-nappes introducing elements of the underlying Čorrovárri Nappe.

Stratigraphy

Although we have attempted to use established names from Váddás and adjacent areas, it was necessary to introduce many new names. The stratigraphic succession is shown in Fig. 2. The stratigraphic sub-division of Th. Vogt (1927) does not conform to modern requirements for stratigraphic nomenclature. A variety of stratigraphic names have later been used in the Váddás area and adjacent districts (Padget 1955, Wontka 1971, Armitage et al. 1971, Zwaan et al. 1975, Zwaan & Roberts 1978). Lindahl (1974) proposed changes of name for some of Th. Vogt's units (1927), but as they were not strictly in accord with the new requirements for stratigraphic nomenclature they were not published.

Kalak Nappe Complex (KNC)

Čorrovárri Nappe

The Čorrovárri Nappe consists mainly of a Neoproterozoic sedimentary succession. The succession is incomplete and truncated by the overlying Váddás Nappe. The rocks underwent Caledonian polyphase metamorphism in the highest greenschist facies, locally up to upper amphibolite facies, and display a penetrative schistosity (Zwaan & van Roermund 1990). The Loddeväggi Formation forms the upper part of a mega-lens in the Váddás area in which sedimentary structures are preserved in the 'pressure shadow' of the numerous mafic dykes. In the centre of the dyke swarm the rocks are migmatitic due to the effects of contact metamorphism (Zwaan & van Roermund 1990). The Luovosskaidi Formation is tentatively interpreted as a mylonitised upper part of the Loddeväggi Formation.

Nahpojohka Group

Derivation of name: The Nahpojohka Group takes its name from the stream running through the Group east of Riehppi. The name Nahpojohka Group was first used by Stevens (1982), and subdivided into the Loddeväggi Formation, Luovosskaidi Formation and Skartasvagge Formation. The Skartasvagge Formation outcrops east of the studied area. The name Nahpojohka Group replaces Th. Vogt's (1927) and Lindahl's (1974) Lilleelv Division.

Previous work: This unit was described in part by Th. Vogt (1927), Lindahl (1974), Zwaan et al. (1975) and Zwaan & van Roermund (1990).

Distribution: The unit occurs in the easternmost part of the area, east of Luovosskaidi, east of Riehppi along Nahpojohka, and on Lán'kavárri southeast of Riehppi (Fig. 2).

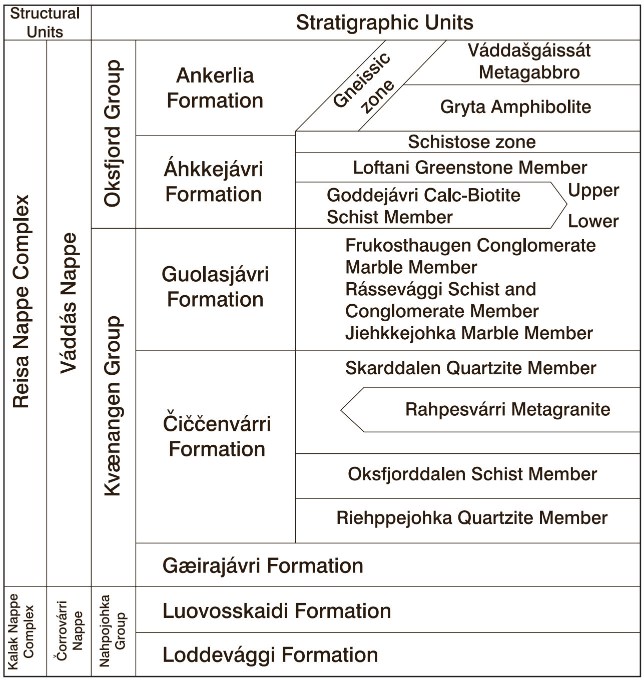


Fig. 2. Tectonostratigraphy and lithostratigraphy of the Váddás area.

Type area/section: An east–west profile along Jiehkkejohka–Nahpojohka–Bogijohka (UTM 524200-7737200 to UTM 525400-7736700, Kvænangsbotnen mapsheet, 1734.2) is nominated as typical for the Group, excluding the Skartasvagge Formation.

Relationships and thickness: The Naphojohka Group is subdivided into two formations (see Fig. 2). The lowest formation, the Loddeväggi Formation, has not been studied in detail in this work. East of Váddás, the thickness is approximately 300 metres according to Zwaan et al. (1975). In contrast to all other units in the Váddás area, the Luovosskaidi Formation increases in thickness from north to south. Contacts with underlying and overlying rock units are considered to be tectonic.

Description: The Naphojohka Group consists of two meta-arkose formations. The lowest formation, the Loddevaggi Formation, represents the most typical meta-arkose, while the upper formation, the Luovosskaidi Formation, shows gradually increasing amounts of psammo-pelitic to pelitic sedimentary rocks upwards in the succession, and has a carbonate-bearing schist near the top. The Loddeväggi Formation is intruded by tholeiitic dykes. Such dykes do not occur in the Luovosskaidi Formation.

Loddeväggi Formation

Derivation of name: The meta-arkoses occupy most of the valley of Loddeväggi east of Váddás (Fig. 2). The name Loddeväggi Formation was introduced by Stevens (1982).

Distribution: This unit occurs in the easternmost part of the area, east of Luovosskaidi, east of Riehppi along Nahpojohka, and on Lán'kavárri southeast of Riehppi (Fig. 2).

Type area/section: As for the Naphojohka Group.

Relationships and thickness: The Loddevággi Formation is the lower of two meta-arkose formations which constitute the Nahpojohka Group in the Váddás area. Only the upper part was studied in detail. According to Zwaan et al. (1975), the total thickness east of Váddás is 300 m. The upper boundary is defined by a change from psammitic to more psammopelitic compositions. This is possibly due in part to strong mylonitisation towards the basal thrust of the Váddás Nappe.

Description: The meta-arkoses of the Loddevággi Formation are light to medium grey and contain interbedded thin layers of mica schist (± garnet) and amphibolite (± garnet) lenses. East of Nahpoorda, there are numerous tholeiitic metadoleritic dykes (Zwaan & van Roermund 1990); these show a gabbroic texture in their thicker parts. In the 'pressure shadow' of the dykes, true cross bedding and a depositional mineral banding can be seen. In the contact aureoles of gabbroic intrusions a gneissic texture is developed in the meta-arkose.

The Loddevággi Formation has equal amounts of quartz and feldspar, both microcline and plagioclase. Some of the plagioclase is weakly sericitised. Muscovite and biotite are minor constituents, poikiloblastic garnet occurs as an accessory mineral. Other accessories are apatite, slightly rounded zircons, titanite, epidote and amphibole.

Luovosskaidi Formation

Derivation of name: The meta-arkose was named by Stevens (1982) after the grassy Luovosskaidi mountain east of Váddás.

Distribution: Most of Luovosskaidi consists of this unit, and it is also found in Storelvdalen from Frukosthaugen to Nahpoorda. South of the Riehppi fault it is exposed at Lán'kavárri and continues west to southwestwards through Gæiraskardet to Reisadalen and Biertavárri.

Type area/section: As for the Naphojohka Group

Relationships and thickness: The Luovosskaidi Formation increases in thickness from north to south (Plate 1), in contrast to the thickness trends in the overlying Kvænangen Group. The contact with the Kvænangen Group is discontinuous. In the northern part of the area, there is an abrupt change from psammopelitic metasediment to the pure marble in the Gæirajávri Formation. In the southern part, a carbonate-bearing metasedimentary rock forms the upper part of the Luovosskaidi Formation. There, the contact appears to be gradational, thought to be due to tectonic intercalation. The lower boundary is also interpreted as tectonic. The psammites, containing equal amounts of microcline and plagioclase show a gradual upward change to pelites due to strain-related recrystallisation close to the base of the overriding nappe. Muscovite was formed from the breakdown of K-feldspar and plagioclase and becomes dominant. It is therefore conceivable that the formation is not a valid sedimentary unit; rather, the rocks may be representative of mylonitised Loddevággi Formation lithologies.

Description: The Luovosskaidi Formation consists of metasedimentary rocks and shows a grading upwards from predominantly psammitic to psammopelitic and in part pelitic. The metasediments were described by Pearson (1971) as banded semipelites. The middle part of the unit at Gæiraskardet consists of a 50–100 m-thick, graphite-bearing mica schist. The upper parts of the Luovosskaidi Formation normally contain small pink to reddish garnet (about 1 mm in size). The meta-arkose splits into slabs along cleavage planes, showing silvery micas, and attempts have been made to use the rock for construction purposes. Intercalated in the meta-arkose, locally, there are thin (0.5 m) bands of garnet-hornblende to biotite schists which are thought to represent strongly sheared and altered mafic dykes (Lindahl 1974).

The meta-arkoses of the Luovosskaidi Formation are composed of quartz and feldspar, with plagioclase as the dominant feldspar. Locally, the mica content is up to 50%, with either muscovite or biotite predominant. The garnet is commonly poikiloblastic with most inclusions randomly orientated and occurring in the central parts of the crystals. Amphibole crystals form the nuclei of some garnets and lens-shaped garnets have grown along the schistosity, leaving a halo depleted in dark minerals. Other large poikiloblastic crystals are biotite and, especially in the upper parts of the unit, amphibole and zoisite. The poikiloblasts commonly show sign of strain rotation after growth. The matrix has a mylonitic schistosity toward the base of the Váddás Nappe. Accessory minerals are epidote, clinozoisite, titanite, apatite and chlorite, and there are also rounded grains of zircon and tourmaline.

Reisa Nappe Complex (RNC)

Váddás Nappe

The rocks of the Váddás Nappe are subdivided into the Kvænangen and Oksfjord Groups. The succession is proven to be right way up from the base of the Nappe, including the Loftani Greenstone Member in the Áhkkejávri Formation. The Ankerlia Formation is strongly affected by the VM such that decisive sedimentary structures are not recognised. The sedimentary and volcanic rocks in the Váddás Nappe are of Late Ordovician to Silurian age, dated by fossils (Binns & Gayer 1980). Pearson (1971) suggested that the succession was deformed by a regional Kvænangen Nappe Fold, but this was not confirmed by the detailed mapping of Wontka (1971), Kleine–Hering (1972), Lindahl (1974) and Zobel (1971). Recent U-Pb dating of the Rahpesvárri Metagranite (Corfu et al. 2005) confirms our earlier, less precise Rb-Sr dating (this paper) and does favour the existence of the Kvænangen Nappe Fold (see summary section for interpretation). The thickness of the Kvænangen Group increases significantly from south to north in the area; over a 20 km strike length, from 200 m at Gæirajávri to more than 1 km close to Váddás (Lindahl 1974). The total thickness of the Oksfjord Group cannot be determined, but the Áhkkejávri Formation is up to 800 m thick. The Loftani Greenstone Member wedges out to the southwest from Riehppi towards

Reisadalen, and from Vaddas to the west towards Nordreisa. Stratigraphic columns along strike are shown in Plate 1.

The rocks of the Váddás Nappe underwent Caledonian amphibolite-facies metamorphism up to kyanite grade, with penetrative shearing in the Kvænangen Group close to the base of the nappe. The Oksfjord Group is less disturbed and sedimentary structures are better preserved, but the succession is not complete as it is truncated by the overlying Kåfjord Nappe. The intrusion of large gabbros in the Oksfjord Group led to disturbances in the succession, and the metasediments were converted to gneisses in their contact aureoles.

Kvænangen Group

Derivation of name: Kvænangen Group rocks form a very characteristic rock succession recognisable throughout Troms county. It is most completely developed in the Kvænangen area south of Váddás.

Th. Vogt (1927) named the Group the Upper and Lower Vaddas Division, later named the Kvænangen Group by Lindahl (1974), but this included the Áhkkejávri Formation which is now included in the Oksfjord Group (Fig. 2). The Kvænangen Group is subdivided into three formations: a regional marker unit named the Gæirajávri Formation, and the Čiččenvárri and Guolasjávri Formations.

Previous work: Th. Vogt (1927) described the Group and a detailed profile at Frukosthaugen. Later, the rocks in the Kvænangen Group were described by Pearson (1971) and Wontka (1971,1974) from the Straumfjord area, by Lindahl (1974) from the Váddás–Riehppi area, by Wontka (1972) and Zobel (1971,1972,1974) from the Reisadalen area, by Padget (1955) from the Biertavárri district and by Stevens (1982) from the Váddás area, as the Váddás Group.

Distribution: The Kvænangen Group can be followed from the Straumfjord area through Váddás to Reisadalen and farther to Biertavárri. The Group was mapped in detail from Gæiraskardet to Skarddalen northwest of Váddás (Lindahl 1974), and covers the lowest part of the hillside west of Lán'kavárri, and the lowest part of the valley side west of Storelva towards Váddašgáissát. In the northwest it covers the upper part of Oksfjorddalen and continues to the Skarddalen-Boatkavárri area (Fig. 1 & Plate 1).

Type area/sections: Two E-W profiles are nominated as typical for the Group, because of its rapid sedimentary facies changes. (1) A profile just south of Frukosthaugen (Th. Vogt 1927) from Storelva (UTM 524400-7741100, Kvænangen map-sheet, 1734.1) to Frukosthaugen (UTM 523600-7741100, Nordreisa map-sheet, 1734.4); and (2) a profile southeast of Riehppejávri, from Jiehkkejohka (UTM 523400-7736900) westward to map reference UTM 522800-7736900 (Reisadalen map-sheet, 1734.3).

Relationships and thickness: The Kvænangen Group is subdivided into three formations (see Fig. 2), and the two upper formations are further subdivided into four and three members, respectively. The Kvænangen Group is characterised by rapid thickness changes, from 200 m at Gæiraskardet in the south to more than 1000 m at Skarddalen in the north. The increase in thickness is greatest in the Čiččenvárri Formation (Plate 1). The upper boundary of the Skarddalen Quartzite member in the upper part of the Group forms a regional stratigraphic hiatus of unknown importance and duration and the overlying Guolasjávri Formation has a transgressive character.

The Group consists mainly of sedimentary rocks; the intercalated marbles are exclusively calcitic. The Group also includes thin amphibolite lenses thought to be strongly sheared and altered mafic dykes/sills. North and northwest of the detailed mapped area the Rahpesvárri Metagranite is tectonically intercalated in the Group. The Metagranite is included in the description because of its importance for understanding the tectonometamorphic history (see later sections). The contact of the Kvænangen Group with the underlying Nahpojohka Group represents a major tectonic break, is mostly sharp, and characterised by mylonites and phyllonites. Only at Lán'kavárri is the change somewhat gradual, due to tectonic intercalation of rocks from underlying and overlying units. The contacts between each Formation and Member within the Kvænangen Group are mostly sharp. The contact between the Kvænangen Group and the overlying Oksfjord Group is sedimentary and sharp; however, the rock types do interfinger to some extent (Plate 1).

Gæirajávri Formation

Derivation of name: The Gæirajávri Formation (Lindahl 1974) takes its name from the small lake Gæirajávri south-southeast of Riehppi, under which the unit passes.

Distribution: The Gæirajávri Formation is the best marker unit in the northern Troms region, and is known from south of Biertavárri (Padget 1955) to the Kvænangen Peninsula 30 km north of Váddás (Zwaan 1988). In the Váddás area, the unit was mapped from Gæirajávri through Lán'kajávri and is exposed in the topographic break between the flat Lán'kajávri and the steep Riehppegáisá. From Nahpoorda it is found just east of Storelva in the valley, and continues over the western part of Luovosskaidi.

Type area/section: A reference area is nominated in the Gæirajávri area (UTM 520000-7731300, Reisadalen map-sheet, 1734.3).

Relationships and thickness: The upper part of the Gæirajávri Formation consists of a pure grey calcite marble, mostly with sharp contacts, and is 10–20 m thick in the Váddás area. The lowest part of the Formation consists of a carbonate-bearing mica schist, a few tens of metres thick, with a maximum thickness close to 80 m at Gæiraskardet. Towards the underlying Čorrovárri Nappe the schist is highly tectonised, reflecting the tectonic character of the contact.

Description: The grey marble consists of 85–95% calcite. 'Impurities' are quartz, plagioclase, muscovite, pyrite, titanite, zircon, chlorite, amphibole and biotite, some of which are concentrated in 1–5 mm layers. Internal microfaulting can be seen, with cracks filled by coarse-grained mobilised calcite.

The carbonate-bearing, pale grey schist commonly contains randomly orientated greenish single crystals or clusters of amphibole crystals up to 5 cm in size on schistosity planes, forming the typical garben schists. Small garnets may also be seen, and some amphibolite lenses are present. Poikiloblastic minerals with inclusions in their cores include amphibole, garnet and zoisite in various amounts, in places up to 25%. The carbonate content of this schist is 10–20%, biotite 25–35% and quartz + feldspar (mainly plagioclase) 10–30%. A colourless chlorite is common. Accessories are muscovite, titanite, epidote and tourmaline.

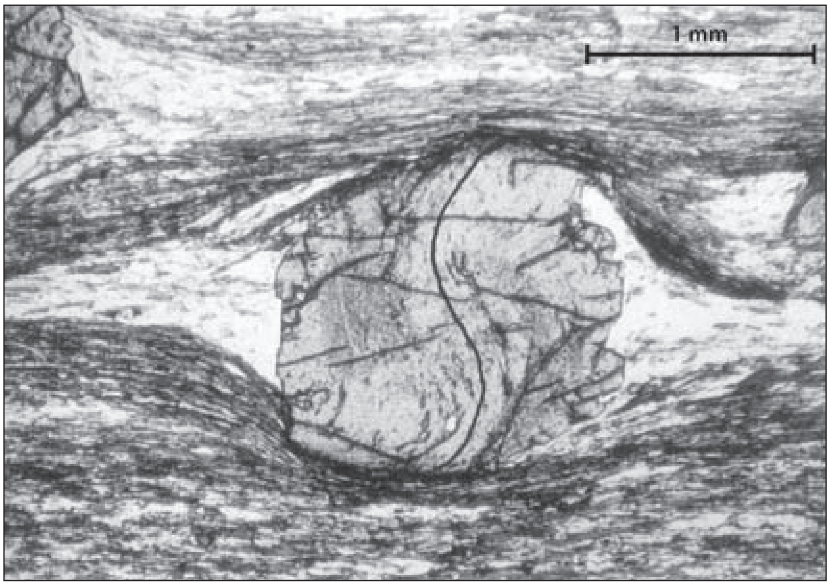


Fig. 3. Garnet porphyroblast with an S-shaped inclusion fabric showing evidence of pre- and syntectonic growth; from the Riehppejohka Quartzite Member. The strain shadows consist mainly of quartz. Plane-polarised light (sample VR 416, thin-section 7632, Photo I. Lindahl).

Čiččenvárri Formation

Derivation of name: The name Čiččenvárri Formation is modified from 'Nitsimvarre Series' introduced by Padget (1955) in the Biertavárri district, and is an older, but now revised spelling of the same word. In the Váddás area the Formation is subdivided into four members.

Distribution: The Čiččenvárri Formation was mapped in the steep mountain slope from Gæiraskardet north to Riehppi, and north of the Riehppi Fault in the lower part of the western slope of Storelvdalen. It constitutes the valley floor in the former mining village of Váddás, covers most of the floor of upper Oksfjorddalen, and continues westward to the Skarddalen area.

Type area/section: A NW-SE section from Storelva (UTM 525350-7741350) towards Frukosthaugen (UTM 524900-7741600) on the Kvænagen map-sheet (1734.1) is nominated as typical for the Formation.

Relationships and thickness: Quartzites and schists dominate the Formation, and the contacts with underlying and overlying units are well defined (Lindahl 1974). The thickness of the Čiččenvárri Formation increases from c. 100 m at Gæiraskardet in the south to more than 600 m at Váddás in the north, and increases again towards the northwest (Wontka 1974).

The Riehppejohka Quartzite Member

Derivation of name: A section of the Riehppejohka Quartzite Member (Stevens 1982) is well exposed where it is cut by the Riehppejohka stream at its junction with the river of Storelva, east of Riehppi.

Distribution: The Riehppejohka Quartzite Member has been mapped from Gæiraskardet to Váddás, following Storelvdalen from Riehppi to Váddás. The typically rusty quartzite unit with graphitic mica schist layers is found widely distributed in the northern Troms region north and northeast of Váddás and towards the south as far as Signaldalen (Binns 1967, Zwaan 1988). Farther south it is not found as a continuous marker horizon, but it occurs in the same suite of rocks as far as Målselv in southern Troms.

Type area/section: A typical section is the lowest part of the section for the Čiččenvárri Formation.

Relationships and thickness: The Member has sharp contacts with underlying and overlying units. The thickness along strike varies from 20 m at Gæiraskardet to 200 m close to Váddás.

Description: In the south (Riehppi–Lán'kavárri area), the unit is dominated by pure quartzite with small amounts of pyrite, while in the Váddás–Frukosthaugen area it is interbedded with grey to black graphite-bearing phyllite. The quartzite and phyllite normally contain scattered grains of iron sulphides, mostly pyrite, which gives the unit a typically rusty red colour on weathered surfaces. The quartzite varies from massive to more schistose.

The quartzite is normally pure, but in places contains 10–25% plagioclase. Minor minerals are muscovite, biotite and pyrite, and accessories are chlorite, titanite, zircon, epidote, carbonate and amphibole. The phyllitic schist consists of 40–50% mica (biotite and muscovite in varying amounts), and 40–50% quartz + minor plagioclase. Poikiloblasts of garnet and zoisite show internal inclusion trails indicative of syntectonic growth. S-textures in garnet are common, as shown in Fig. 3. Chlorite may occur in amounts up to 20%. Accessory minerals are titanite and zircon. The amphibolite lenses consist of amphibole, plagioclase and biotite.

Oksfjorddalen Schist Member

Derivation of name: The Oksfjorddalen Schist Member (Stevens 1982) is found in the valley of Oksfjorddalen, northwest and northeast of Váddás. Pearson (1971) named this unit 'Pelite 1' with Banded Marble in the upper parts.

Distribution: The Oksfjorddalen Schist Member was mapped from Gæiraskardet along the western valley side of

Storelvdalen to Váddás. It covers most of the valley floor of Oksfjorddalen northwest of Váddás.

Type area/section: As for the Čiččenvárri Formation.

Relationships and thickness: The unit is dominated by mica schists, which have sharp contacts with the underlying and overlying quartzites, respectively the Riehppejohka and Skarddalen Quartzite Members. The thickness of the Oksfjorddalen Schist Member increases from 100 m at Gæiraskardet in the south to more than 300 m at Váddás in the north (Plate 1). North of Váddás the base of the Member is not exposed.

Description: The Oksfjorddalen Schist changes in character along strike; in the Riehppi area it is a grey garnet-mica schist dominated by muscovite which produces silvery cleavage surfaces, but towards Váddás it is darker brownish-grey mica schist dominated by biotite, locally with graphite and, in places, containing scattered garnets. The garnet changes in colour from medium red in the south to darker red and smaller grains in the north. Lenses and layers of amphibolite are common, and 3-4 thin layers of marble have been mapped by Lindahl (1974). In the middle of the unit in the Riehppi area, one of these grey marble units reaches a thickness of 50 m, wedging out in the north of the area. Marble is uncommon near Váddás, but farther northwest in the Straumfjord area marble dominates the upper parts of the unit (Pearson 1971).

The Oksfjorddalen Schist has a porphyroblastic texture. The matrix consists of quartz and mica with minor amounts of plagioclase. The porphyroblasts are garnet, biotite, amphibole, zoisite and staurolite, which show internal textures of syn- to post-tectonic growth. Some garnets show S-texture, and inclusions showing a primary layering are found in other porphyroblasts. The cleavage in the biotite porphyroblasts is commonly perpendicular to the schistosity and may show evidence of rotation (Fig. 4). Staurolite porphyroblasts are found only in the Riehppi area in the garnet-mica schist. Differences in sediment geochemistry along strike resulted in a muscovite-biotite ratio of 3:1 with red garnet and staurolite in the south, and a muscovite-biotite ratio of 1:3 with a few dark garnets in the north. Zoisite and amphibole porphyroblasts occur mostly where the schist contains small amounts of carbonate minerals, or in connection with the thin marble layers.

Fig. 4. Rotated, pretectonic, biotite porphyroblast from the Oksfjorddalen Schist Member. The orientation of the inclusions is at a high angle to the schistosity. Plane-polarised light (sample VR 553, thin-section 7625, Photo I. Lindahl).

Some of the plagioclase shows weak sericitisation and biotite is locally chloritised. Accessory minerals are chlorite, tourmaline, zircon, epidote, titanite, pyrite and small amounts of graphite close to Váddás. The grey marble layers consist of 80–90% calcite with minor amounts of quartz, muscovite and zoisite. Centimetre-sized dark needles of zoisite are commonly found in the thickest marble unit. Garben schists are found in transitions from marble to mica schist.

Skarddalen Quartzite Member

Derivation of name: The Skarddalen Quartzite Member (Stevens 1982) covers an extensive area, including the valley of Skarddalen. The unit was named Vaddas Quartzite by Th. Vogt (1927), separating his Lower and Upper Vaddas Divisions. The same name was later used by Wontka (1971) and Lindahl (1974). Pearson (1971) called this unit Vaddas Psammite in his work from the Straumfjord area.

Distribution: The Skarddalen Quartzite Member wedges out 1 km south of the Riehppi Fault, but can be followed as a layer just a few metres in thickness in the succession as far as Gæiraskardet. It follows the western valley side of Storelvdalen to Váddás, and from Váddás to Skarddalen it follows the lower part of the southern and western sides of Oksfjorddalen, and continues westwards through Skarddalen. It is also exposed at Boatkavárri and Rahpesvárri (Fig. 2).

Type area/section: A reference section close to Váddás is nominated (UTM 523000-7744850 to UTM 522900-7744600, Nordreisa map-sheet, 1734.4).

Relationships and thickness: The contacts with the underlying Oksfjorddalen Schist Member and overlying Jiehkkejohka Marble Member are sharp. The thickness of the Member increases from 10 to 200 m from Riehppi northwards to Váddás, and increases further to approximately 500 m in the northwestern part of the mapped area. North of this, at Rahpesvárri, the central part of the Skarddalen Quartzite is feldspar-rich. The contact relationships with the Rahpasvárri Metagranite, which it envelopes, suggest that the arkosic variant of the Skarddalen Quartzite member is the source rock for the Metagranite. Accepting a crystallisation age of around 600 Ma (Corfu et al. 2005) the arkosic variant is different from the Skarddalen Quartzite Member. The most likely interpretation is that the feldspar-rich part of the Skarddalen Quartzite Member and the associated granite represent a tectonical intercalation of part of the underlying Čorrovárri Nappe (see description of the Rahpesvárri Metagranite and summary section). This interpretation had not been considered during mapping, and therefore the nature and location of the boundary between the quartzite and its feldspar-rich variant remain unknown. In the tectonically complex area between Boatkavárri and Nordreisa, units similar to that of the pure Skarddalen Quartzite Member and a meta-arkose similar to the Loddevággi Formation of the Čorrovárri Nappe have been mapped (K. B. Zwaan, unpubl. data).

Description: The Skarddalen Quartzite Member is massive, and mostly without a distinct bedding. In places there are 2–3 m-thick layers of flattened conglomerate with pebbles mainly of quartzite with minor amphibolite, up to 5 cm in size. At Riehppi, the unit comprises only quartzite and is white and glassy, but northwards, especially north of Váddás, it is more a grey meta-arkose, and in addition contains layers of garnet-mica schist, phyllitic graphite-bearing schist (±garnet) with some sulphide minerals, and carbonate-bearing beds. The thickest mica schist unit (up to 30 m) is found in Skarddalen. Amphibolite layers and lenses are also present. They consist of 70% pale green hornblende and 20% plagioclase, with minor zoisite and quartz. Normally, the quartzite contains 80–90% quartz with some feldspar (microcline and plagioclase) and muscovite. At Rahpesvárri and Boatkavárri, the Skarddalen Quartzite Member (now inferred to be a KNC meta-arkose) contains up to 40% feldspar, with more plagioclase than K-feldspar. Accessory minerals are titanite, biotite, epidote and pyrite.

Rahpesvárri Metagranite

Derivation of name: Rappesvarre Granite was used by Th. Vogt (1927), taking its name from the mountain Rappesvarre (now Rahpesvárri) north of Váddás where the major part of the body crops out. Pearson (1970) and Lindahl (1974) interpreted the Granite to be formed by partial melting of the feldspar-rich variant of the Skarddalen Quartzite in which it is enclosed, and since it mostly displays a gneissic texture they named it the Rappesvarre Granitic Gneiss. Here, the gneissic texture is interpreted as being due to later metamorphism and the rock is therefore classified as metagranite.

Previous work: The Rahpesvárri Metagranite has been described by: Th. Vogt (1927), Pearson (1970), Strand (1971) and Lindahl (1974). Barkey (1964) and Bakke et al. (1975) presented a more complete picture of the distribution of the Metagranite Member.

Distribution: The main body of the Rahpesvárri Metagranite is shown by Bakke et al. (1975) to extend over a strike length of 18 km from Boatkavárri west of Oksfjorddalen through Bjørnskardfjellet east of Oksfjorddalen to near Kvænangsfjellet (Fig. 1). The Metagranite crops out over a width of up to 2.5 km. Two geographic features named Rahpesvárri are shown within the outcrop of the gneiss, on the Nordreisa map-sheet, 1734.4: a mountain near UTM 517400–7747700, and a small peak at UTM 522600-7753500. A smaller, faulted-off segment of the Rahpesvárri Metagranite occurs between UTM 520900-7763500 and 517200–7765100.

Type area/section: The Rahpesvárri Metagranite is best exposed at Bjørnskardfjellet (around UTM 519500-7747300, Nordreisa map-sheet, 1734.4).

Relationships: The Rahpesvárri Metagranite occurs as a long concordant intrusion within the Skarddalen Quartzite Member. In Rahpesvárri, the upper contact is mylonitic and partly discordant with the surrounding country rock. The lower contact is both sharp and, locally transitional, displaying features of progressive migmatisation of the meta-arkosic country rock towards the main body of the Metagranite (Fig. 5). In the southeastern area it encloses quartzites. Thin micaceous bands can be traced from the quartzite to the Metagranite where they lose continuity. Amphibolitic lenses, when enclosed in undisturbed parts of the metagranite, display their mafic dyke character; and they are thus older than the granite. Small lenses of marble and quartz conglomerate are locally found as rafts. The marble lenses contain dark brown garnet, a common feature in contact-metamorphosed and contact-metasomatised limestones.

Description: The Rahpesvárri Metagranite is coarse-grained, leucocratic, and consists of quartz, K-feldspar, plagioclase, muscovite and biotite. It has an inequigranular texture with large, deformed, feldspar crystals in a polygonised groundmass of quartz, plagioclase, K-feldspar and a little mica, giving the granite a gneissic appearance. The plagioclase crystals are zoned. The large feldspar crystals are mostly K-feldspar and commonly poikilitic toward the matrix quartz. They are mostly microcline, but some are microperthitic of plume or flame type. Symplectitic intergrowths of quartz wholly within K-feldspar are conspicuous in some samples of the granite (Pearson 1970). Plagioclase displays Carlsbad and albite twinning. The matrix mica is mostly muscovite. Biotite is brown, but green biotite is present in zones of mylonitisation. Muscovite is found scattered throughout microcline, and formed later than the host feldspar.

Geochemistry: Chappell & White (1974) classified Palaeozoic granites in part of eastern Australia into S- and I-types, the S-types being derived from a sedimentary source and I-types from an igneous source. Their scheme has a degree of general applicability. Based on their criteria, the field characteristics and mineralogy of the Rahpesvárri Metagranite resemble S-type granites, but the chemistry has both S-type and I-type characteristics. Some of the critical features:

(a) The Metagranite contains abundant biotite and muscovite (although the muscovite may not be primary), and hornblende is not reported.
(b) The SiO_2 content is consistently high in analysed sam-

ples (> 75%), although only 4 analyses are available (see Table 6).

(c) The samples are mostly metaluminous to slightly peraluminous, and do not qualify as S-type on this criterion. Ratios of molecular $Al_2O_3/(Na_2O + K_2O + CaO)$ are as follows: sample 5006 = 1.087, sample 5007 = 1.036, sample 5008 = 1.051, sample 5009 = 0.955.

(d) The initial Sr^{87}/Sr^{86} ratio is 0.71186±0.00096 (based on 4 samples of metagranite from Boatkavárri). Later analyses of 5 samples from Rahpesvárri gave an initial Sr^{87}/Sr^{86} ratio of 0.70915±0.00439. (Preparation of samples at NGU and analysed by B. Sundvoll). Ratios greater than 0.706 are typical of S-type granitoids.

(e) The Na_2O content of the Metagranite ranges from 2.90 to 5.40%, and tends to be higher than Chappell & White's (1974) S-type granitoids. However, Chappell (1978) described other S-type granitoids with high Na_2O contents and attributed this to less mature source metasediments.

The geochemical data alone are not sufficient to draw a final conclusion on the precise origin of the Rahpesvárri Metagranite. The field occurrence of migmatites in the contact zone between a feldspar-biotite-rich psammitic metasediment and the Metagranite suggests that the metasediment was the source rock (Fig. 5).

A best-fit isochron was calculated from the Rb-Sr isotopic data. The results, in Table 1, are not conclusive as the calculations for the two analysed groups and the groups combined give errorchrons with quality-of-fit numbers from 6.3 (591 Ma) to 29.8 (559 Ma). This is in agreement with the suggestion that the Metagranite is an S-type granitoid. A recent U-Pb age determination on zircon from the metagranite gave an interpreted crystallisation age of 602 Ma (Corfu et al. 2005), confirming that the metagranite and the enclosing feldspar-rich psammite are alien to the Váddás succession. It therefore seems clear that the psammitic metasediment intruded by the Metagranite is not part of the Skarddalen Quartzite, as previously interpreted (Lindahl 1974). It is inferred to represent an infolded, Neoproterozoic, KNC meta-arkose unit (Ramsay et al. 1985) and the Metagranite could be a westerly extension of the anatectic granites within the Čorrovárri Nappe (P. G. Andréasson, pers. comm. 2004) (see summary section).

Table 1. Results of calculation of the best-fit whole rock isochrons based on the Rb-Sr isotopic data. Preparation of samples at NGU and analyses by B. Sundvoll, NGU.

Samples	Best-fit isochorn	Quality of fit number	Initial ratio Sr^{87}/Sr^{86}
4 samples Boatkavárri	591 ± 13.4 Ma	6.28	.71186 ± .00096
5 samples Rahpesvárri	562 ± 25.5 Ma	27.62	.70915 ± .00439
All samples combined	559 ± 16.0 Ma	29.82	.71296 ± .00158

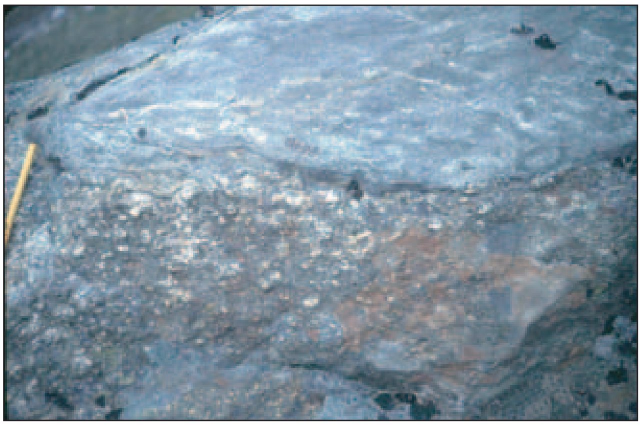


Fig. 5. Transitional contact between the Rahpesvárri Metagranite and the meta-arkosic country rock close to Gildetun at Kvænangsfjellet. (Map reference UTM 523100-7753300, Kvænagen sheet, 1734.1, Photo K. B. Zwaan).

Guolasjávri Formation

Derivation of name: Guolasjávri Formation is a modification of Padget's (1955) Guolas Limestone Series, and constitutes the lowest part of Th. Vogt's (1927) Upper Vaddas Division (Fig. 2). The Formation is subdivided into three Members: Jiehkkejohka Marble Member, the Rássevággi Schist and Conglomerate Member, and the Frukosthaugen Conglomeratic Marble Member. In the continuation of the Jiehkkejohka member towards the southwest around the Guolasjávri lake (see Fig. 1), Binns & Gayer (1980) found Upper Ordovician to Silurian fossils. Around the lake, abundant less deformed mafic dykes are found within the marble. In the Reisadalen area the marble is interbanded with hornblende schist interpreted as metamorphosed lava flows.

Distribution: The Guolasjávri Formation is exposed in the steep mountain slopes from Gæiraskardet to Riehppi; around the tree limit from Riehppi to Váddás; and in the steep mountain slopes from Váddás to Skarddalen.

Type area/section: Frukosthaugen (UTM 523750-7742000, Nordreisa map-sheet, 1734.4) is the type area for the Guolasjávri Formation, where its three members can be studied in detail.

Relationships and thickness: Carbonate units, and to a lesser extent schists, both commonly conglomeratic, dominate the Formation. The contacts with the underlying Čiččenvárri Formation and overlying Oksfjord Group are well defined, displaying a stratigraphic hiatus of unknown importance and duration, but mostly appears as a nonangular unconformity. Locally, the quartzite surface displays channels up to a metre deep filled with the conglomerate, suggesting that the quartzite is older and the succession is the 'right-way up'. Since the quartzite pebbles in the conglomerate seem very similar to the Skarddalen Quartzite Member, it is likely that the sands of the Čiččenvárri Formation were consolidated to sandstone and locally eroded before deposition of the overlying sediments (Lindahl 1974). Ramsay et al. (1985) interpreted the uncon-

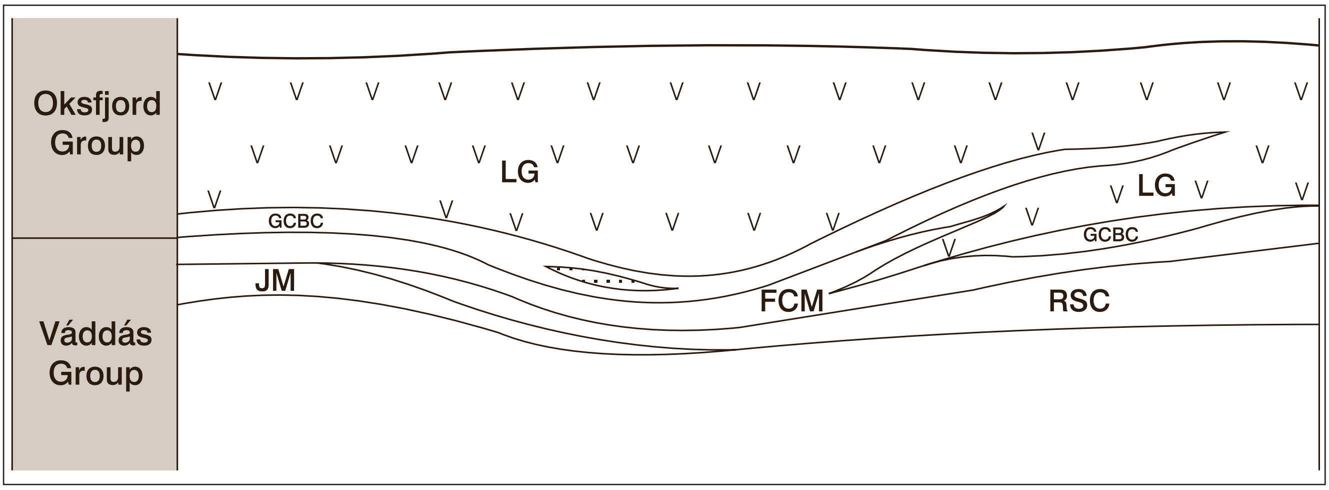


Fig. 6. Sketch of the facies development from north (right) to south (left) of the units close to the contact of the Váddás and Oksfjord Groups. JM – Jiehkkejohka Marble Member; RSC – Rássevággi Schist and Conglomerate Member; FCM – Frukosthaugen Conglomeratic Marble Member; GCBC – Goddejávri Calc-Biotite Schist Member; LG – Loftani Greenstone Member.

formity as a major tectonometamorphic break, the underlying rocks of the Gæirajávri Formation and Čiččenvárri Formation being much older and a part of the KNC. The Guolasjávri Formation increases in thickness from 70 m at Gæiraskardet to a maximum of 300 m in the Kyrkjefjell profile, and decreases to 200 m in the Heindalstind profile in the northwest (Plate 1). A sketch of the facies development of the Formation and its component Members is shown in Fig. 6.

Jiehkkejohka Marble Member

Derivation of name: The Marble Member (Stevens 1982) has a well-exposed and representative section in the stream of Jiehkkejohka where it runs from lake Jiehkkejávri south of Riehppi.

Distribution: The Member was mapped from Gæiraskardet to just north of Váddás where it pinches out (Fig. 6).

Type area/section: As for the Goulasjávri Formation.

Relationships and thickness: The contacts with underlying and overlying Members are sharp. At Gæiraskardet the thickness of the unit is 10–20 m. The maximum thickness of the Jiehkkejohka Marble Member, 100 m, is found at Loftani, before it wedges out northwards (Fig. 6).

Description: The unit consists of yellowish-grey marble. Some horizons contain considerable amounts of quartz and mica, including layers of carbonate-bearing quartzites and mica schist. South of Frukosthaugen, a 3–4-m thick matrix-supported conglomerate is found at the base of the unit (Fig. 7a), with quartzite pebbles decreasing in size upwards. This conglomerate marks the unconformity between the Skardalen Quartzite Member and the Jiehkkejohka Marble Member. Conglomeratic layers are also found within the unit in some of the carbonate-bearing quartzites and mica schists.

The main minerals in the marble are calcite, quartz and mica, mainly muscovite, with accessory minerals titanite, epidote and tourmaline.

Rássevággi Schist and Conglomerate Member

Derivation of name: The Rássevággi Schist and Conglomerate Member (Stevens 1982) takes its name from the Rássevággi valley west of Váddás.

Type area/section: The type section for the Member is at Map reference UTM 518500-7744800 to UTM 518700-7744600, Nordreisa map-sheet, 1734.4. A type area is at Frukosthaugen as for the Goulasjávri Formation.

Relationships and thickness: The contacts with overlying and underlying Members are sharp. The thickness at Gæiraskardet is 10–20 m, gradually increasing northwards to 100 m at Váddás. Farther toward northwest the member has a fairly constant thickness, ranging from 100 to 150 m.

Description: The schist is generally dark brown, but lighter grayish-brown where the carbonate content is higher. It is mostly a carbonate-bearing mica schist, and, locally, there are thin impure calcite marble and quartzite layers. In places the schist is garnet- and amphibole-bearing and was named garben schist by Th. Vogt (1927).

At the base of the unit in Rássevággi and Heindalen an oligomict conglomerate is developed with pebbles from the lower units of the Kvænangen Group. Most of the pebbles are of quartzite, from 5 to 20 cm across (Fig. 7b). In Heindalen the thickness of the conglomerate is at least 10 m, but mostly it is just a few metres thick. The base of the unit represents the same unconformity as shown in Figs. 6 & 7a. In some places the conglomerate is matrix-supported and in other places pebble supported. The matrix is normally mica schist but locally, south of Frukosthaugen, a thin layer of matrix-supported conglomerate with carbonate as matrix occurs within the unit.

The mica schist shows a granular, commonly porphyroblastic texture with garnet, amphibole and biotite, and in one case staurolite as porphyroblasts, all of which have an internal poikiloblastic texture. The poikiloblasts show pre- to syn-D2 growth (as shown in Figs. 3 & 4).

The main minerals in decreasing amounts are quartz,

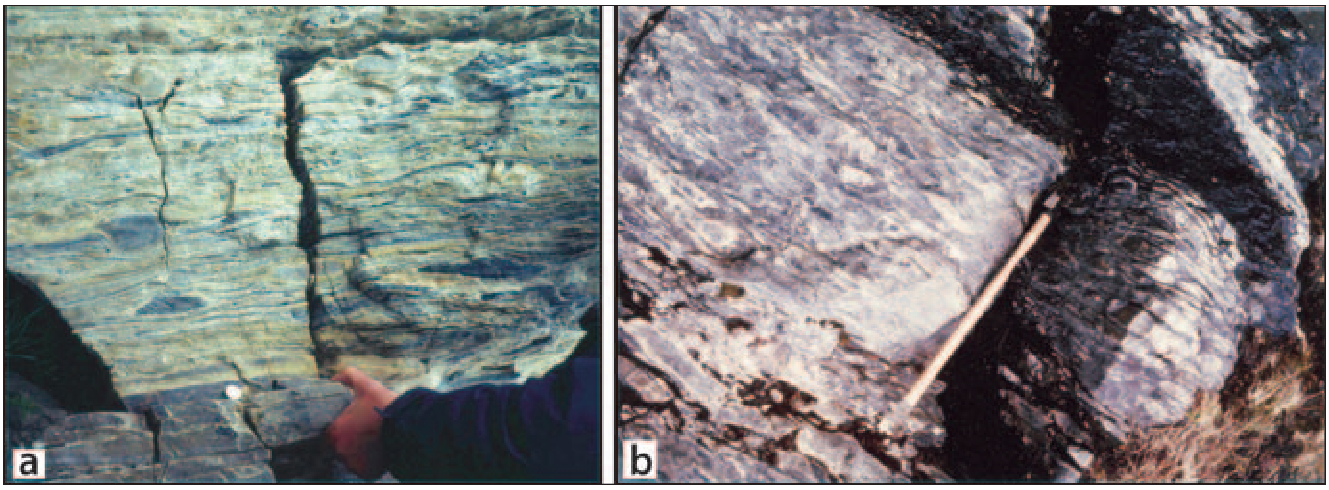


Fig. 7. (a) The contact (the thumb) which represents the unconformity between the Skarddalen Quartzite Member and the conglomerate of the overlying Jiehkkejohka Marble Member, a regional stratigraphic hiatus, looking west (Map reference UTM 524950–7740340, Nordreisa sheet, Photo K. B. Zwaan). (b) Stretched quartzite pebbles in micaceous matrix; clast-supported Conglomerate, looking east. Rassevággi Schist and Marble Member overlying the Skarddalen Quartzite Member (Map reference UTM 519400–7744800, Nordreisa sheet, 1734.4, Photo B. Stevens).

biotite, muscovite and calcite. Small to accessory amounts of epidote, plagioclase, zircon, tourmaline, titanite and apatite have been identified.

Frukosthaugen Conglomeratic Marble Member

Derivation of name: The Frukosthaugen Conglomeratic Marble Member (Stevens 1982) exhibits a typical section on the top of Frukosthaugen hill 3 km south of Váddás. Pearson (1971) referred to the unit as Marble + Marble Schist in his Heindalstind profile.

Distribution: The Frukosthaugen Conglomeratic Marble Member has been mapped across the whole area from Gæiraskardet in the south to Heindalstind in the northwest.

Type area/section: As for the Goulasjávri Formation.

Relationships and thickness: The contact with the underlying Member, and overlying Oksfjord Group is well defined, even though the Frukosthaugen Member interfingers with the Áhkkejávri Formation (see Fig. 6). The thickness of the unit increases from 10–20 m at Gæiraskardet to 70–80 m at Frukosthaugen. In the northwestern part of the area the thickness is approximately 100 m with a maximum thickness of 180 m in the Kyrkjefjell profile (Plate 1).

Description: The Member is dominated by carbonate-bearing rocks, mostly marble and sandy schistose carbonates with yellowish colours. Some thin layers of marble contain graphite and are darker coloured. The graphite-bearing layers appear fine-grained whereas elsewhere the marble is granular and medium-grained. Primary quartz-banding in the marble is common and thin layers of carbonate-bearing quartzite and mica schist are found within the unit.

In some localities the entire Frukosthaugen Conglomeratic Marble Member is conglomeratic; elsewhere, only a few of the layers are pebbly, but these do not persist along strike. The conglomerate is matrix supported, with a matrix mostly of carbonate minerals. The conglomerate is polymictic, but dominated by well-rounded quartzite pebbles smaller than

Fig. 8. Polymictic conglomerate in the Frukosthaugen Conglomeratic Marble Member. Most of the well rounded pebbles are of quartzite and marble. The dark fragments are of a fine-grained carbonate rock. (Map reference UTM 523700-7741700, Nordreisa sheet, 1734.4, Photo I. Lindahl).

10 cm, derived from the underlying Riehppejohka and Skarddalen Quartzite Members. The percentage of pebbles in the conglomerate is mostly below 25%. Large fragments, up to 0.3 x 2 metres, of the dark-coloured marble are found in between the well-rounded quartzite pebbles (Fig. 8) and derive from within the Frukosthaugen Member; they may have been formed by slumping or local erosion.

The marble and the matrix in the conglomeratic layers consist of 40–95% calcite, 5–40% quartz, up to 10% muscovite and some plagioclase. A mineral banding of the silicates on micro-scale is common. The accessory minerals are biotite, titanite and zircon. Locally, zoisite and actinolite are present. The mica schist layers in the unit commonly contain centimetre-sized crystals of amphibole, developed along cleavage planes.

Oksfjord Group

Derivation of name: The Oksfjord Group is a modification of Th.Vogt's (1927) 'Oksfjord Division', but the upper part of his 'Vaddas Division' is included in the Oksfjord Group (Fig. 2). Th. Vogt (1927) also used the name Oksfjord Schist, a unit within his Oksfjord Division. The name Oksfjord Schist was also used by Pearson (1971), and Oksfjord Schist Group was used by Armitage et al. (1971) and Armitage (1977). The Oksfjord Group is subdivided into two formations; the Áhkkejávri Formation, containing the Goddejávri Calc-Biotite Schist Member and Loftani Greenstone Member, and the Ankerlia Formation.

Previous work: Th. Vogt (1927) described the Oksfjord Group only briefly. Later, the unit was described in greater detail by Kleine–Hering (1972, 1973), Wontka (1972, 1974) and Zobel (1971, 1972, 1974) in the Reisadalen–Moskodalen area. The rocks have also been described by Lindahl (1974) and Stevens (1982) from the Váddás–Riehppi area, and by Armitage (1972, 1977) from the Nordreisa area. Earlier Padget (1955) and Vokes (1957) have described the group in the Biertavárri district.

Distribution: Except for the intrusive rocks (VM, etc.), the Oksfjord Group covers extensive parts of the mountainous region between Storelvdalen and Reisadalen (Fig. 1 & Plate 1).

Relationships and thickness: The boundary between the Kvænangen and Oksfjord Groups coincides with a major change in sedimentation, from a shallow-water to a deeper marine environment with contemporaneous volcanic activity. However, the boundary is complex as shown in Fig. 6. The Goddejávri Calc–Biotite Schist Member is not continuous and occurs both below and within the Loftani Greenstone Member, separating the upper and lower parts. A wedge or a separate lava flow of the lower Loftani Greenstone Member pinches out in the Frukosthaugen Conglomeratic Marble Member (Fig. 6). The described hiatus at the base of the transgressive Guolasjávri Formation, the highest formation of the underlying Kvænangen Group, possibly marked a starting point for the change of sedimentary environment.

The Goddejávri Calc–Biotite Schist Member is not present in the northernmost part of the Váddás–Riehppi area. It occurs, but is quite thin in the southern areas, but increases in thickness towards Biertavárri, where Padget (1955) named it the Lower Brown Schist. In the Váddás area, the Loftani Greenstone Member (Lindahl 1974) is up to 600 m thick, wedging out to the northwest and southeast. The Ankerlia Formation has a minimum thickness of more than 1 km. Only the lower part of this formation was mapped in the Váddás area.

Áhkkejávri Formation

Derivation of name: The name Áhkkejávri Formation (Stevens 1982) was taken from the lake Áhkkejávri, in the Raisduottarháldi district (map reference UTM 50550–769540, Raisduottarháldi sheet, 1733.4). The Formation is subdivided into two Members: Goddejávri Calc–Biotite Schist Member and Loftani Greenstone Member.

Distribution: The Áhkkejávri Formation is exposed in the Váddás area in the steep mountain slopes from Doaresgáisá to Gæiraskardet.

Type section: For the Áhkkejávri Formation, three typical sections are nominated: a) A section at the northwest corner of Váddašgáissát, map reference UTM 518900–7744660, (Nordreisa sheet, 1934.4). b) A section at Loftani west of Frukosthaugen, map reference UTM 523700–7741700 to UTM 522900–7741700 (Nordreisa sheet, 1734.4). c) A section just south of the Riehppi Fault, map reference UTM 523000–7736600 to UTM 522600–7736600 (Reisadalen sheet, 1734.3).

Relationships and thickness: On a regional scale, the Áhkkejávri Formation is dominated by the Goddejávri Calc–Biotite Schist Member, which is a purplish-brown carbonate-bearing mica schist. In the northernmost part of the Váddás area, the Member wedges out and interfingers with the Loftani Greenstone Member. The correlation between the two Members of the Formation in the Váddás area is shown in Fig. 6.

Goddejávri Calc–Biotite Schist Member

Derivation of name: This Member is Padget's (1955) 'Lower Brown Schist'. The Goddejávri Calc–Biotite Schist Member takes its name from the lake Goddejávri, in the Biertavárri ditrict (map reference UTM 497950-7692600, Manndalen sheet, 1633.1), beneath which the unit passes.

Distribution: The Goddejávri Calc–Biotite Schist Member was mapped from Gæiraskardet to Skarddalen. It is exposed mostly in the steep mountain slopes, but is more easily accessible between Riehppi and Váddás (Fig. 2).

Type section: As for the Áhkkejávri Formation. A type section is nominated where the Goddejávri Calc–Biotite Schist Member occurs below the lower part of the Loftani Greenstone Member, at the northwest corner of Váddašgáissát, map reference UTM 518900–7744600 (Nordreisa sheet, 1734.4). A section of the Loftani Greenstone Member, between its lower and upper parts, is situated at Frukosthaugen, map reference UTM 523200–7741800 (Nordreisa sheet, 1734.4).

Relationships and thickness: The Member has sharp and well-defined contacts with surrounding units. In the Rássevággi–Heindalen area, the Goddejávri Calc–Biotite Schist Member occurs as a lens below the Loftani Greenstone Member (Fig. 6). The thickness of this lens is close to 100 m in the Kyrkjefjell profile (Plate 1). Elsewhere, the Member is found below the upper part of the Loftani Greenstone Member. Close to Riehppi the thickness is approximately 150 m and a 50 m-thick lens of greenschist occurs within the unit (Plate 1). Just north of Váddás, a 100 m-thick section of the Member wedges out within the Loftani Greenstone Member.

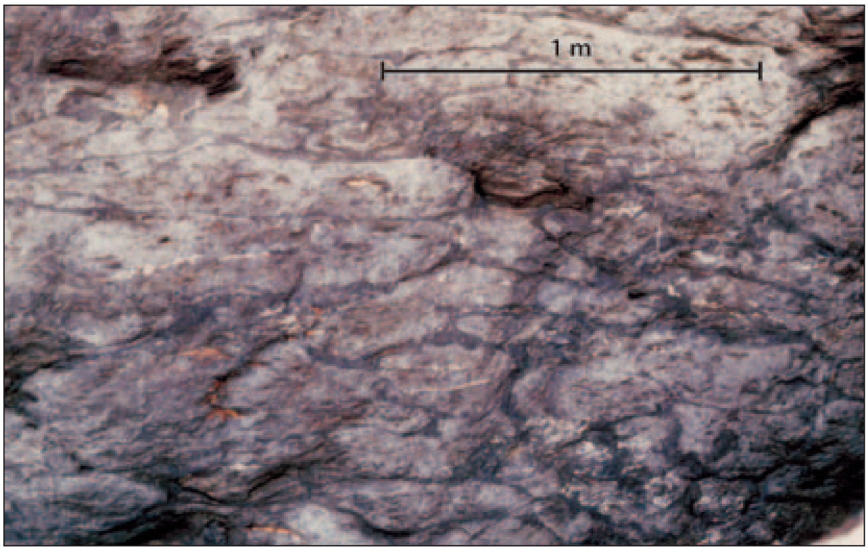


Fig. 9. One of the few good examples of pillow structures in the Loftani Greenstone Member (Map reference UTM 520550–7744600, Nordreisa sheet, 1734.4, Photo B. Stevens).

Description: The calc-biotite schist is purplish-brown and homogeneous, with a few thin layers of more quartzitic composition with a grayish-brown colour. Amphibolite lenses and layers, and lenses of hydrothermal quartz are also present. Garnet, amphibole and, in Skarddalen, staurolite and kyanite occur together as poikiloblasts which show pre- to syn-D2 growth (as shown in Figs. 3 & 4).

The Calc–Biotite Schist comprises quartz, biotite, 10–15% carbonate, and up to 10% of muscovite, garnet, amphibole, plagioclase and epidote- (clino-) zoisite. Accessories are chlorite, tourmaline, titanite and zircon.

Loftani Greenstone Member

Derivation of name: The Loftani Greenstone Member is named after Loftani, a local name (by mistake not shown on the published topographic map) for a wide bench or terrace on the western side of Storelvdalen, south of Frukosthaugen. The name Loftani has been used in geological reports from the area and was also used by Th. Vogt (1927). Lindahl (1974) named the unit Loftani Greenstone.

Distribution: The Loftani Greenstone Member was mapped in detail from Gæiraskardet to Doaresgáisá (Th. Vogt 1927, Lindahl 1974). Southwest of Gæiraskardet, it can be followed across Reisadalen where it wedges out. West-northwest of Doaresgáisá it also pinches out (Fig. 1). In total the Greenstone Member can be followed for 40 km along strike. Other localities with greenstones have been mapped, such as west of Sappen in Reisadalen where a greenstone occurs in the lower part of the Áhkkejávri Formation and the underlying Kvænangen Group. It interfingers with the rocks of both the Guolasjávri and the Čiččenvárri Formations, and even with the marble of the Gæirajávri Formation. Pillowed greenstone occurs locally northeast of Guolasjávri locally in the Ankerlia Formation.

Type area and section: A profile through the lower part of the Loftani Greenstone Member, Goddejávri Calc–Biotite Schist Member and upper part of the Loftani Greenstone Member at Frukosthaugen is a good type section. The map references are: UTM 523700–7741700 to UTM 522900–7741700 (Nordreisa sheet, 1734.4).

Relationships and thickness: The contacts of the Greenstone Member with underlying and interfingering units (Fig. 6) are sharp. In the northwestern and southwestern parts of the area, the contact with the overlying Ankerlia Formation is well defined. East of the VM, however, the upper part of the Loftani Greenstone Member and the lower part of the Gryta Amphibolite are strongly sheared and the contact is difficult to define precisely.

The maximum thickness of the Member is 600 m at Riehppi. Elsewhere in the Váddás area, the total thickness of the upper and lower parts of the Loftani Greenstone Member is 300–400 m (Plate 1). Separate upper and lower Greenstone units have been mapped from Riehppi to north of Váddašgáissát.

Description: The Loftani Greenstone Member is a metabasalt varying from massive to schistose. Much of this massive, fine- to medium-grained greenstone contains scattered plagioclase phenocrysts. Rare but well-developed pillow structures have been observed at Riehppi, Njoammeloalgi, and in the north face of Váddašgáissát (Fig. 9). Some pillows show a radial zonation with vesicles concentrated in the rims. The rims and matrix between the pillows may show concentrations of mm-size idiomorphic pyrite crystals. Tectonic 'pillows' (i.e., pillow shapes resulting from intersecting fracture sets) are common and can be difficult to distinguish from the primary pillows. At Riehppi the greenstone locally shows a gabbroic texture in some massive layers. Thin (2 m) layers of sediments, now (garnet-)mica schist, occur within the Loftani Greenstone Member. Metamorphically mobilised quartz-feldspar and epidote veins occur, especially in the upper parts of the Member.

The upper section of the Member, especially between Váddás and Riehppi, is a schistose rock with diffuse lithological layering; this is distinguished as a separate unit on the

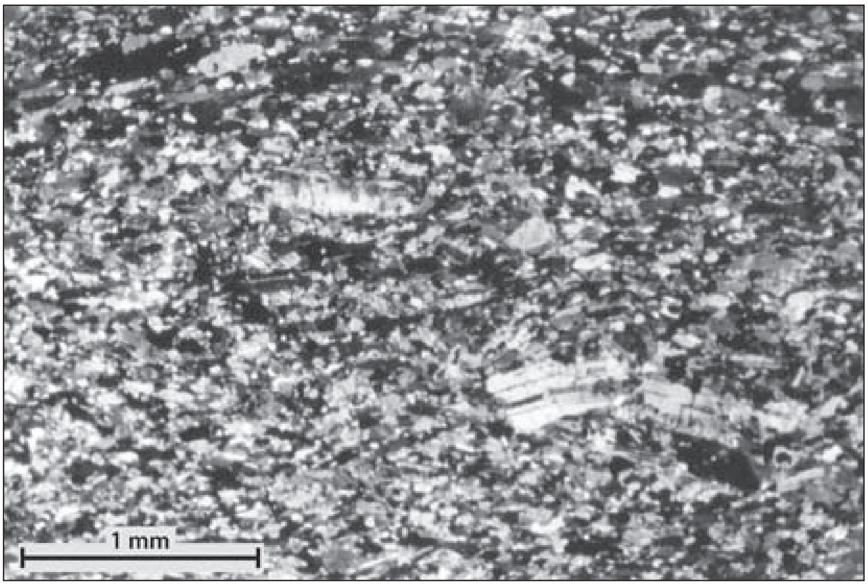


Fig. 10. Relict aligned plagioclase phenocrysts in a recrystallised matrix. Loftani Greenstone Member. Crossed polars (sample VR 334, Map reference UTM 522500-7736800, Nordreisa sheet, 1734.4, Photo B.Stevens).

geological map (Plate 1). It is difficult to distinguish between this part of the Loftani Greenstone Member and the schistose margin of the overlying Gryta Amphibolite. South of Riehppi, however, the boundary between the Greenstone Member and overlying Ankerlia Formation is sharp.

The Loftani Greenstone Member is essentially a hornblende-plagioclase rock, commonly with 5–15% epidote-clinzoisite. Accessory minerals are carbonate, titanite, chlorite and iron sulphides. Relict igneous textures of interlocking plagioclase laths (Fig. 10) with compositional zonation were observed in porphyritic samples. The matrix may be either massive equigranular metamorphic, or schistose.

Fresh samples of the Loftani Greenstone have been analysed; major and trace element data are given in Table 6. The major element geochemistry of the greenstone is similar to the composition of Padget's (1955) 'green beds'. The geochemistry of the igneous rocks in the Váddás area is presented in a later section.

Ankerlia Formation

Derivation of name: Padget (1955) introduced the name Ankerlia Schist for the Formation in the Biertavárri district. The 'Schist' was described as metagreywacke by Armitage (1977). The Ankerlia Formation includes Padget's (1955) Ankerlia Schist and Upper Brown Schist.

Distribution: In the Váddás-Riehppi area the Formation is found in the west, on the highest parts of the mountains and the highest parts of their slopes (Lindahl 1974, Stevens 1982). The unit was mapped to the south-southeast towards Reisadalen by Kleine-Hering (1973) and Zobel (1974), towards the west-northwest in the Nordreisa area by Armitage (1972) and Zwaan (Bakke et al. 1975), and towards the north in the Kvænangen area by Pearson (1970) and Bakke (1974).

Type area and section: The type section is found in the western slope of Kåfjorddalen and up the valley to Sabetjohka; map references UTM 495600–7698600 (Manndalen sheet, 1633.1) and UTM 550800–7698700 (Ráisduottarháldi sheet, 1733.4). The plateau of Čorrogáisá west of Rassevággi is the type area in the Váddás district, between map references UTM 516400–7740100 and UTM 517300–7744100 (Nordreisa sheet, 1734.4).

Relationships and thickness: The VM and the adjacent, related, Gryta Amphibolite intrude the Ankerlia Formation and the upper part of the Loftani Greenstone Member in the northern and eastern parts of the Váddás–Riehppi area. West of Váddašgáissát and along strike to the south, the VM intruded higher in the Formation. The boundary between the Ankerlia Formation and the Loftani Greenstone Member is sharp and conformable. The greatest exposed thickness of the Ankerlia Formation is approximately 1000 m at Čorrogáisá. This is a minimum thickness because the Ankerlia Formation forms the highest formation in the Váddás Nappe and is truncated by the overlying Kåfjord Nappe (Zwaan & Roberts 1978), and also because it has not been corrected for tectonic strain.

The northernmost definite extension of the Formation is found on the island of Kågen (Bakke 1974). To the southwest it is found down to Signaldalen and beyond (Binns 1967). Several workers (J. M. Quenardel pers. comm. 1977, Binns 1978) have suggested that the Ankerlia Formation is equivalent to the Narvik Schist of Gustavson (1966).

Where the Ankerlia Formation overlies the Loftani Greenstone Member the contact is sharp. Where the Ankerlia Formation and the Goddejávri Calc–Biotite Schists Member are in contact, the boundary is more gradational, as described by Vokes (1957) from the Biertavárri district. The upper contact of the Ankerlia Formation in the Nordreisa region is the Cappis Thrust, where there are thick mylonites at the base of the Kåfjord Nappe.

Description: In the Váddás area the Formation is not subdivided, but includes several varieties. The dominating and most characteristic rock-type (Fig. 11) is a banded, alternating light grey to greenish-grey psammite and dark violet to brownish-grey pelite. The bands, mostly 0.2–10 cm in thickness, are generally internally homogeneous with sharp margins, but in places display a vague grading. The psammites are fine-grained, from 0.1 to 0.5 mm, whereas the pelites are coarser, from 1 to 5 mm.

Towards Oksfjord in the northwest of the area, the rocks change laterally to well-banded calcareous pelites. There, the psammites are found only in the highest part of the succession. The mineralogy of the Ankerlia Formation is given in

Fig. 11. Mafic dyke cutting typical thin-bedded, fine-grained meta-greywacke (Ankerlia Formation), at a high angle. The dyke appears to intersect a fold, but the fold may in fact have formed later adjacent to the dyke margin (Map reference UTM 517800–7739900, Nordreisa sheet, 1734.4, Photo B. Stevens).

Table 2. Mineralogy of the principal lithologies in the Ankerlia Formation.

Mineral	Light grey to Greenish-grey psammite	Dark violet to brownish-grey pelite	Calcareous pelite
Quartz	40-50%	40-50%	50-60%
Plagioclase	up to 25%	up to 25%	30%
(An content)	(30-60%)		(40%)
Biotite	up to 10%	20-40%	20%
Amphibole	10-30%	up to 10%	30%
Epidote/ clinozoisite	5%	5%	10%
Carbonate	0	0	10%
Garnet	0	2%	2%

Accessory minerals: Titanite, zircon, tourmaline, chlorite, apatite, rutile. Clinopyroxene and scapolite have been identified close to the Váddašgáissát Metagabbro.

Table 2. In other areas to the southwest, non-calcareous, non-banded pelites are found. In the Manndalen area, the psammites are rich in amphibole and grade into amphibolite. The amphibole-rich rocks are interpreted as metatuffites.

Pearson (1970) found to the north-northwest in the Kvænangen area, in the upper part of the succession, several well-preserved sedimentary structures. These are symmetric and asymmmetric sole marks, ripple marks, load casts, convolute bedding, asymmetric flame structures, complete and truncated Bouma sequences, and graded bedding. To the southwest, Padget (1955), Zobel (1974) and Zwaan found cross bedding and graded bedding. Bulk chemical analyses carried out by Padget (1955), Vokes (1957), Armitage (1977) and Stevens (1982) resemble that of greywacke (Table 3). From the sedimentary structures, Armitage concluded that the metagreywackes of the Ankerlia Formation were formed by turbidity currents. Stevens (1982) explained the scarcity of sedimentary structures and graded bedding in his area by reworking by contour currents (Stow & Lovell 1979). A distal depositional environment is indicated by the fine grain size and thin banding (Padget 1955).

The psammitic layers consist mainly of quartz, plagioclase, amphibole and epidote-clinozoisite in variable proportions. Biotite and pyroxene are minor constituents. Plagioclase compositions are generally in the range $An_{40–50}$, however, compositions up to An_{62} occur near the VM. The pelitic layers consist of biotite and quartz with minor quantities of plagioclase, epidote-clinozoisite, hornblende and garnet. Locally, scapolite is found near mafic dykes and sills.

The rocks display a polymetamorphic microtexture. The psammites are granoblastic with only a weak preferred orientation. The pelites are lepidoblastic, with a foliation axial planar to minor folds of the main deformation phase (D2). Particularly in the pelitic rocks, epidote-clinozoisite, amphibole and garnet can be developed as poikiloblasts, indicating growth during or after the main deformation. Later deformation structures are possibly related to overthrusting of the Kåfjord Nappe. In Reisadalen, the highest parts of the succession underwent strong mylonitisation and weak recrystallisation with formation of a mylonitic foliation and associated ribbon texture.

Table 3. Major element analyses of the Ankerlia Formation from the Váddás area compared with analyses of the same unit from the Biertavárri and Nordreisa areas. The BS samples were analysed at NGU by XRF.

	Samples from the Váddás area: Stevens (1982)			Biertavárri area:		Nordreisa area:
				Padget(1955)	Vokes(1957)	Armitage(1977)
	BS.21	BS.56	BS.98E	1 sample	4 samples	11 samples
SiO_2	60.86	62.80	67.42	61.20	60.42	68.28
Al_2O_3	13.58	13.19	11.56	13.91	14.47	11.86
Fe_2O_3	0.65	0.48		5.59	7.08	6.51
TiO_2	0.83	0.79	0.73	0.84	0.86	0.87
MgO	4.28	3.65	2.56	4.47	4.73	2.16
CaO	8.19	7.20	7.63	9.78	6.73	5.39
Na_2O	2.30	2.40	3.00	1.88	3.08	2.85
K_2O	2.07	1.56	0.96	1.36	1.66	1.88
MnO	0.07	0.07	0.07	0.09	0.12	0.22
P_2O_5	0.19	0.16	0.17	0.20	0.22	–
H_2O	-	-	-	0.79	0.61	–

Sedimentation history

Čorrovárri Nappe

The Nahpojohka Group is interpreted as a Neoproterozoic arkosic facies of sedimentation, forming part of the extensive sandstone deposits that occur widely in the Middle and Upper Allochthons of northern Norway. These sediments are considered to be fluvial terrestrial sediments laid down on the Fennoscandian Shield. The Loddevággi Formation is an arkose with feldspar (K-feldspar and plagioclase) more abundant than quartz; derived from the weathering of Paleoproterozoic granitic basement which is widespread in northern Troms and Finnmark. The Luovosskaidi Formation is psammopelitic to partly pelitic, reducing conditions in the sediment column permitting the preservation of organic matter (now graphite). The Luovosskaidi Formation contains more quartz than feldspar (dominated by plagioclase) and is rich in muscovite. A different source rock is indicated; but another possibility is that of strain-related breakdown of K-feldspar in the rocks of the Loddevággi formation close to the basal thrust of the Váddás Nappe.

Váddás Nappe

Tectonically overlying the Nahpojohka Group (top of Čorrovárri Nappe) is the Kvænangen Group (lower part of the Váddás Nappe)(Plate 1). The Váddás Nappe rocks are predominantly calcareous, in part chemical sediments. Carbonate predominates, with transitions to calcareous pelitic to psammitic sediments and pure quartz sands. Conglomerates occur in several of the units, and the composition of some layers changes rapidly along strike.

In the lower part of the Kvænangen Group (especially in the Riehppejohka Quartzite Member), continuous to discontinuous graphite- and pyrite-bearing pelitic layers indicate that local anoxic conditions might possibly have been involved.

The Kvænangen Group is interpreted to have been deposited in shallow-marine to fluvial, with possible reef, lagoonal or back-arc conditions, giving both detrital and chemical contributions to the succession. At some levels there was subaerial exposure and erosion, as for example on top of the Skarddalen Quartzite Member and the Frukosthaugen Conglomeratic Marble Member.

From Biertavárri to Gæiraskardet the total thickness of sediments produced was more or less the same, but from Gæiraskardet to Váddás the thickness doubled (Plate 1). Detailed mapping in the Váddás area (Lindahl 1974) showed that each well-defined unit which is several tens of metres thick around Váddás is just m-thick 10–15 km farther south but can still be recognised (Plate 1). In the Váddás area there are numerous conglomerates at several lithostratigraphic levels. This increase in thickness towards the north is considered to be a general sedimentary facies development.

The Gæirajávri Formation is a pure carbonate rock and one of the most consistent in thickness throughout the Váddás area. Locally, it shows depositional mineral banding (mainly quartz). In the northern Troms region this Formation is a marker horizon.

Deposition of the Čiččenvárri Formation started with quartz-sandy sediments interbedded with muds laid down under reducing conditions, giving organic matter and iron sulphides (Riehppejohka Quartzite Member). Changes in sedimentation within the lowest Member were rapid and repeated.

The Oksfjorddalen Schist Member represents a change to semipelitic (psammopelitic) sedimentation with carbonate precipitation at certain stages. Locally, also in this unit, deposition took place in a reducing environment, permitting preservation of organic matter. The overlying Skarddalen Quartzite Member shows the largest increase in thickness of all units from Riehppi to Skarddalen. It represents deposition of quartz-sand in the south, changing to a more feldspar-rich and arkosic composition with increasing thickness in the north, especially northwest of Váddás (Lindahl 1974).

The variation in thickness of the Skarddalen Quartzite Member is interpreted mainly as sedimentary. Overlying the quartzite, however, is a discontinuous, fluvial, pebble-supported conglomerate with micaceous matrix (the Rássevággi Member). The pebbles are mainly of quartzite indicating a local subaerial erosion of the subjacent quartzite, modifying the thickness to a certain degree.

Ramsay et al. (1985) considered this contact to represent a major unconformity, based on the interpretation that the rounded quartzite pebbles in the conglomerate are derived from the underlying Skarddalen Quartzite Member. The pebbles preserve an internal fabric, which, in their view, represent an inherited fabric formed during an Early Caledonian tectonometamorphic event. The authors agree that the contact represents a major unconformity but are sceptical to the interpretation that the rocks had undergone an Early Caledonian tectonometamorphic event (see rock descriptions).

The locally developed conglomerate on top of the Skarddalen Quartzite Member is the base of the carbonate-rich Guolasjávri Formation. Deposition of the Guolasjávri Formation took place in a lagoonal environment with carbonate reefs, interrupted by an infill of detrital material with fragment size ranging from clay to 20 cm pebbles. This produced the rapid changes of composition observed within the three members of the Formation.

The Jiehkkejohka Marble Member is dominated by carbonate rocks with local intercalations of conglomerate, while the Rássevággi Schist and Conglomerate Member is represented by fine-grained clastic sedimentation with thick conglomerates locally developed, mainly at the base. The Frukosthaugen Conglomeratic Marble Member represents a return to carbonate deposition. The Member is dominated by a matrix-supported conglomerate, the matrix consisting of carbonate to sandy carbonate. The pebbles, mainly well-rounded quartzite, but also well-rounded carbonate, could have been carried by floodwater from nearby land to a lagoon area or a back-arc marine environment. Such floods may have ripped up semi-consolidated mudstone and limestone and redeposited these angular clasts and the farther-transported rounded clasts, together with locally derived carbonate sand. This semi-consolidation thus produced the observed mixture of well-rounded quartzite pebbles, rounded carbonate pebbles and large fragments of carbonate-shale material in a sandy carbonate matrix.

The Oksfjord Group represents a major change in deposition with the introduction of submarine volcanism. The water depth is believed to have increased gradually. In the first stages, the Áhkkejávri Formation was deposited in relatively shallow water; this is a discontinuous unit with a substantial carbonate content. Volcanism commenced in shallow-water, and the lower part of the Loftani Greenstone Member was, in part, extruded directly on the Frukosthaugen Schist and Conglomerate Member. Locally, at Njoammeloalgi, the Greenstone interfingers with the Frukosthaugen Schist and Conglomerate Member. This is interpreted as a lava flow in the lagoonal environment, with further subsequent deposition of the conglomerate, passing upwards into the Goddejávri Calc-Biotite Schist Member. At Váddás, the Goddejávri Member separates the lower and upper parts of the Loftani Greenstone Member.

The volcanism had its centre in the Váddás–Riehppi area, producing the largest thickness of up to 600 m at Riehppi. The main vent or vents to the eruptions have not been found, but must be located either east of the outcropping greenstone, now eroded, or west of it, now unexposed. The sheared amphibolite dykes/sills in the underlying sediments could represent a part of the volcanic episode, but not the main vent system. The basalt extends over a distance of 40 kilometres in length or width and is the main extrusive mass in the Váddás–Biertavárri region.

Smaller amounts of basalt (greenstone) have been recognised in the Biertavárri district, as pillow lava (Padget 1955, P. Bøe, pers.comm. 1977) and agglomerates (P. G. Andréasson, pers.comm. 2004) in the Guolasjávri Formation. The 'Greenbeds' in the Ankerlia Formation were also interpreted by Padget (1955) as probable extrusive rocks, and their major element composition is similar with that of the Loftani Greenstone Member (Lindahl 1974).

The Ankerlia Formation was interpreted by Padget (1955) as sediments of greywacke type. Armitage (1977) concluded that the more psammitic bands in the unit resemble greywacke, originally laid down as turbidites. The mineral composition of the Ankerlia Formation, represented by a combination of amphibole, calcic plagioclase and epidote-clinozoisite, may indicate some form of basic source rock. Basic intrusions and extrusions are found locally, but the source may also be a greenstone terrane in the Precambrian basement. Contributions to the greywackes may have come from airfall tuffs, and reworking produced contourites.

The sulphide deposits in the Váddás–Biertavárri region are interpreted as volcanogenic. They all occur within the Oksfjord Group and are associated with basic volcanism. They were mainly deposited at or near the top of the Loftani Greenstone Member in the Váddás area. The intrusion of the VM does not seem to have affected the sulphide deposits, except for a certain degree of contact metamorphism. Sulphide deposits in the Ankerlia Formation can, in part, be shown to be associated with smaller greenstone bodies.

Sulphide mineralisation

The sulphide deposits in the Váddás–Riehppi area occur at four different stratigraphic levels of fairly limited thickness (Fig. 12). Lowest in the succession is a single deposit (Lower Njoammeloalgi), in the Goddejávri Calc–Biotite Schist Member, just above the lower part of the Loftani Greenstone Member. The next horizon, near the base of the upper part of the Loftani Greenstone Member, contains a single deposit, the Riehppegáisá deposit. At or near the top of the Loftani Greenstone Member, the extensive, mineralised Váddás horizon can be followed for 35 kilometres along strike from Reisadalen in the southwest to Doaresgáisá in the northwest. Massive to semi-massive sulphides occur in separate bodies linked together by sulphide disseminations or thin sulphide bands. The Váddás horizon contains the main mineralisation in the area and the Váddás deposit is the main deposit. The Biertavárri Zone is the highest level of mineralisation, located in the Ankerlia Formation. The major deposits in this zone are in the Biertavárri area in Kåfjorddalen (Vokes

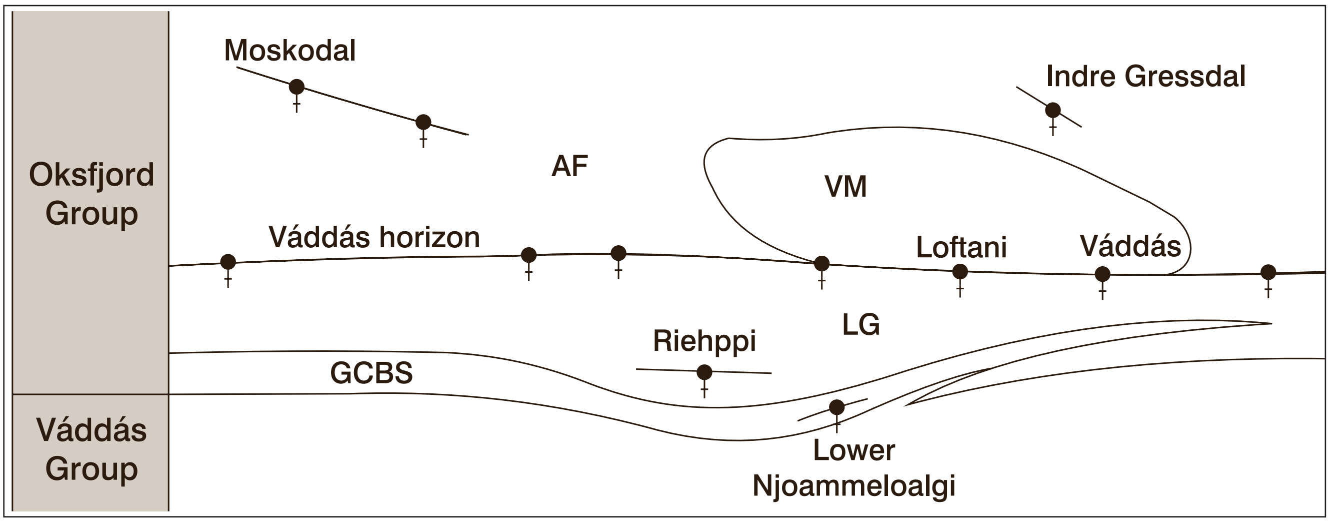


Fig. 12. Schematic locations of the sulphide mineralisations in the Váddás area. GCBS – Goddejávri Calc-Biotite Schist Member; LG – Loftani Greenstone Member; AF – Ankerlia Formation; VM – Váddašgáissat Metagabbro.

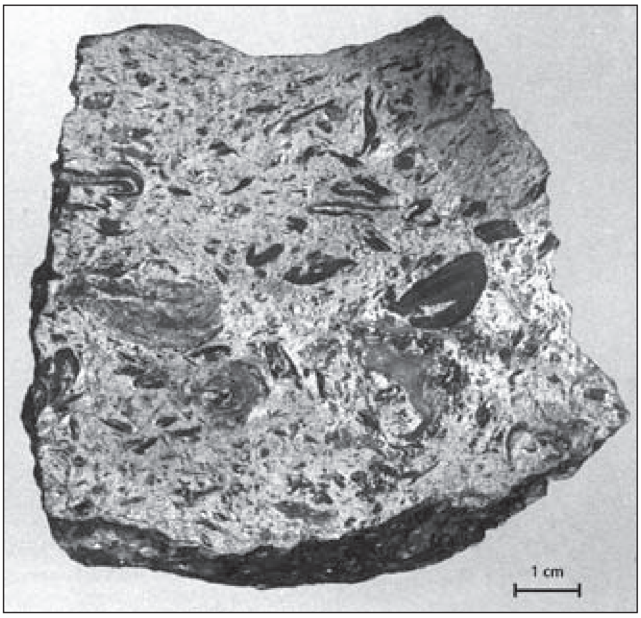


Fig. 13. Typical texture in the ore from the Riehppegáisá deposit; wall rock fragments of greenstone to greenschist in a sulphide matrix (pyrrhotite). The detached blocks of greenschist are partly replaced by sulphides. (Map reference UTM 522850–7736800, Reisadalen sheet 1734.3 (sample VR 362, Photo I. Lindahl).

1957). In the Váddás area there are a few semi-massive bodies in this position, the most important of which are Moskodalen and Høgfjellvatn (Kleine–Hering 1973), Røieldal and Indre Gressdal (Lindahl 1975). The sulphide deposit named Stoll I is located within the Gryta Amphibolite at Grytlia, close to Váddás.

The sulphide deposits in the region rarely contain more than 50–60% sulphides, and therefore gangue silicates are always an important part of the mineral parageneses. The texture of the ores shows that the deposits have been through the same metamorphism and deformation as the host rocks. Idiomorphic minerals such as pyrite, arsenopyrite and magnetite are poikiloblastic, whilst minerals such as sphalerite, chalcopyrite and pyrrhotite show typical metamorphic intergrowths (Stanton 1964). Features indicative of local mobilisation of chalcopyrite and galena can be observed, occupying strain shadows (Lindahl 1974), similar to structures described by Vokes (1969,1971) from other Caledonian deposits.

The ore deposits in the Váddás area have been strongly deformed both before and during metamorphism. The ores are 'durchbewegt' (Ramdohr 1980), whereby fragments from the wall rock have been incorporated, and rounded wall rock and quartz fragments are enclosed in the sulphide matrix (Fig. 13). This 'durchbewegung' or 'ball texture' (Vokes 1973) is typical of many of the Caledonian massive sulphide deposits and is found in all deposits in the Váddás area. Characteristics of the deposits are compiled in Table 4. The mineralogy of the sulphide bodies is simple, with metals of economic interest, i.e. copper and zinc, occurring in chalcopyrite and sphalerite.

The following is a brief characterisation of the mineralisation at each of the four known stratigraphic levels:

I. Lower Njoammeloalgi Deposit
The Lower Njoammeloalgi deposit is a small, lensoid, semi-massive sulphide body, comprising mostly pyrrhotite.

II. Riehppegáisá deposit
The Riehppegáisá deposit ranges from an dissemination to a semi-massive pyrrhotite ore with sphalerite and chalcopyrite (Fig. 13). Drillcores give an average grade of 2% Zn and 0.5% Cu (3 mill. tonnes). Minor galena is irregularly distributed in the ore. The host rock of the deposit is the Loftani Greenstone Member, which in the ore zone contains a considerable amount of talc. The alteration to talc is strongest where the durchbewegung is most intensive. One of the well-exposed examples of primary pillows is located in the host rock close to the ore.

III. The Váddás horizon
The mineralisation in the Váddás horizon seems to be situated at or near the top of the Loftani Greenstone Member. East of the VM the rocks below the ore horizon are strongly sheared (Stevens 1982), and their origin is uncertain. They could alternatively represent either, metabasalt, metabasaltic tuff, or part of the overlying Gryta Amphibolite.
In areas where the Gryta Amphibolite does not occur adjacent to the Loftani Greenstone, the mineralisation is found on top of the Greenstone. The pronounced shearing effect is most likely related to folding of the succession, with maximum competence contrast at the margin of the Gryta Amphibolite.
The sulphide bodies in the Váddás horizon are pyrrhotite-pyrite copper ores. The zinc content in the Váddás deposits is generally below 0.1%, but just north and south of Riehppi the zinc content of the horizon rises to 1%. Trends of increasing zinc content along strike

Table 4. Some principal features of the sulphide mineralisations in the Váddás area.

Mineralisation	Associated rock	Type	Thickness	Characteristics
Biertavárri Zone	Ankerlia Formation	Pyrrhotitic Cu-Zn	0–4 m	Several small deposits within the sediment
Váddás Horizon	Loftani Greenstone	Pyrrhotite-Cu-(Zn)	0–3 m	Extends for 35 km along strike on top of the upper Loftani Greenstone
Riehppegáisá deposit	Loftani Greenstone	Pyrrhotitic Zn-Cu	2–20 m	Within the thickest part of the upper Loftani Greenstone
Lower Njoammeloalgi	Goddejávri Calc-Biotite Schist Member	Pyrrhotitic Cu-Zn	c .1 m	Between lower and upper Loftani Greenstone

within the same ore body are found in upper Njoammeloalgi. Precious metals in the ore, based on analyses of chalcopyrite concentrates from flotation, are low (24 ppm Ag and 1.7 ppm Au).

Sulphide minerals in the ores are pyrrhotite, pyrite, chalcopyrite and accessory sphalerite. Oxides are represented by magnetite and hemo-ilmenite intergrowths, which occur in the ore and not in the host rocks. Silicate minerals are mainly plagioclase and hornblende, with anthophyllite, staurolite and a green-coloured spinel in various amounts.

IV. Biertavárri zone

Ore deposits of the Biertavárri type (Vokes 1955) are pyrrhotitic and occur in relatively small bodies of a few hundred thousand tonnes in the Ankerlia Formation. The deposits are not restricted to a particular stratigraphic position, and compared with the other types they are relatively rich in copper (2–4%). Some contain significant amounts of zinc. Magnetite is common and the minerals cubanite, galena, arsenopyrite, native bismuth, cobalt pentlandite and hedleyite have been identified locally (Kleine–Hering 1973, Lindahl 1973, 1975).

Genesis of the ore deposits

Together with the ores of the Sulitjelma and Røros districts, the ores in the Váddás–Riehppi area have been interpreted as Besshi-type deposits formed in thick volcanic-sedimentary sequences, deposited near the Ordovician-Silurian boundary (Grenne et al. 1999). The Riehppegáisá deposit records a significant influx of hydrothermal activity, contributing with Mg leading to the talc content and an irregular mineralisation of lead. The mineralisations and deposits are restricted to the Loftani Greenstone Member, either within the member or close to the top. The extensive Váddás horizon was deposited during the closing stages of the volcanism. A high Co/Ni ratio (5-10) (Lindahl 1974) supports a volcanogenic origin for the ores (Tatsumi 1970) and also that the contibution of metals from the VM was small.

The deposits of the Biertavárri Zone are mostly sediment hosted (Vokes 1957), like the single lower Njoammeloalgi deposit at a lower stratigraphic level. The small sulphide bodies in the Ankerlia Formation occur at different stratigraphic positions, and have varying content of detrital basic intrusive or extrusive material. The metal source is considered to have been fluids from local volcanism of far smaller scale than in Váddás.

Intrusions

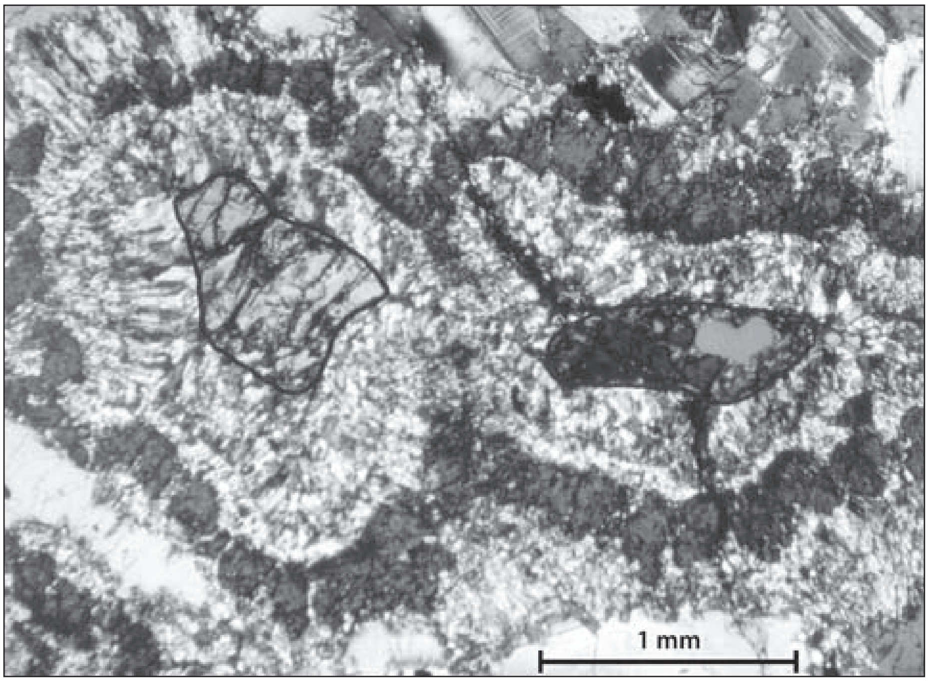
Čorrovárri Nappe

Mafic dykes in the Nahpojohka Group have been described by Lindahl (1974) and Zwaan et al. (1975) and were subject to an extensive study by Zwaan & van Roermund (1990). They occur as an extensive, weakly deformed dyke swarm where the Loddevággi Formation forms a mega-lens in the mountain Čorrovárri. The dykes have retained their discordant intrusive character, igneous textures and minerals (Fig. 14), and have a tholeiitic basaltic composition (Zwaan & van Roermund 1990). Outside the mega-lens they were deformed and metamorphosed to amphibolite lenses. Based on Sm-Nd dating they have a Late Neoproterozoic age (Zwaan & van Roermund 1990) and are thus much older and genetically unrelated to the dolerites in the Váddás Nappe.

Mafic dykes in the Nahpojohka Group

The central part of the Loddevággi Formation forms a tectonic mega-lens, the Čorrojávri Mega-lens, in which the sedimentary characteristics of the rocks are preserved. The lens contains a swarm of mutually parallel orientated dykes with a general NNW–SSE trend. They are discordant and cut the flat-lying metasedimentary rocks at high angles. In the most densely intruded area, 20 dykes were counted over a distance of 500 m. Dykes range in length from 50 to 1000 m, and are up to 10 m thick. In the Čorrovárri area, the host rocks are partly migmatised. Mutual intrusive relationships of mafic dykes and felsic neosome of the migmatite are

Fig. 14. Kelyphitic texture in olivine gabbro dykes in the Loddevággi Formation. Olivine (core) is altered to hypersthene, garnet and amphibole (Section Va 70, Map reference approx. UTM 525400-7736600, Kvænangsbotnen sheet, 1734.2, Photo I. Lindahl).



found. To the south of Čorrovárri the host rocks are less migmatised, and felsic pegmatites are found to be cross-cut by the dykes. In this area the sedimentary structures are better preserved and no regional metamorphic foliation was observed.

The dykes display a fine- and even-grained subophitic texture with clinopyroxene and plagioclase as the main constituents. Small amounts of metamorphic garnet and hornblende are found. The thickest dykes have a dioritic to olivine gabbroic composition and gabbroic texture, also with clinopyroxene and plagioclase as the main constituents. An olivine-bearing gabbroic dyke was found with well-developed kelyphitic texture (Lindahl 1974). The thick corona rims consist of hypersthene, garnet and hornblende (Fig. 14); most of the grains of plagioclase and pyroxene have a contact zone of epidote.

Two different relationships were observed between mafic dykes and migmatite. Some dykes cut through the migmatite, while others are disrupted by the migmatite and form inclusions, which appear to have reacted with the migmatite. Thus, two generations of dolerite are identified, both with the same orientation. The migmatite displays an even-grained granular texture, on a microsopic scale, but exhibits a flowage foliation on a macroscopic scale.

It may be concluded that the mafic dykes intruded clastic sedimentary rocks which do not appear to have been subjected to regional metamorphism prior to intrusion. The parallel orientation of the dykes over a long distance indicate intrusion within a regional tensional system, and the pervasive contact metamorphism suggests a deep-seated emplacement. The dykes are tholeiitic with a transitional geochemical character between MORB and within plate basalt (Zwaan & Roberts 1981, Roberts 1990). It has been suggested that the intrusion of the dykes is probably related to thinning and rifting of continental crust (Zwaan 1987). Based on comparisons with Vøring Plateau Tertiary dykes and lavas, the Nahpojohka dykes have been suggested to mark the actual inception of sea-floor spreading of the Iapetus Ocean (Roberts 1990).

Deformation of the dykes

Flow structures and accompanying contact-metamorphic features are found associated with the intrusion of larger gabbroic bodies (southwest of the map area). The Čorrovárri Nappe underwent pervasive ductile shearing, possibly during the stacking of the KNC (see summary section). Towards the margins of the mega-lens, the dykes are deflected to the north-northwest at the western margin and to the south-southeast at the eastern margin. Along the margins the rocks are deformed and metamorphosed with the formation of a blastomylonitic schistosity with clasts of plagioclase and garnet giving the deformed neosome of the migmatite the appearance of a streaky augen gneiss. The dolerite dykes display transitions from boudins to long, thin layers of garnet-hornblende schist subparallel to the regional schistosity.

Váddás Nappe

In the Váddás Nappe there is one major gabbro body, comprising the VM and the contiguous Gryta Amphibolite. It intrudes the Ankerlia Formation in the mountain massif of Váddašgáissát, and extends a considerable distance to the southwest. Bakke et al. (1975) indicated the presence of several other gabbroic intrusions in neighbouring areas related both to the Váddás Nappe and to the KNC (Fig. 1). Boudins of amphibolite are common in the metasediments of the Kvænangen Group. These probably represent sheared remnants of dolerite dykes and sills. However, no cross-cutting dykes have been observed, but are locally well preserved in the Guolasjávri area. In the Ankerlia Formation, dykes, sills and boudins of dolerite are common. The rocks show minor to substantial alteration to amphibolite-facies minerals and have a tholeiitic composition. Doleritic dykes also intrude part of the VM and the Gryta Amphibolite. The dykes are highly altered, commonly deformed and show a gneissic texture.

Small bodies of felsic igneous rocks occur within the VM and the Ankerlia Formation. The composition varies from dioritic to granitic, and the texture from medium grained to pegmatitic. Within the VM the felsites are low in K_2O and regarded as late-stage differentiates of the VM. In the Ankerlia Formation the felsites have a distinctly higher K_2O content and are regarded as a result of partial melting from the greywacke.

Váddašgáissát Metagabbro (VM)

Derivation of name: Th. Vogt (1927) named this gabbroic intrusion the Vaddas Gabbro or Vaddas Phacolith. The name Vaddas Gabbro was also used by Lindahl (1974). The name Vaddas is replaced, because it has been used for other stratigraphic units. The term Metagabbro is used for textural reasons discussed later.

Previous work: The VM was described as the Vaddas Gabbro by Th. Vogt (1927) and Lindahl (1974). Stevens (1982) studied the northern portion, mostly north of the Riehppi Fault. Earlier Kleine–Hering (1973) had studied parts of the Metagabbro farther south, around Moskodalen.

Distribution: The VM occupies much of the upper part of the mountain massif known as Váddašgáissát, the upper part of adjacent Ruksesgáisá, and extends southward to Moskodalen (Fig. 1 & Plate 1). The total extent is shown in Fig. 1. Other large, possibly related gabbros or metagabbros occur about 11 km north of Váddás in the mountains north-east of Oksfjordhamn (Nuovas), to the west near Nordreisa (Ste), and to the south in the Reisadalen area (Zwaan et al. 1975).

Type area and type section: Váddašgáissát is nominated as the type area, with a type section extending approximately from UTM 522050–7742900 to 522700–7743300 (Nordreisa map-sheet, 1734.4).

Thickness: The VM crops out over a maximum width of 3.5 km on Váddašgáissát, and 4 km across Ruksesgáisá and Oaivvoščohkka, to the south. The Gryta Amphibolite is interpreted as part of the original gabbro and this adds another

0.7 km to the outcrop width. The outer shape of the body resembles a fold or a huge lens, and the internal layering is intensely folded in places. The body appears to taper towards the north. The strongly asymmetrical zoning in the body suggests that it is a lens rather than a large fold.

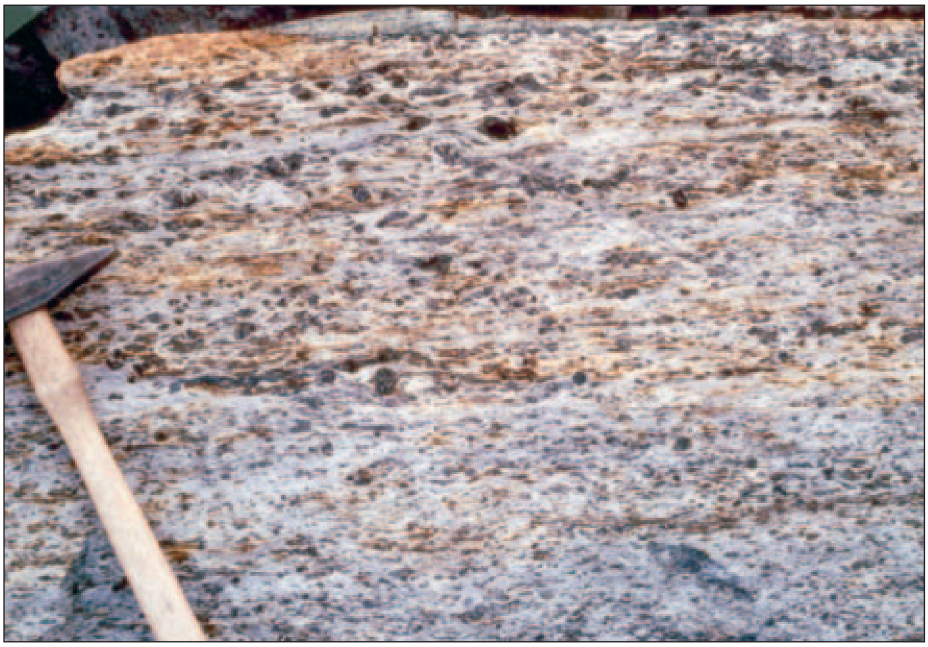


Fig. 15. Typical gneissic texture in very coarse-grained, olivine-bearing Váddašgáissát Metagabbro. Pyroxene augen in a plagioclase-rich matrix. (Map reference UTM 522000-7741650, Nordreisa sheet, 1734.4, Photo B. Stevens).

Relationships: On the western side of Váddašgáissát the VM shows intrusive relationships with the Ankerlia Formation. A gneissic zone along the contact contains contact- metamorphosed and partially melted metagreywacke, plus metagabbro. Some small felsic intrusions in the contact zone and in the metagabbro have chemical compositions compatible with partial melting of sediments. On the eastern side, the VM abuts against the Gryta Amphibolite, and both are thought to represent parts of the same original gabbro intrusion (see below). The amphibolite, along its eastern boundary, rests concordantly on the Loftani Greenstone Member. The contact zone between the Amphibolite and Greenstone is sheared. In the northern face of Váddašgáissát, the VM also abuts against Gryta Amphibolite (Plate 1). This rests concordantly on the Loftani Greenstone Member on the eastern side of the north face, but diverges on the western side and is there in direct contact with the Ankerlia Formation.

Mafic dykes intrude the eastern part of the VM, and also probably comprise a substantial part of the Gryta Amphibolite. Irregular bodies of felsic rock occur within the northern, western and southern margins of the Metagabbro. The felsic rock commonly occurs as the matrix of a breccia containing blocks of metagabbro.

Description: The VM is an internally deformed and recrystallised gabbroic intrusion. Layered and non-layered zones, zones of different grain size, and zones with and without olivine have been mapped (Plate 1).

The various zones in the VM can be broadly grouped from east to west, as follows (the Gryta Amphibolite is included in the list, since it is interpreted as part of the original gabbro):

1. Gryta Amphibolite. This occurs along the eastern margin of the VM and appears to wrap around the northern end of the Metagabbro. It is interpreted as an altered part of the VM. It consists of equigranular amphibolite with polygonal grain shapes, plus abundant porphyritic amphibolite and gneissic amphibolite. Towards the south there appears to be some gradation to non-layered, medium-grained metagabbro, and a unit of layered amphibolite is also developed.
2. Zone of coarse to very coarse olivine metagabbro. Apart from the Gryta Amphibolite, most of the eastern half of the VM consists of coarse- and very coarse-grained olivine metagabbro (Fig. 15). At outcrop-scale the rock is essentially non-layered or weakly layered, although

Fig. 16. Medium-grained, thin-layered Váddašgáissát Metagabbro with one thick layer of olivine-rich metagabbro. Such features are common near the boundary between layered and non-layered zones. (Map reference UTM 520900-7742650, Nordreisa sheet, 1734.4, Photo B. Stevens).

Fig. 17. Prominent magmatic layering in the Váddašgáissát Metagabbro. (Map reference UTM 518900-7738300, Nordreisa sheet, 1734.4, Photo I. Lindahl).

some large-scale layering is present. Within the zone there are thin units of medium-grained, layered 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 investigation has shown that this layering mainly consists of a swarm of mafic dykes with intervening metagabbro. The dykes show considerable deformation, but some chilled margins and porphyritic centres are preserved.

3. Zone of medium to coarse olivine metagabbro. Medium- and coarse-grained, layered and non-layered olivine metagabbro (Fig. 16) occupies the central-western part of the Metagabbro body. These rocks have sharp boundaries against the very coarse metagabbro to the east, but rather diffuse boundaries against the olivine-poor metagabbro 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 some minor layered units have been mapped (Fig. 17).
5. Gneissic zone. Along the western margin of the VM there is a narrow zone (about 200–250 m) in which the rocks have developed a gneissosity and in places exhibit lithological layering and intense folding. In some cases it is difficult to identify the original rock. The zone appears to contain deformed and contact-metamorphosed metasedimentary rocks (Ankerlia Formation), but may also contain deformed metagabbro. Most samples from the gneissic zone contain plagioclase, pyroxene and hornblende, as in the VM. However, some contain, in addition, quartz and biotite and are more compatible with the metagreywacke (Ankerlia Formation).

Mineralogy: The VM consists mostly of plagioclase, clinopyroxene and orthopyroxene, commonly with olivine, hornblende, magnetite and/or ilmenite. Apatite and titanite are common minor constituents (Table 5). Green spinel is a rare accessory mineral. In places hornblende is a major mineral, and in those cases the mineralogy resembles that of the Gryta Amphibolite. The igneous or metamorphic status of these minerals is discussed below.

Mineralogical variations exist on all scales. Some parts of the VM are very finely layered, on a scale from a millimetre to a few centimeters, defined by variation in the proportions of plagioclase, pyroxene and olivine. Plagioclase-rich layers are white, pyroxene-rich layers grey to grey-brown and olivine-rich layers are yellow. The units shown in Fig. 17 as layered metagabbro are characterised by this mm- to cm-scale layering. In some of the weakly to non-layered units, a diffuse layering on the metre scale can be seen. This is also largely defined by mineralogical variations. On the scale of mapping, a number of continuous and discontinuous units are delineated (Fig. 2) ranging from tens of metres to over a kilometre in width. Such units are defined on the basis of grain size, development of layering, and the presence or absence of olivine.

Table 5. Mean percentages and ranges of main minerals in samples from various mapped units in the Váddašgáissát Metagabbro (see Fig. 2).

Reference number	Plag	(An)	Cpx	Opx	Ol	Amph	Opaque
1*	58	64	30	3.5	4	3	2
	40-70	50-75	20-50	0-10	0-10	0-10	0-5
2	62.5	71	22.5	2.5	9.5	2	1
	60-65	65-75	20-30	0-5	5.15	0-5	0-1
3	55	56	29	4	6	3	3
	45-65	36-82	15-35	0-10	0-15	0-10	0-10
4	52.5	57	25	4	0	10	3.5
	20-70	42?-65	0-38	0-15	0-30	2-5	
5	40	65	15	2	0	32	7
	30-50	40-80	0-30	0-5		15-50	2-15

* Excludes one unusual sample containing 50% olivine and two samples containing 50% hornblende.

1. Coarse to very coarse olivine metagabbro, non-layered to poorly layered, 13 samples.
2. Coarse- to medium-grained olivine metagabbro, non-layered, 4 samples.
3. Medium-grained olivine metagabbro, layered, 13 samples.
4. Medium-grained metagabbro, layered, no olivine, 4 samples.
5. Medium-grained metagabbro, non-layered, no olivine, 3 samples.

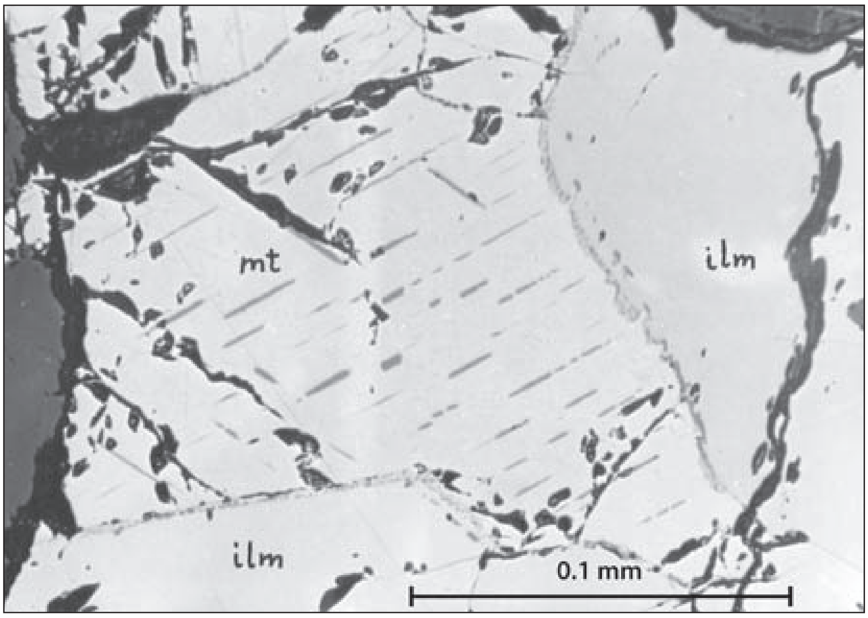


Fig. 18. Photomicrograph of Váddašgáissát Metagabbro showing magnetite (mt) with hercynite(?) exsolution lamellae (111), surrounded by ilmenite (ilm). The grain boundary between magnetite and ilmenite has a myrmekite-like texture. Polished section, reflected light, 1 nicol, 224 x air (sample VR558, polished section 3495). (Map reference UTM 521100–7738700, Nordreisa sheet, 1734.4, Photo I. Lindahl).

Olivine is present in the mapped units in the central and eastern parts of the VM (but absent in the Gryta Amphibolite), and is absent from the units on the western side. In the central and eastern parts, some samples contain no olivine, but in general 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-grained metagabbro contains approximately 50% olivine. The olivine variation in the VM is asymmetrical. Olivine tends to be an early phase in basic rocks, suggesting that the eastern side of the VM was the original base. The eastern side is also generally coarser grained.

The composition of plagioclase mostly ranges from An^{50} to An^{80}, but no systematic variation was noted. Clinopyroxene is present in all samples of metagabbro. Orthopyroxene was identified in some samples, but there is no consistent pattern. In a few places, narrow zones of metagabbro contain high concentrations of magnetite and ilmenite. The magnetite contains exsolved lamellae of spinel (probably hercynite) (Lindahl 1974) (see Fig. 18).

Textures: Most of the VM consists of non-layered and layered, hornblende-poor metagabbro. The rocks are termed metagabbro because they show tectonometamorphic structures such as gneissosity, schistosity and folded layering in outcrop, and in thin-section show abundant evidence of polygonal recrystallisation. Some samples are polygonal aggregates of minerals with no monomineralic aggregates. The texture of these rocks could also be explained as an igneous accumulate texture (Vernon 1970). However, other samples, particularly those from the coarse- and very coarse-grained metagabbros, show monomineralic aggregates of polygonal grains.

The textural evidence indicates that the VM was deformed and recrystallised in the solid state. Plagioclase, clinopyroxene, orthopyroxene and olivine took part in this recrystallisation. All minerals appear to have been in equilibrium. Reaction coronas between olivine and plagioclase are rare, indicating relatively low pressures during cooling (about 6-8 kb between 600°C and 1300°C; see Gardner & Robins 1973, Nesbitt et al. 1970, Esbensen 1978, Griffin & Heier 1973, Sapountzis 1975).

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 grains.

The recrystallisation occurred either above the stability limit of hornblende, i.e. granulite-facies conditions, or under lower-temperature conditions too dry for the formation of hornblende, with hornblende forming later as water entered the Metagabbro. A high-temperature recrystallisation interpretation is preferred because of the very well developed polygonisation, the fact that gabbro is unlikely to be completely dry (e.g., Wager & Brown 1968), and the very ductile or even fluidal character of the folds in the layering and gneissosity within the VM. Most of these folds show no axial plane cleavage (Fig. 19). Most probably the gabbro was

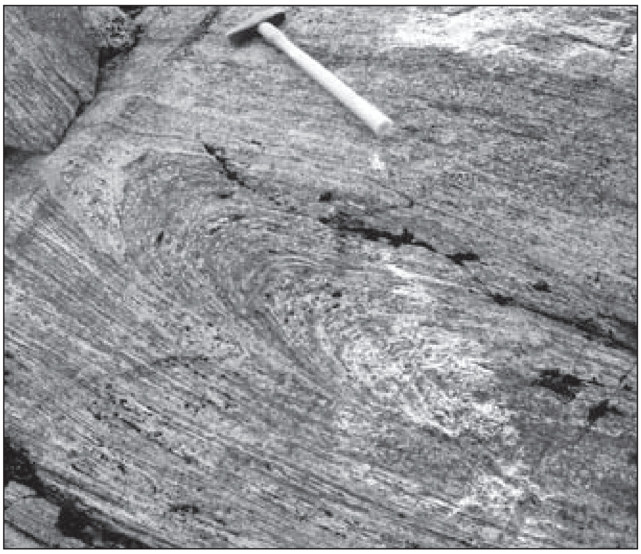


Fig. 19. Folded gneissosity in coarse- to very coarse-grained olivine-bearing Váddašgáissát Metagabbro. No obvious schistosity axial planar to the fold can be detected. (Map reference UTM 522200–7741700, Nordreisa sheet, 1734.4, Photo B. Stevens).

deformed during cooling, leading to recrystallisation at granulite-facies temperatures. It is unlikely that granulite-facies recrystallisation occurred after cooling, because the enclosing rocks show no sign of such high-metamorphic conditions.

The fine-scale layering described above is a prominent feature of parts of the VM. It is very similar in appearance to rhythmic cumulate layering described from other layered gabbros (e.g., Wager & Brown 1968, Munday 1974, Robins & Gardner 1974), but is more prominently developed than in some other layered gabbros. Much of the layering is relatively continuous on outcrop scale, but lenticular layering is common. Low-angle truncations resembling cross-beds occur sporadically, and graded layering is only rarely observed (e.g., near UTM 519650–7742500, Nordreisa map-sheet 1734.4). The gradations from a pyroxene-rich base to a plagioclase-rich top indicate that the western side of the gabbro was the original top.

Gryta Amphibolite

Derivation of name: Gryta Amphibolite (Stevens 1982) takes its name from a type locality 2 km southwest of Váddás.

Previous work: The Gryta Amphibolite largely corresponds to the "Contact-metamorphic Series" described by Lindahl (1974), and was later described by Stevens (1982).

Distribution: The Gryta Amphibolite lies along the eastern and northern margins of the VM. Few observations were made on the north face, due to poor access.

Type area and type section: The eastern side of Váddašgáissát is the type area. The type section is at Gryta, from UTM 522000–7742900 to 522700–7743300 (Nordreisa map-sheet, 1734.4). Reference sections are from UTM 522100–7743200 and from UTM 522400–7739800 to 523100–7740000 (Nordreisa map-sheet, 1734.4).

Thickness: Approximately 700–800 m along the eastern side of Váddašgáissát plateau, and about 450 m in the north face. The extent to which internal folding may have contributed to the thickening is not known.

Relationships: Along the eastern side of Váddašgáissát, the Amphibolite dips moderately to steeply westward under the VM. The upper contact tends to be a sharp boundary between medium-grained amphibolite and coarse to very coarse metagabbro. However, there is a transition in places where the rock has the texture of a coarse metagabbro but the mineralogy of amphibolite (i.e. hornblende and plagioclase). Much of the amphibolite texturally resembles the non-layered medium-grained metagabbro on the western side of the VM, and the layered amphibolite near Oaivvoščohkka closely resembles the medium-grained, layered metagabbro. Some samples of the Amphibolite contain substantial amounts of clinopyroxene and, similarly, some samples of metagabbro contain large amounts of hornblende.

It is concluded that the Gryta Amphibolite and VM were part of the same original gabbroic intrusion. The lower contact of the Gryta Amphibolite, against the Loftani Greenstone Member, is a highly schistose zone with diffuse layering. The schistose zone has a diffuse contact with the Amphibolite, but a sharper contact with the Greenstone. The Amphibolite is similar chemically to both the VM and the Loftani Greenstone Member, but a gabbroic origin is favoured because of textural similarities.

Description: Most of the Gryta Amphibolite consists of intermixed medium-grained, equigranular amphibolite with polygonal grain shapes, amphibolite with a porphyritic texture, and gneissic amphibolite with many gradations. The porphyritic amphibolites are probably mafic dykes altered to amphibolite that were probably part of the same dyke swarm which intruded the adjacent coarse to very coarse metagabbro. In a few places, apparent transitions can be seen from porphyritic amphibolite to gneissic amphibolite, suggesting that at least some of the gneissic amphibolite developed from deformation of dykes. It is also possible that the more felsic laminae in the gneissic amphibolite represent products of partial melting or metamorphic segregation from originally equigranular amphibolite.

Near Oaivvoščohkka there is a lenticular zone of very well layered amphibolite (Fig. 20). The layering and folding of the layering is similar in character to that observed in the layered medium-grained metagabbro.

Mineralogy: Samples of Gryta Amphibolite consist mainly of plagioclase and hornblende, but a few contain substantial amounts of clinopyroxene. Accessory magnetite

Fig. 20. Folds in layered Gryta Amphibolite. The felsic material is partly mobilised along the axial planes of the folds. (Map reference UTM 522800–7739000, Nordreisa sheet, 1734.4, Photo B. Stevens).

is present in all samples, and epidote-clinozoisite, titanite, apatite, zircon, and pyrite/pyrrhotite occur sporadically.

Textures: The term amphibolite is used to signify the metamorphic character of the rock. This is based on the abundant polygonal grain shapes and gneissic textures, closely resembling textures in parts of the Metagabbro. The Gryta Amphibolite is not termed a metagabbro because there are no distinguishable gabbroic textures.

There are two possibilities for the timing of transformation of the amphibolite from the gabbro: (1) the amphibolite developed coevally with the polygonal recrystallisation in the gabbro, or (2) the amphibolite mineralogy developed at a later stage, replacing polygonised metagabbro. If the latter had occurred, a more irregular pattern of amphibole replacement of pyroxene might be expected, including partial replacement of pyroxene grains by amphibole, and replacement of single pyroxene grains by aggregates of amphibole grains. Also, the energy required to permit recrystallisation could promote metamorphic reactions. Therefore, the former explanation is favoured.

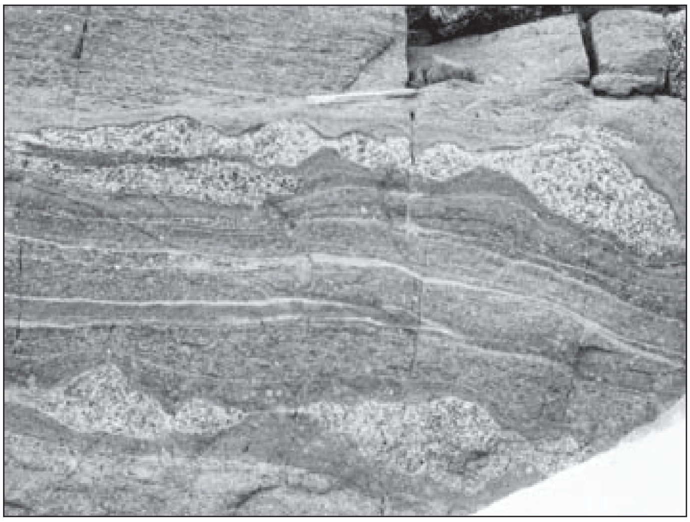


Fig. 22. Irregularly layered and boudinaged, coarse to very coarse Váddàšgáissát Metagabbro and medium- to fine-grained rocks which are probably deformed dykes. (Map reference UTM 522000-7738550, Nordreisa sheet, 1734.4, Photo B. Stevens).

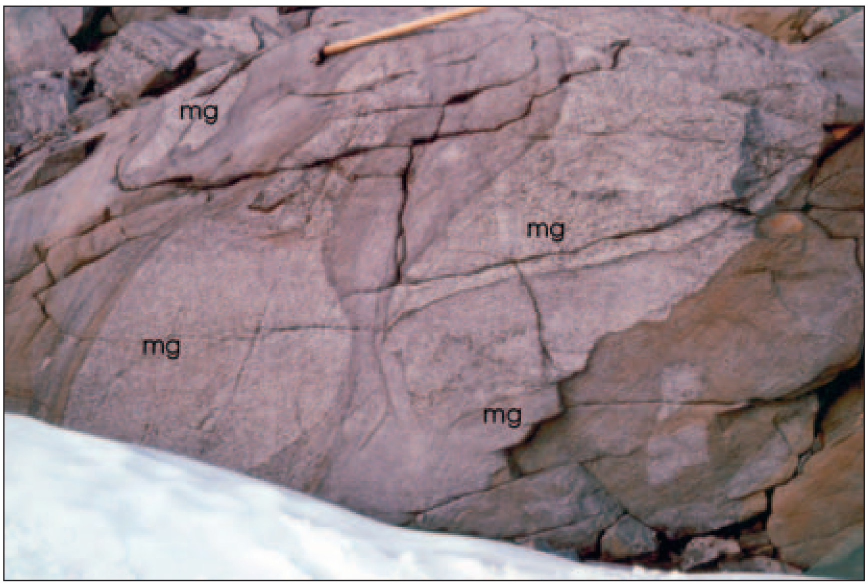
Mafic dykes in the Váddašgáissát Metagabbro (VM) and Gryta Amphibolite

The porphyritic amphibolite and much of the gneissic amphibolite within the Gryta Amphibolite are interpreted as mafic dykes. The phenocrysts are of plagioclase, some zoned, and many show signs of deformation. The matrix is hornblende and plagioclase, mostly recrystallised. Within the Gryta Amphibolite it is generally difficult to identify the contacts between dykes and host rock. The mineralogy of both is very similar, though subsequent deformation and recrystallisation appear to have obscured the original contrasts.

Within the VM, dykes were only positively identified in a zone about 300 m wide along the eastern margin, adjacent to the Gryta Amphibolite. Some dykes have porphyritic centres grading to fine-grained chilled margins against the sharp contacts with the VM (Fig. 21). In other places, probable dykes and the host VM are so deformed that they appear as alternating gneissic layers and/or boudins, preserving little of the original textures (Fig. 22).

The dykes trend approximately parallel to the strike of the VM, but are somewhat irregular in orientation. In some outcrops the dykes show splits around screens of metagabbro, and have irregular offshoots.

Fig. 21. Irregular mafic dykes (dark) in coarse- to very coarse-grained olivine-bearing Váddašgáissát Metagabbro (paler = mg). In the dykes, some chilled margins can be seen, as well as inclusions of the Metagabbro. (Map reference UTM 522350–7741600, Nordreisa sheet, 1734.4, Photo B. Stevens).



In thin-section, the dykes in the VM show relict igneous texture, including plagioclase phenocrysts and interlocking plagioclase lath textures in the matrix. Extensive metamorphic recrystallisation of the matrix is also common. The dykes have a similar mineralogy to the enclosing metagabbro. An average of three dyke samples showed: 48% plagioclase (An_{70}), 31% clinopyroxene, 6% olivine, 12% amphibole and 3% iron (-titanium) oxides. The main variation is in the olivine and amphibole content.

Thin-section examination showed that hornblende forms polygonal grains in apparent equilibrium with clinopyroxene and plagioclase, suggesting that hornblende was stable when recrystallisation occurred. This

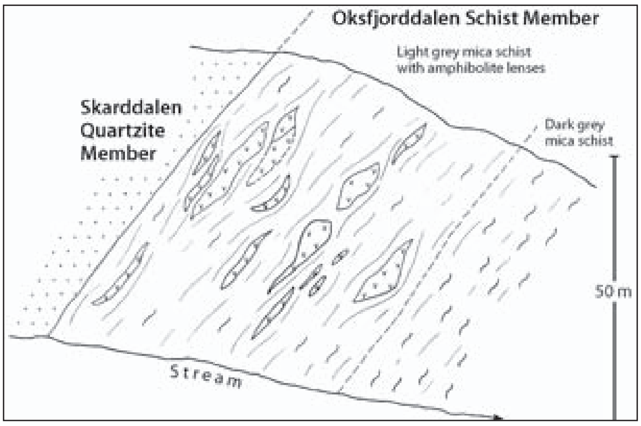


Fig. 23. Sketch of the steep side of the gorge from Luovttatvággi to Storelvdalen, looking towards north. This shows the nature of amphibolite lenses, possibly boudins of dykes, in the upper parts of the Oksfjorddalen Schist Member, overlain by the Skarddalen Quartzite Member. (Map reference UTM 524150–7740350, Kvænangen sheet, 1734.1).

contrasts with the host metagabbro in which hornblende was apparently unstable during recrystallisation.

Mafic dykes/sills in the Kvænangen Group

In the Kvænangen Group amphibolite boudins are common (Fig. 23). No cross-cutting structures have been found, except in the Skarddalen Quartzite at Rahpesvárri, and the texture in all the boudins is metamorphic (Lindahl 1974). The mineralogy of the lenses is dominated by amphibole and plagioclase, with some biotite, and titanite, chlorite, carbonate, apatite, zircon and pyrite/pyrrhotite are present as accessories.

Mafic and felsic instusiones in the Oksfjord Group

The extent of the occurrences of mafic dykes/sills in the Ankerlia Formation has not been fully mapped. Stevens (1982) mapped a strip about 5 km long and about 1 km wide along the western margin of the VM, within which the Ankerlia Formation contains a high density of dykes and sills. The distribution density of these mafic intrusions is between 10% and 50% of the rock volume, perhaps over 50% in places. Most of the intrusions are subparallel or parallel to bedding or transposed bedding and hence are sills. The dykes show low to high angles of discordance. Boudins of mafic rock are also common and are interpreted as deformed dykes/sills.

The mafic dykes/sills are basaltic in composition. Minerals and textures are igneous with various degrees of metamorphic mineral growth and recrystallisation. The igneous minerals were essentially plagioclase (An_{44-72}) and clinopyroxene, with olivine present in a few samples. Hornblende is the most prominent metamorphic mineral, commonly occurring as a partial replacement of clinopyroxene. Epidote-clinozoisite, titanite and chlorite are minor metamorphic minerals. The variation of main minerals of the dykes/sills based on the study of 9 thin-sections is: 35–60% plagioclase, up to 35% clinopyroxene, 10–65% hornblende and up to 5% Fe- (Ti-) oxides.

Porphyritic textures are common, with plagioclase phenocrysts in a matrix of interlocking plagioclase laths with interstitial clinopyroxene. The original textures have been modified to various degrees by metamorphic recrystallisation and, in places, the rocks are deformed to basic gneisses. In outcrop, some of the dykes/sills appear to be completely undeformed, whilst others are intensely deformed. However, even the least deformed show considerable alteration of clinopyroxene to metamorphic hornblende.

Felsic intrusions in the VM and the Ankerlia Formation

Small bodies of felsic igneous rocks occur within the VM and the Ankerlia Formation. The felsic rocks range in texture from pegmatitic to granitic and gneissic (Fig. 24). They range in mineralogy from diorite to trondhjemite to granite. In the main part of the VM, sporadic felsic pegmatites occur along joints. The pegmatites generally comprise quartz, feldspar and hornblende, but some biotite may be present.

Near the western and northern margins of the Metagabbro, irregularly shaped bodies of granitic to pegmatitic rock commonly form the matrix of breccias, incorporating blocks of metagabbro (Fig. 25). These felsic rocks consist 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 VM. Many of these felsites appear to have undergone the same deformation that affected the

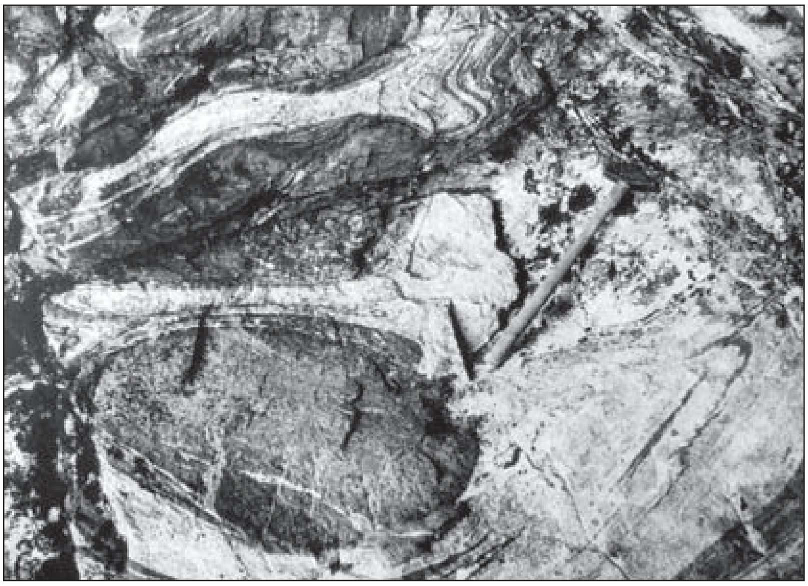


Fig. 24. Felsic pegmatitic intrusion in the Váddašgáissát Metagabbro. The gabbro fragments are subrounded and show flow banding. (Map reference UTM 523900–7740050, Nordreisa sheet, 1734.4, Photo I. Lindahl).

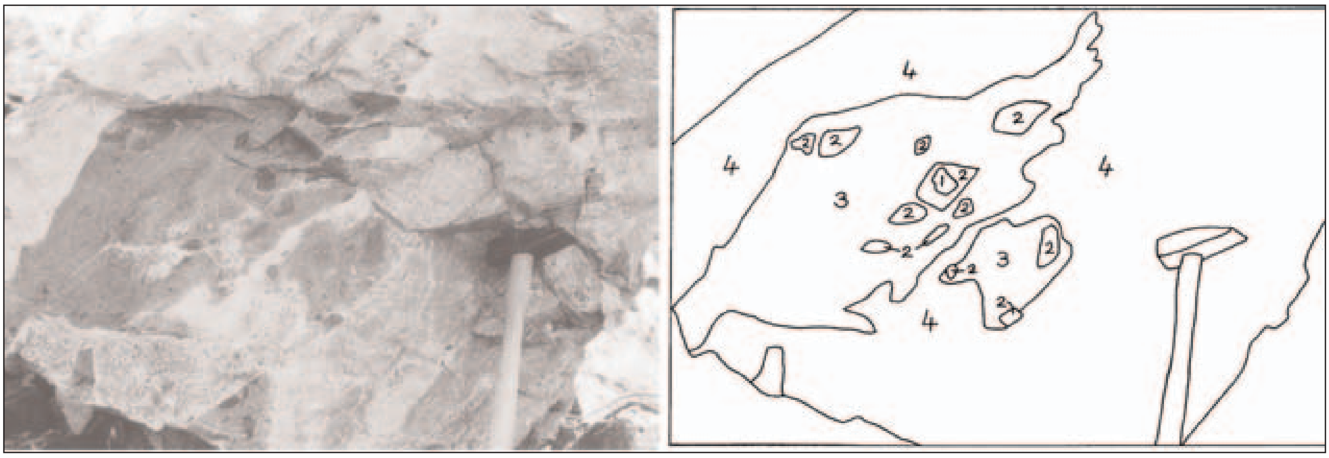


Fig. 25. Amphibole-bearing felsite containing blocks of more basic rocks. Apparent block-in-block textures may be due to reaction between felsic and mafic components. Loose boulder, Moskodalen. 1. Gabbroic rock with large mafic crystals – igneous texture; 2. Amphibolite or dolerite – granular texture; 3. Leucocratic amphibolite – granular texture; 4. Amphibole-bearing felsite with minor biotite-bearing pegmatite. (Map reference UTM 513150–7732200, Reisadalen sheet, 1734.3, Photo B. Stevens).

Table 6. Arithmetic means of analyses of samples from the Váddás area. Analysed by XRF at the Geological Survey of Norway. Major elements are given in per cent and trace elements in ppm.
*Trace elements analysed for 5 samples.
Numbers in parentheses – number of analyses used to calculate the mean value.

Rock unit	**Loftani Greenstone**	**Váddašgáissát Metagabbro**	**Gryta Amph.**	**Dolerites**	**Ankerlia* Formation**	**Felsites**	**Rahpesvárri Metagranite**
Number of samples	12	15	4	10	8	4	4
SiO_2	49.62	47.30	48.76	49.31	62.49	73.18	76.54
TiO_2	1.45	0.82	1.40	1.41	0.84	0.35	0.15
Al2O_3	15.95	16.05	16.03	15.38	13.53	13.33	12.56
Fe_2O_3	9.94	8.80	10.59	10.34	6.25 (7)	2.05	1.13
MnO	0.18	0.13	0.19	0.17	0.10	0.03	0.03
MgO	7.19	8.81	7.93	7.69	3.93	0.44	0.29
CaO	11.30	12.01	11.54	11.91	7.61	2.39	0.39
Na_2O	2.71	2.28	2.45	2.48	3.68	3.88	3.90
K_2O	0.09	0.13	0.10	0.21	1.22	2.84	4.67
P_2O5	0.15	0.11	0.14	0.12	0.18 (7)	0.04	0.10
LOI	0.15	0.15	0.15	0.16	0.15 (5)	0.13	0.09
Sum	98.73	99.59	99.28	99.18	98.98	98.66	99.85
Ba	20 (11)	57 (14)	16	41 (8)	182	403	326
Rb	<5 (7)	8 (2)	8 (1)	14 (4)	40 (4)	55	148
Sr	163	166	155	157	223	161	56
Zr	117	52 (14)	105	104	177	295	104
Nb	6	8 (5)	6 (3)	11 (2)	13 (4)	11	14
Y	38	23	34	34	34	57	44
La	9 (2)	7 (7)	5 (2)	5 (3)			
Ce	21 (2)	15 (7)	14 (2)	13 (3)			
V	264	176	269	238	156	14	7
Cr	237	370	238	288	176	5 (1)	<5
Co	35	36	43	39	25	11 (2)	<5
Ni	53	117	102	81	73	7 (3)	<5
Cu	69	60 (14)	74 (3)	115 (9)	29 (3)	8 (3)	<5
Zn	91	51	77	70	50	26	15

other rocks (mostly metasediments) in the gneissic zone. Some felsites are folded, some occur as boudins, and some have developed a schistosity defined by a parallel orientation of biotite. In the gneissic zone there are deformed breccias with elongated fragments of country rock in deformed felsite.

From the limited petrography and chemical analyses (Stevens 1982 and Table 6) there appear to be two types of felsic intrusions, although gradations could exist. One type is characterised by a high K_2O content (4-6%) and abundant K-feldspar. The other is low in K_2O (less than 0.5%) and low in feldspar.

The low K_2O felsic rocks may be late-stage differentiates of the very K-poor metagabbro. The high-K_2O felsic rocks (Table 6) have compositions close to granitic melts, and could have formed by partial melting of the Ankerlia Formation. The latter contains quartz, plagioclase and biotite, and up to 1 or 2% K_2O, thereby providing a likely source for a granitic partial melt. From Winkler's (1980) experimental work it could be inferred that suitable melts should have formed from Ankerlia Formation rocks at 700–750ºC if the water pressure was in the range 2–6 kb.

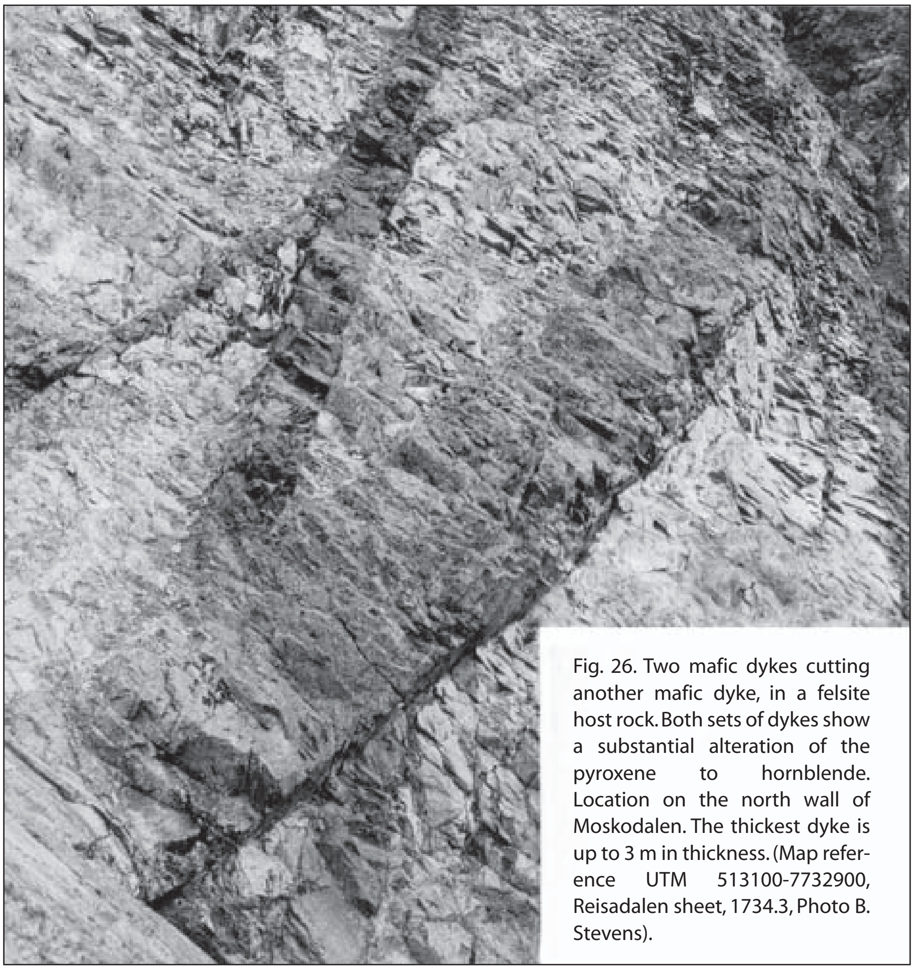


Fig. 26. Two mafic dykes cutting another mafic dyke, in a felsite host rock. Both sets of dykes show a substantial alteration of the pyroxene to hornblende. Location on the north wall of Moskodalen. The thickest dyke is up to 3 m in thickness. (Map reference UTM 513100-7732900, Reisadalen sheet, 1734.3, Photo B. Stevens).

Some important relationships between the felsic and mafic intrusive rocks in the Ankerlia Formation are revealed in Moskodalen, southwest of Váddás. The relationships were studied in an outcrop in the north wall of Moskodalen and also in talus boulders in the valley floor. At UTM 513400-7732100 (Reisadalen sheet, 1734.3), there are numerous talus boulders of felsite breccia. Included in the breccia are angular blocks of mafic rocks of various types (Fig. 25). Many have a doleritic texture with intersecting plagioclase laths, similar to those in the dykes/sills in the Ankerlia Formation at Váddás. In places, the doleritic blocks are separated from the felsic matrix by thick amphibolite reaction rims. Several blocks of coarsely porphyritic dolerite also occur in the felsite. These and most of the other mafic blocks are interpreted as fragments of mafic dykes and sills. A smaller number of fragments are of layered metasedimentary rocks, probably metagreywacke from the Ankerlia Formation.

In the north wall of Moskodalen (UTM 513000-7732900, Reisadalen map-sheet, 1734.3), mafic dykes intrude an irregular mass of felsite and also intrude the host Ankerlia Formation (Fig. 11). The Ankerlia Formation rocks are folded, but the time relationship between folding and intrusion is ambiguous. Many of the dykes are parallel, but some intersect other dykes (Fig. 26). One dyke grades from a mafic rock at the top to a felsic rock at the base. Another mafic dyke is cut by a thin felsic dyke.

The felsite is of the high-K_2O, high-K-feldspar type (Stevens 1982, analysis BS98c), probably derived from the partial melting of a greywacke from the Ankerlia Formation. The mafic dykes are chemically similar to dykes in the Váddás area, but higher in K_2O, perhaps indicating contamination of the dykes by the felsites (Stevens 1982).

The relationships in Moskodalen suggest that the mafic 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 intrusion of the gabbro, then the felsite and the dykes were probably emplaced at about the same time as the gabbro.

Many mafic dykes and felsites show relatively little evidence of deformation, whereas the Metagabbro is intensely and thoroughly deformed. Hence, it is likely that the one generation of deformation recorded in the Metagabbro predated emplacement of the dykes and felsites.

Geochemistry of the intrusive rocks

A considerable number of samples of greenstone, gabbro, amphibolite and mafic dykes have been analysed (Table 6). The rocks are all essentially mafic in composition, with SiO_2 contents mostly between 47 and 53% (Figs. 27–29). On most binary or ternary chemical plots the rocks form a single group or trend. In order to determine their chemical and tectonic affinities, discriminant diagrams were used, taking into account precautions summarised by Rollinson (1993). Plots

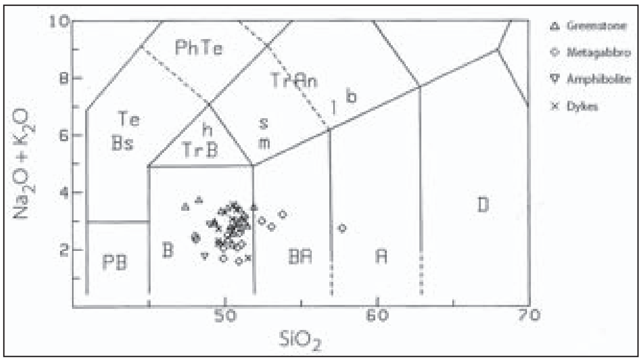


Fig. 27. All Váddás mafic rocks plotted on the alkali-silica diagram of Le Maitre (1984). The analyses are recalculated to 100% on a volatile-free basis. All samples except for a few metagabbros (probably feldspar-rich cumulates) plot in the basalt field (B). BA = basaltic andesite, A = andesite, D = dacite, PB = picrobasalt (see original reference for other fields).

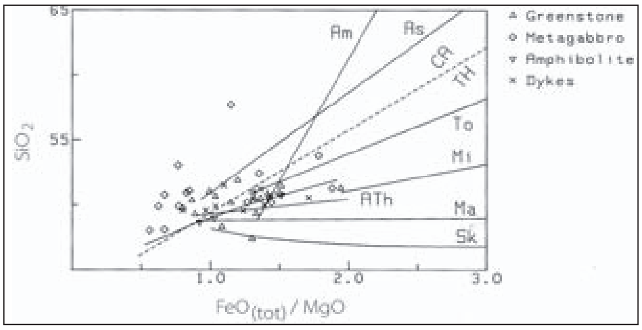


Fig. 28. All Váddás mafic rocks plotted on a FeO(total)/MgO vs SiO_2 Diagram, showing a general evolutionary trend towards a tholeiitic composition – arc tholeiites or ocean-floor tholeiites. The spread of data points results largely from the presence of cumulate metagabbro samples. Trend lines after Miyashiro et al. (1982). CA = calc-alkaline, TH = tholeiitic, Am = Amagi volcano (Japan), To = Tofua Island (Tonga Arc), Mi = Miyake-jima (Izu-Bonin Arc), ATh = Abyssal tholeiite, Ma = Macauley Island (Kermadec Arc), Unlabelled line = Kilauea (Hawaii).

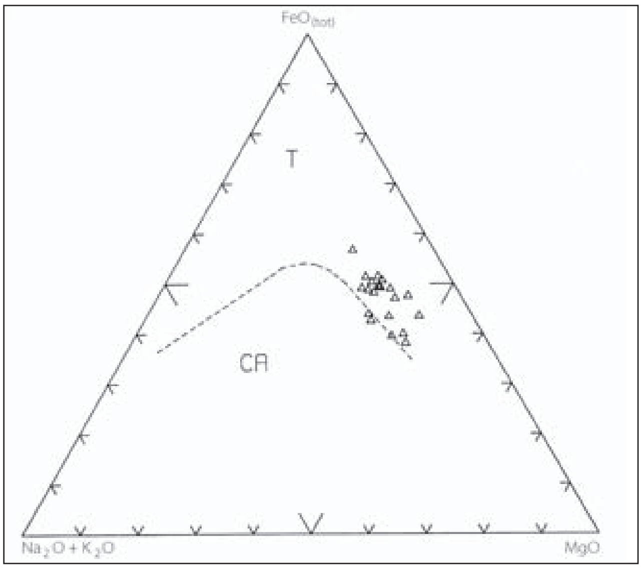


Fig. 29. Váddás samples with unaltered, non-evolved, non-cumulate basaltic compositions, plotted on an AFM diagram, discriminating between tholeiitic (T) and calc-alkaline (CA) compositions (after Irvine & Baragar 1971).

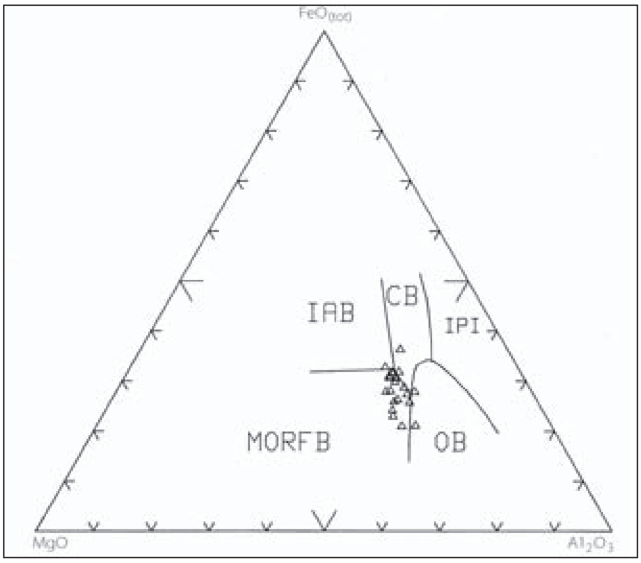


Fig. 30. Selected Váddás samples plotted on a MgO/FeO(total)/Al_2O_3 diagram. MORFB = ocean-ridge and ocean-floor basalts, OB = orogenic basalt, IAB = ocean-island basalt, CB = continental basalt, IPI = spreading centre island basalt. Fields after Pearce et al. (1977).

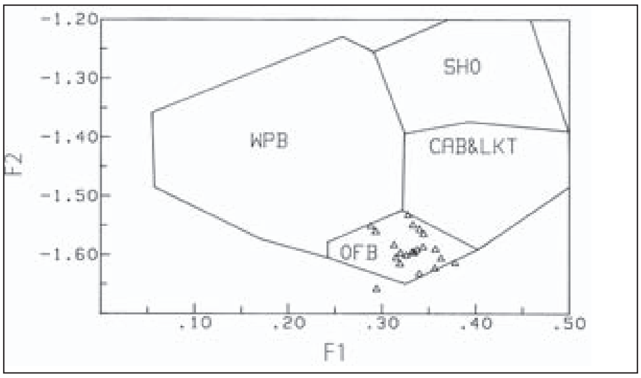


Fig. 31. Plot of major element discriminant functions (after Pearce 1976). WPB = within-plate basalts, SHO = shoshonites, CAB = calc-alkali basalt, LKT = low–potassium tholeiite, OFB = ocean-floor basalt.

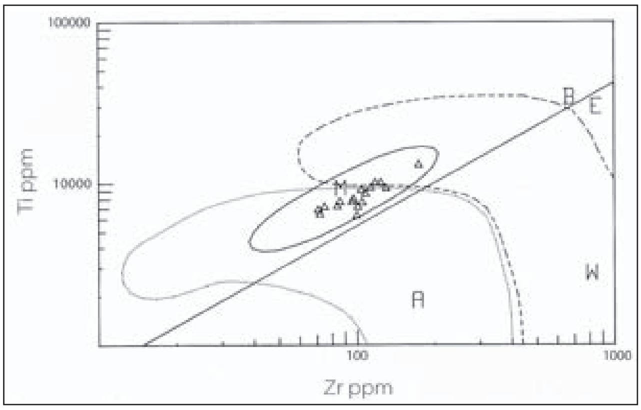


Fig. 32. Plot of log Ti/log Zr. Fields after Pearce (1982); B = basaltic compositions, E = evolved compositions, M = mid-ocean ridge basalts, A = arc lavas, W = within-plate lavas.

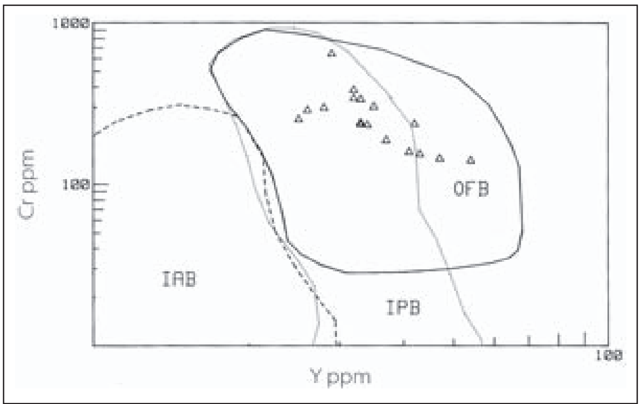


Fig. 33. Plot of log Cr/log Y. Fields after Pearce (1976): OFB = ocean-floor basalt, IPB = intra-plate basalt, IAB = island-arc basalt.

of K against Zr, and Ti ppm against Zr were constructed, and samples deviating substantially from the linear trends defined by most of the points were rejected as possible chemically altered rocks. A plot of log Ti against log Zr was used to eliminate rocks with evolved (i.e., not basaltic) compositions. A plot of Al_2O_3 against TiO_2 was used to separate rocks with cumulate compositions from rocks with the composition of a basaltic liquid.

Using all these procedures, all but one of the gabbro samples, most of the dykes, two of the amphibolites and three of the greenstones were eliminated. The remaining group of samples, exhibiting unaltered, non-evolved, non-cumulate basaltic compositions, were plotted on a number of discrimination diagrams shown in Figs. 29–33. The group consists of 14 greenstones (10 on minor element plots), 1 metagabbro, 2 amphibolites and 4 mafic dykes.

On the AFM plot (Fig. 29), a definite tholeiitic trend is indicated. In Figs. 30–33, the rocks plot within the field of ocean-floor basalts. On individual diagrams, other fields partly overlap the ocean floor basalt field, but overall it is very clear that the rocks have the composition of ocean-floor tholeiites.

History of emplacement and deformation

In the Váddás Nappe there was a complex history of intrusion and deformation. The intrusive rocks are the gabbro, which became the VM and Gryta Amphibolite, the felsic intrusions in the gabbro and metasediments, and the mafic dykes which intrude many other rocks. All of the intrusive types show some metamorphic and deformational effects, but these vary greatly.

The VM intrudes the Ankerlia Formation, of possible Silurian age (see later section). The Metagabbro exhibits cumulate layering (in part), recrystallisation, folded layering, folded schistosity/gneissosity and faulting. The Metagabbro is intruded by mafic dykes, felsic pegmatitic dykes and irregular felsic bodies.

The felsic intrusions transect the Ankerlia Formation, the VM, and some of the mafic dykes. The felsite commonly occurs as the matrix of a breccia containing fragments of metagabbro, or fragments of mafic dyke. In Moskodalen, the felsite matrix of a breccia appears to have reacted with the dyke fragments. Many of the felsites appear to be undeformed. However, partial metamorphic alteration is common, and some felsites show deformation features in thin-section, and/or in outcrop. Schistosity is well developed in some felsites and in the gneissic zone (see description of the VM) on the western margin of the VM.

Dolerite dykes intrude many stratigraphic units, including the VM and the Gryta Amphibolite, and are particularly prominent in the Ankerlia Formation. In Moskodalen, doleritic dykes intrude felsite. In some outcrops in the Váddás area the dykes appear to be undeformed; in others they occur as boudins or amphibolite lenses. All samples examined in thin-section show some metamorphic alteration. It is not known whether the dykes were intruded in just one episode or at different times.

In determining the history of emplacement and deformation there are a number of critical relationships, as follows:

1. There are no major chemical or mineralogical differences between the dykes, and all show some metamorphic alteration. It is therefore possible that all the mafic dykes in the VM, Amphibolite and Ankerlia Formation were emplaced in one episode.
2. In Moskodalen, mafic dykes intrude K-rich felsite, and felsite intrudes, brecciates and reacts with mafic dykes. Assuming only one generation of mafic dykes and felsites, these mutually intrusive relationships suggest that both were emplaced in the same episode.
3. If the K-rich felsites were formed by partial melting of the Ankerlia Formation as a result of emplacement of the gabbro (as is suspected), then the emplacement of gabbro, felsites and dykes occurred over a short geological time span. This is supported by the similarity in chemistry between the Metagabbro and the dykes (Table 6).

In the following discussion it is assumed that there was only one episode of dyke formation and that the K-rich felsites were formed by partial melting related to gabbro emplacement.

The deformation history of the VM shows some similarity with that of the Ankerlia Formation. The VM shows an abundance of isoclinal folding with no axial plane schistosity, and features irregular thickening and thinning of cumulated layering, and some mobilisation of felsic components. A lesser number of folds within the VM, exhibit an axial plane schistosity.

Within the Ankerlia Formation the well developed layering (either bedding or transposed bedding) exhibits abundant tight folds with no obvious axial plane schistosity. In places, these folds appear to be gently refolded, and rare crenulation cleavage is present. It is possible that the isoclinal folds in the VM are the same generation as the tight folds in the Ankerlia Formation, here tentatively classified as D1 (see summary section), while the folds with axial plane schistosity in the VM are equivalent to those with crenulation cleavage in the Ankerlia Formation (D2, see summary section). Given the apparent granulite-facies metamorphic recrystallisation in the metagabbro, it is likely that D1 took place while the temperature of the metagabbro was higher than that of the enclosing rocks, i.e., during cooling of the recently emplaced gabbro.

Both the VM and the Ankerlia Formation are intruded by mafic dykes. In both cases some dykes are virtually undeformed whereas others are boudinaged and gneissic in character. Dykes in both the VM and the Ankerlia Formation are altered to varying degrees to an amphibolite mineralogy, and partial polygonal recrystallisation of dyke rocks is common, particularly in dykes within the VM. Within the VM, hornblende occurs only as a minor alteration phase, whilst in the dykes it is much more prominent.

In the coarse- to very coarse-grained phases of the VM, cumulate layering is not well developed, but there is a well developed gneissic layering defined by an alternation of pyroxene-rich and plagioclase-rich laminae. This gneissic layering has undergone isoclinal folding equivalent to the isoclinal folding of the cumulate layering in the finer-grained, well–layered phases of the VM.

The simplest explanation of the above features is that the gabbro was intruded during or just prior to the D1 (see summary section) phase of folding in the Ankerlia Formation. The D2 folding occurred after the gabbro had entirely crystallised (except perhaps for a very small pegmatitic melt fraction), but before the gabbro had cooled to the temperature of the enclosing rocks. During deformation the gabbro recrystallised to a polygonal-textured metagabbro, a gneissosity formed parallel to the cumulate layering, and was deformed along with the cumulate layering (D2). At this time the main mass of the VM was at a temperature above the stability limit of hornblende, while the lowest section of it had cooled to a temperature closer to that of the enclosing rocks, and recrystallised to become the Gryta Amphibolite. Metamorphism of the country rocks produced amphibolite-facies minerals, locally with kyanite and staurolite (M2).

Mafic dykes intruded both the VM and the Ankerlia Formation soon afterwards, undergoing partial metamorphism in amphibolite facies. Deformation of a zonal nature accompanied the amphibolite-facies metamorphism, and caused extension of some of the dykes in boudinaged layers within the VM, and in amphibolite lenses within the Ankerlia Formation. The open folds (D2) with axial plane schistosity in the VM, and crenulation cleavage in the Ankerlia Formation may have formed at this time, but no clear relationships between these features and the dykes were observed.

The felsites may have originated in part as the last, pegmatitic fractionate of the gabbro, and in part as a partial melt of the Ankerlia Formation. Some felsites show strong deformation textures, while other areas are very weakly deformed, similar to the mafic dykes. The felsite may have been largely in a liquid state during initial deformation of the gabbro, but crystallised before the later, zonal, amphibolite-facies deformation.

The model outlined above suggests that the VM was intruded during or just prior to D1 folding, and deformed (D2) before it cooled to the temperature of the enclosing rocks. Previous discussion indicated that deformation took place at 6–8 kb, i.e., probably at a depth of 20 km or more.

The interpretation also requires that the dykes were intruded at great depth, between two closely spaced deformations. Both the VM and the dykes have oceanic tholeiite compositions, typical of magmas emplaced in thin crust in extensional tectonic environments. In that respect, the above interpretation appears anomalous, with tholeiites intruding at about 20 km in a possible compressional setting. In the above interpretation it is also difficult to see any genetic connection between the VM and dyke rocks, and the compositionally very similar Loftani Greenstone Member. If the interpretation is correct, then the similarity in compositions is coincidental.

Based on the discussions and assumptions above, the following order of events is deduced:

1. Gabbroic magma emplaced, T = 1400ºC or greater. Partial melting of Ankerlia Formation.
2. Crystallisation and development of cumulate layering in gabbro.
3. Deformation (D1), producing schistosity/gneissosity in the gabbro, then folding of the gneissosity and layering. Polygonal recrystallisation of the gabbro to form metagabbro at T <800ºC and amphibolite at T > 800ºC.
4. Intrusion of mafic dykes in Metagabbro, Amphibolite and the Ankerlia Formation. Mutual intrusion of mafic dykes and felsite (granophyre).
5. Amphibolite-facies (kyanite grade) regional metamorphism (D2, M2). Country rocks deformed and metamorphosed, and minor hornblende alteration in Metagabbro; dykes boudinaged and partly altered to amphibolite-facies assemblages.

Summary of structure, metamorphism and tectonostratigraphy in the Váddás area

The principal characteristics of the regional metamorphism in the upper Kalak Nappe Complex in the Nordreisa area have been described by Zwaan et al. (1975), Zwaan & Roberts (1978) and, for the Čorrovárri area, modified by Zwaan & van Roermund (1990). The complex displays a tectonostratigraphic succession formed as a result of repeated thrusting and folding, and with a gradually upward-increasing metamorphic grade and intensity of deformation. The main schistosity in the rocks of the Čorrovárri Nappe (the uppermost tectonic unit) labelled as late-S2 by Zwaan & Roberts (1978) and Zwaan & van Roermund (1990) is defined by minerals typical of intermediate amphibolite-facies metamorphism. This schistosity formed in the waning stage of the general regional metamorphic M2 phase of Zwaan & van Roermund (1990) overprinting an early fabric (early-M2) which, in part, developed in granulite facies (see later). The schistosity is penetrative and relatively coarse-grained, due to ductile shear strain, and is almost parallel to the compositional banding. It is also axial planar to intrafolial isoclinal folds and is indicative of combined vertical flattening and layer-parallel shearing. The initial formation of the Čorrovárri Nappe and the Čorrojávri Mega-lens is inferred to be related to this deformation phase (see description of the Čorrovárri Nappe).

Because of the strain-shielding effect of the tectonic lens it forms a low-strain window, thus preserving earlier tectonometamorphic fabrics. The earliest metamorphic phase recorded is an intermediate-pressure/high-temperature, granulite-facies, contact metamorphism (M1) due to the emplacement of the mafic dykes, and this was accompanied by a comparatively ductile deformation (see also Krogh et al. 1990). Structures related to this phase are overprinted by an upper amphibolite to granulite-facies regional metamorphism (early-M2, Fig. 14). Together with the above-described late-M2 it represents an early period of thrusting which also affected the underlying Nabar Nappe (for details, see Zwaan & van Roermund 1990). The M1 and M2 features were also found on Sørøya by Krill & Zwaan (1987) and formed the two basic arguments for their reinterpretation of the Finnmarkian deformation in that area. It questioned the synorogenic character of the Seiland Igneous Province, and a rift-related origin was proposed. The M2 phase was inferred to represent the Finnmarkian Deformation; an event believed to be of regional metamorphic character, unrelated to the earlier intrusion of the Seiland Igneous Province.

Work by Daly *et al.* (1991) suggested that the Klubben Psammite (Formation), probably a northern correlative of the meta-arkosic rocks of the Čorrovárri Nappe, was initially deformed prior to c. 800 Ma, during the proposed Porsanger orogeny (now Porsangerhalvøyan, Roberts 2003). Traces of this tectonometamorphic event in the Čorrovárri Nappe are possibly represented by the local occurrence of a weak deformation of sedimentary structures of unknown character which pre-dates the intrusion of the mafic dykes (Zwaan & van Roermund 1990).

The entire multiphase, Scandian metamorphic sequence in the rocks of the Váddás Nappe has been described in detail by Pearson (1970), Lindahl (1974) and Zwaan & Roberts (1978). They recognised three main deformation episodes. The first deformation episode (D1) in the country rocks away from the VM developed under comparatively low-grade metamorphic conditions and is registered only as a faint foliation enclosed in the cores of garnet porphyroblasts. At the same time the Váddás Nappe was affected by an early deformation with ductile folding with no axial plane schistosity and only local high-grade metamorphism, the origin of which is not fully understood. However, this early deformation and metamorphism could be associated with the emplacement of the gabbro.

These early (D1) fabrics are strongly overprinted by structures of the second deformation (D2) phase and completely recrystallised during the accompanying intermediate amphibolite-facies metamorphism (Pearson 1970; see section on history of emplacement and deformation, this paper). The D2 folding and axial planar schistosity is penetrative and this regional foliation is almost parallel to the compositional banding. Fold axes and mineral lineations trend NNE–SSW. The psammites and the igneous rocks of the Váddás Nappe display a polygonal granoblastic texture with only a weak preferred orientation. The pelites are lepidoblastic, showing a continuous foliation almost parallel to the compositional banding and axial planar to minor folds.

The initial thrusting of the Váddás Nappe probably started during this D2 phase. The high-grade thrust zones at the top and base of the nappe, and the gneissic zone around the VM, display mid amphibolite-facies blastomylonites and post-kinematic growth of staurolite, kyanite, garnet, amphibole and zoisite. This post-kinematic growth, producing the characteristic garben-schists, may be the result of a regional tectonic-burial metamorphism caused by the stacking of the nappes. In the case of the gneissic zone around the VM, it is inferred that the main mass of the Metagabbro was still at a temperature above the stability limit of the D2 intermediate amphibolite-facies minerals, suggesting that intrusion and later thrusting were closely related. This fabric and mineral assemblage, also found in the Luovosskaidi Formation, was defined by Zwaan & van Roermund (1990) as their M3 in the Čorrovárri Nappe. This equivalence (i.e., D2=M3) implies that, in this phase, the Váddás Nappe was emplaced on top of the Čorrovárri Nappe. Consequently, this suggests that the Čorrovárri Nappe was affected by two phases of regional shearing. The early 'Finnmarkian' regional metamorphism is represented by the above-described M2, and was subsequently overprinted by the M3 of the Čorrovárri Nappe which coincides with the Scandian D2 thrusting of the Váddás Nappe.

The KNC and RNC are thought to represent a northern continuation of the Seve and Köli Nappe Complexes. The contact displays apparent structural and metamorphic concordance in the Váddás area, as described above, but regionally this contact is of a discordant character. Along the thrust contact to the southwest the Čorrovárri Nappe wedges out completely and the basal unit of the Váddás Nappe (the Gæirajávri Formation) overlies successively lower tectonic units of the KNC (Binns 1978, Zwaan & Roberts 1978, Quenardel & Boullier 1979). In the Signaldalen area, the middle amphibolite-facies Váddás Nappe rocks lie on middle greenschist-facies meta-arkose of the Nalganas Nappe, the lowest unit of the KNC in that area (Fig.1; Zwaan & Roberts 1978, Zwaan 1988). This discordance can be followed farther to the southwest and ends with renewed concordance between the Seve and Köli Nappe Complexes east of Rostadalen (Gustavson & Skålvoll 1977). Such regional discordances have been described by Greiling & Zachrisson (1996), associated with a marked imbrication of the competent felsic rocks of the Lower and Middle Allochthons (Särv and Seve/Kalak Nappe Complexes), detached from the more incompetent pelitic rocks and marbles of the Upper Allochthon (Köli/Váddás) by regional flexural shearing (Andréasson et al. 2003). This detachment surface acted as the roof of the thrust system during final thrusting of the rock pile to its present position.

The metamorphic fabric and associated structures in the thrust contact zone between the two nappe complexes in the Váddás area are partly destroyed by the subsequent deformation structures inferred to be related to late-Scandian gravitational collapse of the orogen, generally labelled as D3. It is characterised by a grain-size reduction resulting in a fine-grained, middle greenschist-facies, blastomylonitic schistosity, enveloping the M3 porphyroblasts of the Čorrovárri Nappe rocks and the D2 minerals of the Váddás Nappe rocks. In less strained zones D3 is represented by open, upright to tight recumbent folds on all scales with an axial planar anastomosing spaced cleavage. Related mega-folds with wavelengths of 10 km or more resulted in local repetition of parts of the tectonostratigraphic succession including parts of the Čorrovárri Nappe (the Trollfjell Recumbent Synform of Ash (1967), the Kvænangen Nappe Fold of Pearson (1970) (here called the Kvænangen Recumbent Fold), and the Storevika Recumbent Syncline (Sturt et al. 1981). All these D3 folds are verging to the west or southwest (Hooper et al., in Ash 1967, Hooper 1971).

The eastern part of the Kvænangen Recumbent Fold is highly flattened in the area of Rahpesvárri and explains local reappearance of members of the Kvænangen Group on opposite fold limbs. In the core of the fold, rocks inferred to belong to the underlying KNC (Pearson 1971) are found. They are represented by a string of deformed ultramafic rocks (Zwaan et al. 1975), meta-arkoses, the 600 Ma Rahpesvárri Metagranite and Zn-Pb-Cu deposits in a hornblende schist zone (Strand 1971). Those types of ore-deposits are not found in the Váddás succession. A feature of the Kvænangen Recumbent Fold is the combination of flattening and simple shear in long limbs resulting in excision of parts of the tectonostratigraphic succession with a marked development of pinch-and-swell structures, augening of fold hinges and boudinage. Close to the high-strain zones, folds become non-cylindrical with their axes rotated to the southwest and a paper-thin mylonitic foliation with ribbon texture was developed.

The final stage in the structural history is that of brittle deformation, forming large-scale gentle folds and monoclines, and associated steep-dipping faults and joints discordant to the earlier structures (Pearson's D4, see profiles in Zwaan et al. 1975). In the coastal Nordreisa district, representing the thinned cratonic margin, E–W trending block faulting related to this final stage is well developed (Ramsay et al. 1985). In the Váddás area it is represented by two main hinge faults; the Durmålsskardet Fault (Barkey 1964) and the Riehppi Fault (Vogt 1927), the latter with a vertical displacement of 0.5–1 km. From Váddás to Riehppi there is a series of related faults with smaller displacements (Lindahl 1974) with a horsetail configuration depicting a dying out of the faulting (Plate 1). These faults are assumed to be Permian in age (Olesen et al. 1997, Roberts & Lippard 2005). Interestingly, the axes of both the D3 and the D4 mega-folds are orientated perpendicular to the faults and the folds are markedly different in configuration on either side of the main faults. Also, both the mega-folding and the faulting dies out to the south. This relationship suggests a combination of mainly normal faulting with an oblique component, folding the country rock, and a more protracted history of the block faulting. This combination is also inferred for the Tjeldsund fault system east of Harstad (Zwaan et al. 2002).

Age of sequence and regional correlation

The age of intrusion of the Čorrovárri dyke swarm is around 582–578 Ma (Sm-Nd and Rb-Sr mineral isochrons, Zwaan & van Roermund 1990). The related, but undated gabbroic lenses in the lower part of the Čorrovárri Nappe and less commonly in the underlying Nabar Nappe (Zwaan 1988) have a southwesterly extension in the Oahpis and Bæccegæhal'di gabbros (Zwaan et al. 1975, Zwaan & van Roermund 1990) and the troctolitic complex of Ráisduottarháldi (Halti Igneous Complex) in the Kåfjord area (Bøe 1976, Lehtovaara & Sipilä 1987, Sipilä 1990). Interestingly, it seems that the Oahpis gabbro and some of the related amphibolitic bodies farther to the west, on both sides of Reisadalen, cut through the high-grade (M2) mylonite that forms the basal thrust to the Čorrovárri Nappe.

Regionally, the Čorrovárri dyke swarm and the related gabbros in the Čorrovárri area are considered to be a part of the Seiland Igneous Province (Krill & Zwaan 1987, Andréasson 1987, Zwaan & van Roermund 1990) farther north whose age is now well constrained to between 577 and 555 Ma (Roberts et al. 2004). The dykes and gabbros are correlated to the south with the Ottfjället dolerite dyke-swarm of the Särv Nappe and the mafic plutonic rocks in the Seve Nappe Complex in Sweden derived from the rifted margin of Baltica and the early Iapetus ocean floor (Andréasson 1994, Andréasson et al. 2003).

Earlier, conflicting ages were obtained for the Halti Igneous Complex, ranging from 564 Ma (Sm-Nd mineral ages from gabbro by Matsson (1994)) to 434 Ma (U-Pb ages on baddeleyite and zircon by Vaasjoki & Sipilä (2001)), but the recent U-Pb determination of 437 Ma on zircon from a plagiogranite seems to confirm the younger age (Andréasson et al. 2003). This suggests a genetic relationship with the undated, but assumed Late Ordovician to Early Silurian VM (Lehtovaara & Sipilä 1987, Andréasson et al. 2003) and "other mafic suites developed as short-lived marginal basins throughout the entire length of the Baltic margin" (Andréasson & Gee 2004). This also implies that the Čorrovárri and Nabar Nappes were intruded by nearly the same type of mafic intrusions in two different time periods. Since the Halti Igneous Complex is most likely genetically related to the VM in the Váddás Nappe, the Čorrovárri and Nabar Nappes probably form part of the basement to the Váddás sedimentary rocks. No intrusions of the two above-mentioned types occur in the lowermost units of the KNC underlying the Nabar Nappe; this argues for a two-stage history of assembly of the KNC.

The combined thrusting of the Čorrovárri Nappe with the Nabar Nappe is possibly related to the early (Finnmarkian) Caledonian deformation and metamorphism in the time span 505–491 Ma registered in the KNC correlative rocks in Sweden (van Roermund 1982, 1985, Stephens & van Roermund 1982, Dallmeyer et al. 1991). The oldest age is based on Sm-Nd isotopic dating (Mørk et al. 1988) of eclogite boudins in rocks belonging to the Seve Nappe Complex in the county of Norrbotten (Andréasson et al. 1985). This tectonothermal event was considered as compressional associated with the development of a westerly dipping subduction zone. The youngest 491 Ma age, obtained from ^{40}Ar-^{39}Ar mineral dating of retrogressed eclogites, was thought to be related to exhumation of the subducted rocks (Dallmeyer & Gee 1986). These ages were confirmed by Essex et al. (1997), who reported U-Pb ages of 475–500 Ma with no evidence of a second (Scandian) tectonometamorphic event. Eclogite is not found in the Čorrovárri Nappe and its northern correlative, the Sørøy-Seiland Nappe (Zwaan & van Roermund 1990), but the upper amphibolite to granulite-facies early-M2 event described earlier is possibly related to it. Mørk & Stabel (1990) also correlated the high-grade metamorphism of mylonitic magmatic rocks (502 Ma) in the Sørøy-Seiland Nappe with the eclogite-facies event in the Seve Nappe.

The Finnmarkian collision has been suggested to be palaeogeographically related to the preceding rifting (Zwaan & van Roermund 1990). This history of opening and subsequent closure is reported for many Proterozoic suture zones in Africa where there were earlier intrusions of alkaline rocks and carbonatites (Burke et al. 2003). Since there are no eclogites in the Čorrovárri Nappe and its northern correlatives in west Finnmark, the Finnmarkian collision in the northernmost Caledonides was possibly more of a transpressional character (Roberts 1988).

An attempt to date the regional schistosity and mylonite fabric of rocks in the basal thrust zone of the KNC was not definitive (Roberts & Sundvoll 1990). This Rb-Sr whole-rock, thin-slab technique yielded an age of 380 Ma for the late brittle mylonites of the basal thrust, but gave an uncertain 'Finnmarkian' age of 479 Ma for the earlier high-T ductile mylonites. Rb-Sr whole-rock dating of the slaty cleavage in the Gaissa Nappe underlying the KNC reflects an overall, pervasive metamorphic imprint at around 500–480 Ma (Sundvoll & Roberts 2003). This possible, two-stage orogenic development is also indicated by Rb-Sr isochron ages of around 504 Ma by Pringle (1973) and 520 Ma by Taylor & Pickering (1981) on the parautochthonous Neoproterozoic rocks of the Varanger Peninsula.

Results of recent age determinations on rocks of the Seve Nappe Complex farther south are confusing and partly conflicting with this scenerio. Sm-Nd mineral isochrons of c.450 Ma from subduction related eclogite-facies rocks in the Seve Nappe of central Sweden provide evidence for further transpression throughout the Ordovician (Brueckner et al. 2004). From roughly the same area, Gromet et al. (1996) obtained 440–425 Ma (U-Pb) for the only regional metamorphism they could recognize which "challenge the idea of an unified tectonic history for the Seve nappes" op.cit., and indicate "that all of the Caledonide history in those parts of the Seve occurred as a result of the Siluro-Devonian Scandian orogeny" op.cit.. A similar metamorphic age of 420 Ma, from monazites, has been found for the correlative Sørøy-Seiland Nappe rocks in west Finnmark, north of Čorrovárri (Slagstad et al. in press).

We propose that the conflicting ages of both the Halti Igneous Complex and the transpression/subduction-related metamorphism could find its natural explanation in a transtensional regime for the Čorrovárri Nappe rocks and, thus, the Seve/Köli contact throughout the Ordovician and the Early Silurian. Rehnström (2003) summarised this coordinated transpression-transtensional history with the help of palaeomagnetic data by concluding that this coincides in time with a rapid anti-clockwise rotation of Baltica away from the Ægir Sea and into the Iapetus Ocean. In such a regime one can expect an alternating occurrence of transpression and transtension in restricted areas along the Baltoscandian continental margin (Sturt & Roberts 1991, Nilsen et al. 2003). This has a profound effect on the interpretation of the contact between the Seve and Köli Nappe Complexes which is thought to be an extension of the Kalak-Váddás contact farther to the south in Sweden. The Köli Nappes, with their fragmented ophiolites and island arcs, are generally considered to represent oceanic terranes more outboard of Baltica, but at least the lowest unit of the Köli Nappe Complex could have been laid down along the thinning edge of Baltica (Andréasson et al. 2003, Brueckner et al. 2004). This suggests that the KNC, including rocks of the Seiland Igneous Province, deformed or not deformed by the Finnmarkian orogenic phase, still formed part of the Baltoscandian margin continental area which was affected by subaerial weathering and served as a substrate during deposition of sediments of the Kvænangen and Oksfjord Groups.

The hiatus between the rocks of the Čiččenvárri Formation and the overlying rocks of the Guolasjávri Formation is non-tectonic and is of unknown duration. It marks an important change in the stratigraphic character of the succession. The Guolasjávri Formation is roughly dated by fossils to Late Ordovician-Silurian (Binns & Gayer 1980); this is the only available age determination for the rocks of the Váddás Nappe. Concretionary schist in related marbles in the Guolasjávri area and farther to the southwest are very similar in macroscopic appearance to the Ordovician nodular limestone of the lithostratigraphic succession in the Oslo Graben, and may thus strengthen this age determination (K.B.Zwaan, unpubl. data, 1998). The underlying rocks of the lower part of the Kvænangen Group can be much older since the sandy rocks underlying the hiatus would have consolidated, because they provided the quartzite pebbles for the overlying conglomerate. The change to the turbiditic Oksfjord Group is also reflected in successions of the Köli

Nappe Complex; these turbidites are dated to latest Llandovery to Early Wenlock (Andréasson et al. 2003).

The Váddás stratigraphic succession can be followed over the whole of Troms county and southward to Narvik, and confirms that it represents a relatively undisturbed stratigraphic succession. The final emplacement of the entire, composite KNC is possibly related to thrusting of the Váddás Nappe to its present position and, thus, a Scandian phenomenon (Roberts & Sundvoll 1990). If the correlation of the Halti Igneous Complex with the VM holds, the VM should be about 437 Ma. The conclusion in this paper that the intrusion of the VM and deformation of its contact aureole are closely related, fits well with a conclusion in recent literature that "the Scandian collisional orogeny was immediately preceeded by development of short-lived marginal basins of inferred back-arc origin" (Andréasson & Gee 2004, p. 76). This confirms the notion of short-lived, transtensional basins and associated magmatism in the Upper Allochthon during Late Ordovician-Early Silurian time along the length of the Scandinavian Caledonides (e.g. Sturt & Roberts 1991, Nilsen et al. 2003).

Conclusions

1) The rift-related intrusion of the gabbro suite with a related basic dyke swarm at around 580 Ma is the earliest recognised thermodynamic phase in the Neoproterozoic metasedimentary rocks of the Čorrovárri Nappe.
2) The high-grade, early metamorphism (M2) in the Čorrovárri Nappe resulted in it being welded together with the Nabar Nappe. This tectonometamorphic event possibly represents the not well understood Finnmarkian, transpressional collision phase at around 500 Ma. It is of minor importance in the Vaddas district and may have been restricted palaeogeographically to an area along the western edge of the Baltoscandian margin.
3) In latest Cambrian-earliest Ordovician time this phase terminated with exhumation and erosion, followed by deposition of the Oksfjord Group succession. This original stratigraphic contact between the Kalak and Váddás Nappe rocks is thought to be a northern extension of the contact between the Seve and Köli Nappe Complexes.
4) Throughout the Ordovician and the Early Silurian the Baltoscandian continental margin underwent transpression and transtension in restricted areas as a result of a rapid anti-clockwise rotation of Baltica away from the Ægir Sea and into the Iapetus Ocean.
5) In the Late Ordovician this resulted in renewed rifting involving the assembled Čorrovárri-Nabar Nappe rocks with ultimate deposition of the Kvænangen Group turbidites. From 445 to 435 Ma, the Halti Igneous Complex and the VM (Váddašgáissát Metagabbro) intruded, immediately prior to assembly of the Čorrovárri-Nabar Nappes with the underlying nappes of the Middle Allochthon, and initiation of the thrust contact with the overlying RNC (Reisa Nappe Complex) during the Scandian orogenic phase at around 430 Ma.
6) A late- to post-Scandian, W- to SW-directed collapse of the outer margin of the orogen then occurred, progressively affecting, the entire tectonostratigraphic succession now exposed in the Váddás area.
7) A phase of Permian block-faulting of the continental margin then followed, characterised by regional E-W to NE-SW-trending normal faults and related semi-ductile to brittle, gentle megafolds of the intervening crust, suggestive of oblique movements along the faults.

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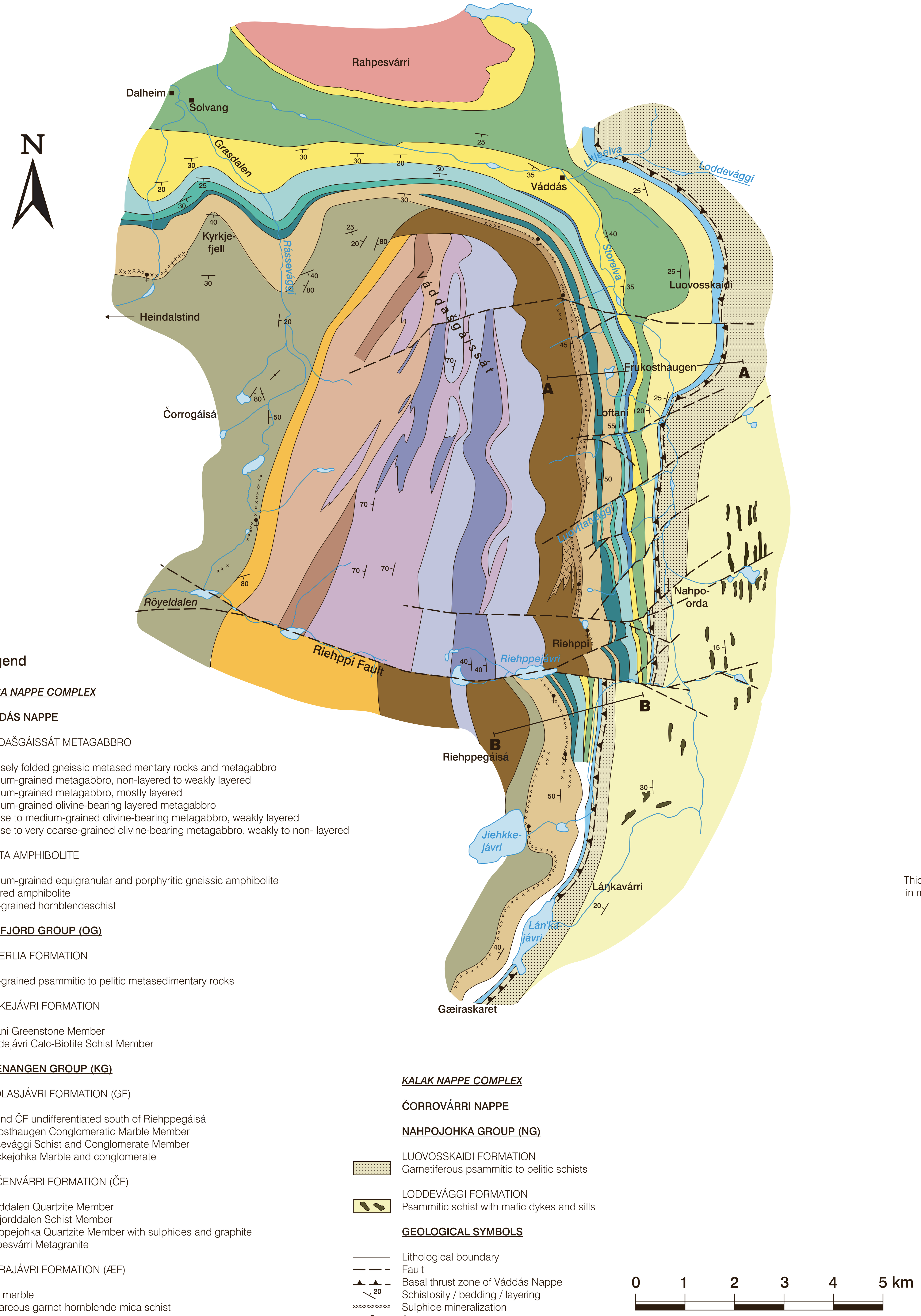

Legend

REISA NAPPE COMPLEX

VÁDDÁS NAPPE

VÁDDAŠGÁISSÁT METAGABBRO

- Intensely folded gneissic metasedimentary rocks and metagabbro
- Medium-grained metagabbro, non-layered to weakly layered
- Medium-grained metagabbro, mostly layered
- Medium-grained olivine-bearing layered metagabbro
- Coarse to medium-grained olivine-bearing metagabbro, weakly layered
- Coarse to very coarse-grained olivine-bearing metagabbro, weakly to non- layered

GRYTA AMPHIBOLITE

- Medium-grained equigranular and porphyritic gneissic amphibolite
- Layered amphibolite
- Fine-grained hornblendeschist

OKSFJORD GROUP (OG)

ANKERLIA FORMATION

- Fine-grained psammitic to pelitic metasedimentary rocks

ÁHKKEJÁVRI FORMATION

- Loftani Greenstone Member
- Goddejávri Calc-Biotite Schist Member

KVÆNANGEN GROUP (KG)

GUOLASJÁVRI FORMATION (GF)

- GF and ČF undifferentiated south of Riehppegáisá
- Frukosthaugen Conglomeratic Marble Member
- Rássevággi Schist and Conglomerate Member
- Jiehkkejohka Marble and conglomerate

ČIČČENVÁRRI FORMATION (ČF)

- Skarddalen Quartzite Member
- Oksfjorddalen Schist Member
- Riehppejohka Quartzite Member with sulphides and graphite
- Rahpesvárri Metagranite

GÆIRAJÁVRI FORMATION (ÆF)

- Grey marble
- Calcareous garnet-hornblende-mica schist (Garben schist)

KALAK NAPPE COMPLEX

ČORROVÁRRI NAPPE

NAHPOJOHKA GROUP (NG)

LUOVOSSKAIDI FORMATION

- Garnetiferous psammitic to pelitic schists

LODDEVÁGGI FORMATION

- Psammitic schist with mafic dykes and sills

GEOLOGICAL SYMBOLS

- Lithological boundary
- Fault
- Basal thrust zone of Váddás Nappe
- Schistosity / bedding / layering
- Sulphide mineralization
- Sulphide deposit