A rift-related mafic dyke swarm in the Corrovarre Nappe of the Caledonian Middle Allochthon, Troms, North Norway, and its tectonometamorphic evolution

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The Corrovarre Nappe is the highest tectonic unit of the Kalak Nappe Complex, in the Caledonian Middle Allochthon, in the Nordreisa area of Troms, North Norway. The nappe consists of meta-arkoses, metapelites and calc-silicate schists intruded by gabbroic sills and associated mafic dykes. The rocks are best preserved in the Corrojavrre megalens. Here, a genetic relationship is described between intrusion, deformation due to extensional tectonics and partial melting of the host rock in the metamorphic aureole zone of the mafic intrusions. The associated two-pyroxene granulite-facies 'contact' metamorphism (M1) was overprinted by Caledonian, regional, Barrovian to Saxonian-type metamorphism (M2), and initial thrusting occurred at this time. The metamorphic grade of M2 varies throughout the Corrovarre Nappe; from top to bottom, a middle amphibolite, an upper amphibolite, and a middle amphibolite facies zone. This internal inverse zonation is attributed to late-M2 regional thrusting. It is suggested that the M2 metamorphic episode may equate with the Early Ordovician metamorphic event recognised in the Seve Nappe Complex in Sweden further south. The M3 metamorphic phase was retrograde and represents either the waning stage of the M2 episode or involved thrusting of the Vaddas Nappe upon the Corrovarre Nappe, in Silurian time. A reconnaissance Sm-Nd and Rb-Sr age determination study has indicated that the mafic dykes intruded at c. 580 Ma. Their chemistry is somewhat transitional between ocean-floor and continental tholeiites. It is concluded that the dykes and associated magmatism are related to thinning and rifting of the Baltoscandian Shield prior to Early Caledonian deformation and nappe emplacement. This conclusion is also considered to be valid for the correlative Seiland Igneous Province.

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Introduction

The Nordreisa area of the county of Troms, northern Norway, constitutes a part of the northern extremity of the Caledonides in Scandinavia. During the 1970's the area was mapped by the Geological Survey of Norway (NGU) in order to cover the 1:250,000 map-sheet Nordreisa (Zwaan 1988). The mountain Corrovarre, a key area for the interpretation of this part of the Caledonides, was mapped in great detail (1:50,000, Gautier et al 1987). In the Nordreisa area the Caledonian tectonostratigraphy consists of the Middle (Kalak Nappe Complex, KNC) and Upper Allochthons (Reisa Nappe Complex, RNC) (Zwaan & Roberts 1978, Roberts & Gee 1985, Lindahl et al. in prep.). Four nappe units are distinguished in the KNC; from bottom to top, the Gargia, Nalganas, Nabar and Corrovarre Nappes (Zwaan 1988). The rock sequences in the KNC are dominated by monotonous banded meta-arkoses, locally with 100 m-thick, monomict, quartz conglomerates; polymict conglomerates occur lower in the sequence. The arkoses grade upwards into an interbanded sequence of thin meta-arkoses and garnet-mica schists. Within the arkoses of the Nabar Nappe, rare quartzites are found. In the Corrovarre Nappe (Fig. 1) (and its northern correlative, the Sørøy Nappe; see tectonostratigraphy), calcareous metapelites and thin marbles occur within the meta-arkose sequence. The present thickness of the sedimentary sequences is about 500m in the distinctive tectonic units (Zwaan & Gautier 1980, Zwaan et al. 1975), but the original

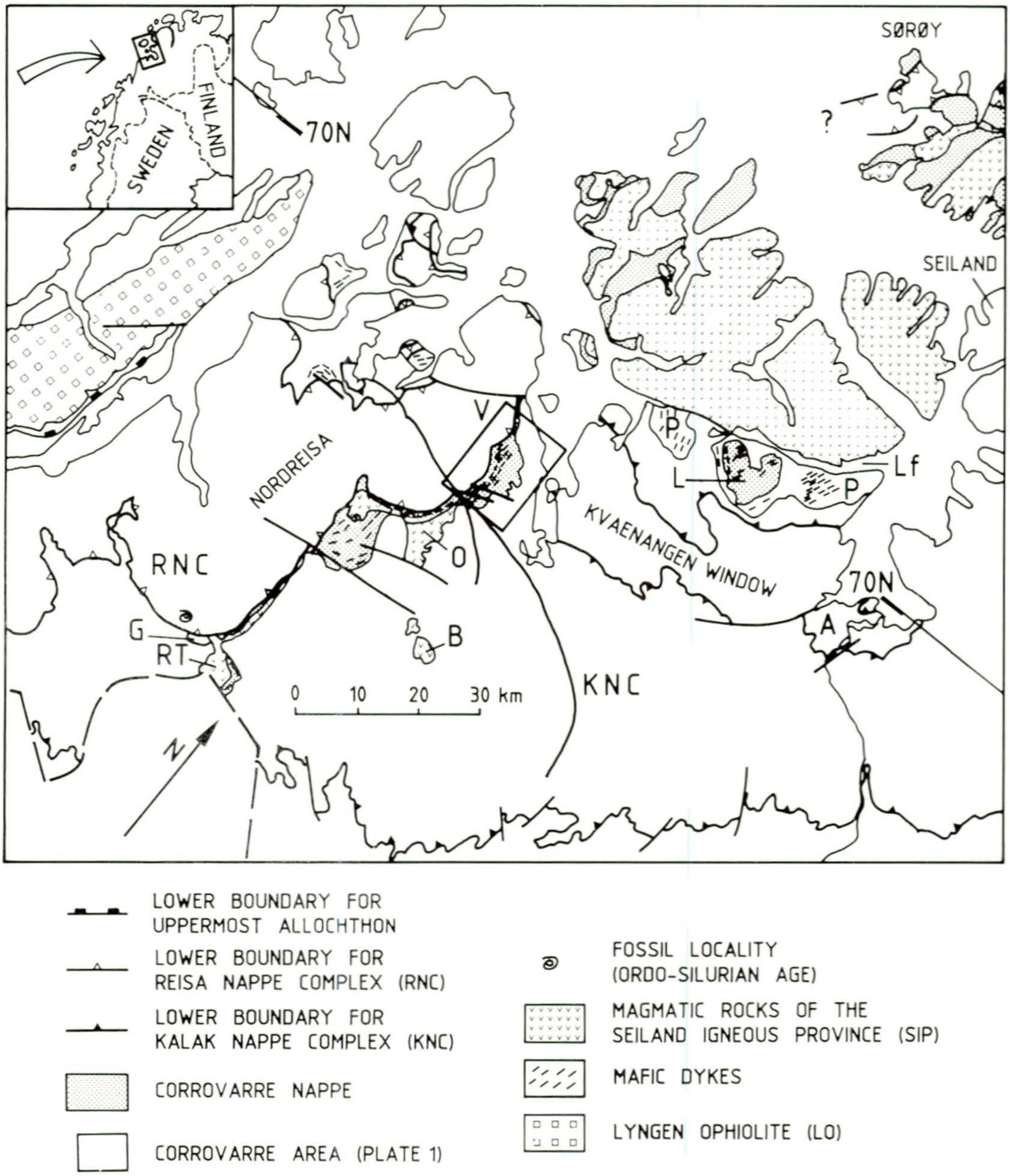

Fig. 1. Generalised geological map showing the setting of the Corrovarre Nappe with respect to the Middle and Upper Allochthons of the Caledonian Orogen in northern Norway. A=Alta window, B=Bæccegæhal'di, G=Guolasjav'ri, L=Langfjell Nappe, Lf=Langfjord, O=Oapis, P=Pølvatn Nappe, RT=Raisduodarhal'di Troctolite, V=Vaddas, ?=tentative extension of the Reisa Nappe Complex.

thickness is not known as most of the rocks have been tectonically reworked.

In the Nalganas and Nabar Nappes the sedimentary sequence, with a thin basal grit, overlies a basement «plinth» (Ramsay et al. 1985) of different types of Precambrian rocks. The gneissic rocks in the Corrovarre Nappe are considered to be metamorphic derivates of the

Late Precambrian sediments (see below). A basement plinth is therefore either missing or masked by thorough mylonitic overprinting. Sedimentary structures are abundant in the internal parts of the Gargia and Nalganas Nappes. In the higher nappes, sedimentary structures have been largely obliterated by a penetrative mylonitisation. In these units early structures are, however, still preserved only in the strain shadow areas of competent rock bodies such as discordant igneous rocks.

A reconnaissance investigation revealed that trough cross-bedding is the most characteristic primary structure in the metasediments. Within this bedding, soft-sediment deformation structures are commonly seen. The most likely sedimentary environment is that of braided rivers (A. Siedlecka, pers.comm. 1986). Neither fossils nor tillites have been found in the Middle Allochthon of North Norway. Daly et al. (1987) and Lindahl & Bjørlykke (1988) dated intrusives and Pb mineralisation occurring in this sequence as older than 800 and 900 Ma, respectively.

The metasedimentary sequences in the Middle Allochthon of the Scandinavian Caledonides are characterised by their wide areal extent, a monotonous arkosic composition, and for the higher nappes, local abundances of dolerite dykes. A flood-plain environment with braided rivers has been inferred, with deposition in ensialic basins. These basins were formed by crustal subsidence due to attenuation of the continent Baltica prior to, but associated with the opening of the Iapetus Ocean (Kumpulainen & Nystuen 1985). In contrast, the Late Precambrian to Tremadoc mature sedimentary rock sequences of the Lower Allochthon in northern Norway (Gaissa Nappe Complex) and the foreland Autochthon are generally devoid of mafic dykes. According to Gayer et al. (1987) and Stephens (1988) the successions of the Middle Allochthon were deposited in the westerly distal part of this passive miogeoclinal Baltoscandian margin. We propose, however, that the sediments forming the Kalak Nappe Complex were unrelated to the sedimentary basinal sequence of the Lower Allochthon, a proposal supported by the age determination studies of Daly et al. (1987) and Lindahl & Bjørlykke (1988).

Formerly, the rocks of the Corrovarre Nappe, together with rocks of the overlying Vaddas Nappe (the lowest tectonic unit of the RNC, see Table 1), were correlated with the Sørøy Nappe, the rocks of which were considered to be older than Upper Cambrian (Sturt et al. 1978). After the discovery of Ordovician-Silurian fossils (Binns & Gayer 1980) in the highest marble member of the Kvænangen Group in the Vaddas Nappe (Table 1), correlation thus became problematic. This marble and the formations above it could no longer be correlated with the three highest groups (starting with the Falkenes Group) of the Sørøy Nappe, even though they are remarkably similar (Table 1). Alternatively, a previously unrecognised tectonic contact at the level of the

Table 1.
REISA NAPPE COMPLEX (RNC)

Vaddas Nappe	*Vaddas Nappe*
Øksfjord Group	Metagreywacke
Metagreywacke	Olivine gabbro
Olivine gabbro	
Kvænangen Group	
Marbles, cgl., greenst.?------	Marbles, cgl., greenstone
and graphitic pel.	Sørøy Nappe
Garbenschist	Hellefjord Group
	Metagreywacke
	Aafjord Group
KALAK NAPPE COMPLEX (KNC)	Pel., graphitic,
	calcareous pel.
Corrovarre Nappe	
(CN)Upper tectonic unit	Falkenes Group
Nappujåkka Group	Marble, calcareous pel.
Luovusskaidde Fm.	Storelv Group
semip, amph.lenses	Interbanded qzite and pel:
Loddevagge Fm.	Klubben Group
Meta-arkose, mafic dykes	Meta-arkose, locally
Skartasvagge Fm.	calc.pel. and marble intruded
Calcareous hornfels, with	by SIP with anatec. contact
marble, mafic dykes and	aureoles
gabbroic bodies	
	? ----------------------
Lower tectonic unit	Eidvågeid Group
Blastomyl. rocks of the	granodioritic and amphibolitic
Nappujåkka Group with abundant maf. to ultramaf. bodies,	gneiss
less deformed in the	(Precambrian basement)
Goattegielas tec. lens	
	? ------------------------
Nabar/Pølvann Nappe	*Gildetun Nappe*
Garnet-mica schists	
Meta-arkose with mafic dykes	
in NNW (Pølvann Nappe	? ------------------------
Granodioritic and amphibolitic gneiss	*Navitdal Nappe*
(Precambrian basement)	

Nalganas Nappe	
Garnet-mica schists	
Meta-arkose	
Granodi. and amphib. gneiss,	
greenst., metased.	
(Precambrian basement)	
Gargia Nappe	
Meta-arkose	

Table 1. Tectonostratigraphic sequences of the RNC and KNC. Left-hand column, according to Lindahl et al. (in prep.) and this paper. Right-hand column, according to Ramsay et al. (1985).

Storelv Group (see Table 1) may interrupt the Sørøy sequence.

The present authors therefore prefer to correlate the Corrovarre Nappe, as defined in this publication, with the Sørøy Nappe. From Corrovarre to the south the Corrovarre Nappe is correlated with the Särv and Seve Nappe Complexes in Sweden. To the west the Corrovarre Nappe is overthrust, and close to Guolasjav'ri (Fig. 1), 50 km south of Corrovarre, truncated by the basal tectonic contact of the RNC. The RNC is generally correlated with the Köli Nappe Complex (Upper Allochthon) in Sweden.

According to Sturt et al. (1978) the KNC rocks were metamorphosed and thrust onto the Baltoscandian Shield principally in Late Cambrian/Early Ordovician times (the Finnmarkian orogenic phase, c 540-490 Ma). This concept was based largely on the time relationships between tectonism and magmatism of members of the Seiland Igneous Province (SIP) (for references, see Ramsay et al. 1985). The SIP was thus regarded as representing synorogenic (Finnmarkian) magmatism. On the contrary, the RNC contains Ordovician-Silurian fossils and has been affected only by the Silurian (Scandian) orogenic phase (Gee 1975).

In the Corrovarre Nappe a mafic dyke swarm and associated mafic to ultramafic intrusions are present (Figs. 1,2,3, Zwaan et al. 1975, Boe 1976, Gautier et al. 1987, Lehtovaara & Sipilä 1987). The intrusions are considered to be southern correlatives of the SIP which dominates the Sørøy Nappe. Detailed mapping by Zwaan in 1985 of the dyke swarm in Corrovarre casted doubts upon the synorogenic character of the SIP. The present study includes further detailed mapping by Van Roermund in 1987 and laboratory investigations. The aim of the study has been to investigate more closely the time relationships between tectonism, magmatism, metamorphism and migmatisation in the Corrovarre Nappe and to formulate a petrogenetic model for the highest nappes of the Middle Allochthon of the Caledonides in North Troms.

Regional setting of the intrusive rocks

Intrusive rocks form an important component of the highest tectonic unit of the KNC, the Corrovarre and Sørøy Nappes (Table 1, Figs. 1,2,3). In the underlying Nabar Nappe, only minor intrusions are present in its northeastern extremity, west of Kvænangen. However, the Pølvatn Nappe (Fig.1), north of the Alta-Kvænangen Window, is a possible correlative of the Nabar Nappe and this contains abundant mafic dykes (Gautier et al. 1987).

Typical for the magmatic province is the occurrence of mafic dyke swarms together with gabbroic to ultramafic sill-like bodies. The dykes intruded the sediments and, in the case of the Pølvatn Nappe, the underlying Precambrian basement (Gautier et al. 1987). The genetic relationship between the dykes and the gabbroic bodies is obvious in the SIP; however, in the Nordreisa area (this study) this relationship is commonly obscured by tectonic disturbance. Accepting a common age for the

Fig. 2. Aerial photograph, depicting the northern part of the Corrojavrre tectonic lens (lower centre), thinning towards the north-northwest. For orientation, compare with Plate 1.

Fig. 3. Mafic dyke swarm, seen from Corrovarre (2530 4735), looking northwest. Note reindeer herd on snowdrift. The prominent contact in the middle-ground marks the boundary between the Corrovarre Nappe and the overlying Vaddas Nappe. Photo, Per Ryghaug.

intrusive rocks, the magmatic province thus has a NE-SW trend today which seems to be confirmed by the occurrence of mafic dykes in the underlying Nalganas Nappe in the Porsanger area (Gayer et al. 1978, and for correlation Ramsay et al. 1985). In the Nordreisa area this magmatic province ends with the Oappis and Bæccegæhal'di gabbros (Zwaan et al. 1975) and the Raisduoddarhal'di troctolite in the Kåfjord area (Bøe 1976) (Fig. 1). The troctolite complex contains a mafic dyke swarm syngenetic with the troctolitic cumulates (Lehtovaare & Sipilä 1987, Sipilä in prep.). The Porsanger dykes, the SIP and the Nordreisa igneous rocks together form a magmatic province in the upper part of the KNC, with a minimum strike length of 300km today (Fig.1).

The magmatism in the Sørøy Nappe (SIP) shows a petrochemical evolution from tholeiitic basalt through high-K calc-alkaline magma to alkali olivine basalt and peridotite (Robins & Gardner 1975). The differentiation is strongest in the northeastern part of the province where nepheline syenites and carbonatites are also present (Heier 1961, Robins & Tysseland 1983). In the southwest (Kvænangen area, north of Langfjorden Fig. 1) the tholeiitic basalt chemistry of the subalkaline intrusions persisted into the late stages of the intrusive period (Robins & Gardner 1975).

Characteristic for the SIP is the mutual relationship between igneous activity and deformation accompanied by granulite-facies metamorphism which also affected the sedimentary host rocks. Gabbros, which are the main rock-type, commonly have a 'gneissic' appearance. The gneisses formed early in the SIP history (Heier 1961) and led Barth (1953) to propose «a metamorphic and metasomatic formation of the layered gabbros from an originally layered series of supracrustal rocks». Oosterom (1963) thought the gneissification happened «in a deep-seated zone of the Caledonian orogen». During the 1970's, the SIP was considered to be syntectonic and to represent a type of mantle diapir stemming from a zone lying immediately above a progressively steepening, eastward-dipping, subduction zone (Ramsay 1973, Robins & Gardner 1975, Sturt et al. 1982). Alternative interpretations of the genetic origin of this province have recently been proposed, based on the rift-related petrochemical characteristics of the petrochemistry of the intrusions (Bergström & Gee 1985, Andreasson 1987, Sipilä in prep.). Furthermore, the relationship between the above-mentioned metamorphic structures and the intrusions was considered to be restricted to the contact aureole of the SIP (Krill & Zwaan 1987, Sipilä in prep.). Although this interpretation has been challenged by Sturt & Ramsay (1988), it is important since it casts severe doubts on the synorogenic nature of the magmatic province.

The present authors consider that the tectonic-intrusive history of the KNC is comparable to that of the Särv- and Seve Nappe Complexes in Sweden (Greiling 1989, Kathol 1989). As a consequence we think that the Seve Nappe Complex should be considered part of the Middle Allochthon and not the Upper Allochthon. Thus, the magmatic province of the KNC would have formed part of the Baltoscandian rift magmatism that pre-dated the Caledonian orogeny. This constituted a 1000 km-long, NNE-SSW trending belt parallel to the present Caledonian orogenic trend, e.g. the Baltoscandian Dyke Swarm (BDS) of Andreasson (1987). For the BDS, Andreasson (1987) inferred a continental rift situated close to the continental-oceanic interface. An alternative interpretation, involving a correlation of the SIP and the Lyngen Ophiolite (LO, Zwaan 1988), which forms part of the Uppermost Allochthon (Fig. 1), is tentative and less likely. In the case of the LO, Minsaas & Sturt (1985) regard this as part of the Iapetus ocean floor. The ophiolite was deformed, uplifted and eroded before being overlain unconformably by an Ordovician-Silurian volcanosedimentary sequence.

The tectonostratigraphy of the Corrovarre area

Ramsay et al. (1985) subdivided the Vaddas Nappe (RNC), as defined by Lindahl (1974), and correlated the lower part (starting with the lowest (?) marble formation, Table 1) with the Sørøy Nappe. Further, they divided the Nabar Nappe into two tectonic units, the Gildetun Nappe overlying the Navitdal Nappe (Table 1). This subdivision was not documented with any detailed maps or descriptions, and has not been confirmed by our study.

Zwaan in Gautier et al. (1987), Zwaan (1988) and Lindahl et al. (in prep.) have revised the tectonostratigraphy of the Middle and Upper Allochthons of the Nordreisa area and defined boundaries for what they call the Corrovarre Nappe. In the present paper this nappe is subdivided into upper and lower tectonic units. These are not distinguished as two separate nappes because the rock-types in each unit have much in common. Metamorphic criteria (see below), however, could argue for further subdivision of this nappe.

The upper tectonic unit is assumed to be incomplete as it is truncated by the overlying Vaddas Nappe. The rock sequence forming this unit constitutes the Nappujåkka Group, and is subdivided from structural top to bottom into the Luovusskaide Formation, the Loddevaggi Formation and the Skartasvaggi Formation. The last two formations are correlated with the Klubben Group of the Sørøy Nappe (Table. 1).

The lower tectonic unit, which is also composed of rocks of the Nappujåkka Group, is considered to represent a 750m-thick shear zone forming the basal thrust zone of the nappe. The rocks are mainly in a blastomylonitic condition, enveloping numerous tectonic lenses in which the character of the original rock-type can still be recognised. The largest lens, the Goattegielas lens, has been mapped out as a separate structural unit (Plate 1).

An important constituent of the Corrovarre Nappe is a mafic dyke swarm (Plate 1, Fig. 3). In addition, the lower tectonic unit contains larger sill-like bodies of gabbroic to ultramafic rock, the relationship of which to the host rocks is not clear due to intense post-intrusion shearing. Mafic dykes cross-cut foliated parts of the gabbros. The gabbroic to ultramafic bodies are interpreted to be genetically related to the dykes. From the lower part of the Loddevaggi Formation downwards the host rocks are migmatised in the neighbourhood of abundant mafic dykes and some gabbroic bodies are also migmatised.

Rock descriptions

Lindahl et al. (in prep.), have described the Luovusskaide and Loddevaggi Formations and the mafic dykes in some detail. Some new data on these rocks are presented below along with descriptions of the Skartasvaggi Formation and the rocks of the lower tectonic unit.

The upper tectonic unit

Nappujåkka Group

The Luovosskaidde formation

The upper boundary to the rocks of the overlying Vaddas Nappe is sharp. The Vaddas Nappe rocks start with zoisitic, staurolitic and hornblendic garbenschists with quartz as the main felsic mineral, and in part they are carbonate-bearing. This is in clear contrast to the fine-grained quartz-feldspar-garnet schists of the Luovosskaidde Formation. The rocks of both formations are highly strained since they define (in places together with the upper part of the underlying Loddevaggi Formation) the broad mylonitic contact zone between the KNC and the RNC.

The metasediments are semipelites with a gradual transition from the underlying arkosic psammites of the Loddevaggi Formation. Thin mafic, apparently concordant, intrusive sheets are present as layer-parallel garnet-hornblende schists with igneous textures in the central parts of thicker units.

Metamorphic textures: The microstructures display a complicated tectonometamorphic history. An anastomosing, spaced, two-mica foliation(S3, see below) envelops lens-shaped domains which carry the earlier, coarser-grained, continuous, muscovite-kyanite foliation (S2, see below). The S3 fabric is a retrograde structure. The plagioclase forming this foliation is oligoclase to albite, K-feldspar is untwinned, and staurolite (but no kyanite) was still stable in early S3 textures. In the higher Vaddas Nappe part of the shear zone, porphyroblasts of weakly pleochroic amphibole, staurolite, zoisite-clinozoisite and chlorite form the anastomosing foliation but are also broken, wrapped around by S3 and polygonised.

The Loddevaggi Formation

This formation has a maximum structural thickness of 750m and consists of thick-banded, fine- to medium-grained meta-arkoses. The regular banding is considered to be transposed bedding since sedimentary structures such as cross-bedding (Fig. 4) are still preserved. The strongest concentration of mafic dykes is in the lower (eastern) part of the formation and they are always discordant with respect to bedding. The meta-arkoses are migmatitic in the vicinity of the dyke swarm.

Metamorphic textures: Cross-bedded, non-migmatitic, psammitic rocks have a fine- and even-grained granular (granoblastic) texture of randomly orientated crystals of up to 60% quartz, 30% feldspar (mainly oligoclase but also K-feldspar) and 10% greenish-brown to yellow pleochroic biotite. The biotite is concentrated in the thin laminae which together with opaques depict the cross-bedding. The felsic minerals in these laminae are finer grained as compared with the psammitic beds. The migmatised psammites have the same mineral assemblage but contain more twinned K-feldspar; they have the same granophyric texture but are coarser and more evenly grained. The later regio-

Fig. 4. Cross-bedding in meta-arkose of the Loddevaggi Formation within 2dm of a cross-cutting mafic dyke. Coin 2.5cm diameter. Locality: 2605 3925.

Fig. 5. Hornfels of the Skartasvagge Formation with preserved horizontal, parallel-laminated and possibly rippled layering. Cross-cutting mafic dyke with a c. 6mm-thick chilled margin. The black marker-top is 4cm in length. Locality: 2490 2815.

Fig. 6. Random two-pyroxene-plagioclase microstructure in layered hornfels of the Skartasvaggi Formation. In the central parts of the photograph, dark grey: porphyroblasts of pyroxenes (0.5mm). White: quartz and small labradorite grains, medium grey: yellow biotite. Dark grey bands at top and bottom: mainly fine grained pyroxene. Plane-polarised light. Locality: 2550 4750.

nal metamorphism (M2, see below) transformed the rocks mainly into garnet-muscovite-kyanite-biotite schists. Kyanite, muscovite and garnet commonly occur as large porphyroclasts. Kyanite also occurs as small needles along the grain boundaries of feldspar and as inclusions within garnet porphyroclasts.

The Skartasvaggi Formation

This formation is up to 500m thick and shows a thin but gradual transition into the Loddevaggi Formation. Towards the contact meta-arkoses of the Loddevaggi formation become thinner and more regularly banded, from calcareous migmatitic psammite into fine-grained greyish-green hornfels. The Skartasvaggi rocks have a high content of Ca-rich minerals and are possibly metamorphic marls with a higher melting point than that of the anatectic melt and, as a consequence, they have preserved their original, sedimentary, mineral banding (Fig. 5). In about the middle of the formation there are one or more marble layers, up to 4m thick. The mafic dyke swarm reaches its highest density in this formation, and the host rocks are net-veined and partly broken up by a granitic to granodioritic anatectic neosome.

Metamorphic textures: The hornfelses have a strain-free random microstructure. Different mineral layers show different grain sizes but the grain size is homogeneous within individual layers (Fig. 6). The fine-grained bands are rich in mafic minerals; mainly ortho- and/or clinopyroxene with less feldspar, calcite and spinel. The paler bands are more coarse-grained, consisting mainly of quartz, plagioclase and K-feldspar. Wollastonite and sillimanite are rare minerals in these hornfelses, and are inferred to have formed during this phase. Locally the rock is rich in scapolite porphyroblasts. The migmatised rocks have a "viscous"

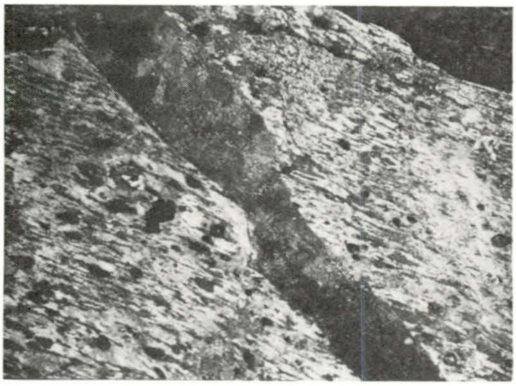

Fig. 7. 'Cluster'foliation in metagabbro transected by a 1-2 dm thick mafic dyke. Locality: 2745 4665.

foliation (McLellan 1984) defined by the compositional layering. Commonly, however, M1 minerals (see below) overgrew randomly this foliation. The mobilised marble recrystallised into a coarse-grained, sugary, calcite rock with wollastonite and clinozoisite as minor constituent minerals.

The lower tectonic unit

The upper boundary of the lower tectonic unit is knife-sharp and tectonic (Plate 1). In contrast, the boundary with the Goattegielas tectonic lens is more gradational on account of the less severe deformation. The Goattegielas lens has a maximum thickness of 500m. In the metasediments, a regular banding in arkosic psammites and garnet-mica schists of 1 dm thickness can be recognised locally. The rocks are typical of the Nappujåkka Group, but due to the strong deformation, they mainly have a blastomylonitic appearance. The mylonites enclose amphibolites, clinopyroxene-garnet-plagioclase granulites and slightly migmatitic K-feldspar-kyanite gneisses. The lens contains many gabbroic to ultramafic bodies up to 300m thick which, in places, are foliated. Foliated gabbros are truncated by mafic dykes (Fig. 7), described below. The lower boundary of the tectonic unit lies within a mylonitic zone. The lithological contact could nevertheless be mapped out because clasts of glassy pinkish garnet are lacking in the blastomylonites of the underlying Nabar Nappe, which are also rich in staurolite and zoisite.

Metamorphic textures: The blastomylonites in this unit consist of large clasts of a glassy pinkish garnet, muscovite, biotite, colourless to blue kyanite, and white feldspar up to several centimetres across enveloped by a fine-grained mylonitic foliation (see fig.4 in Zwaan & Roberts 1978). Both twinned K-feldspar and plagioclase are present. In the mylonitic foliation the same minerals are recrystallised but in this case K-feldspar is mostly untwinned.

Igneous rocks

Mafic dykes

Both tectonic units of the Corrovarre Nappe contain mafic dykes but only in the Loddevaggi and Skartasvaggi Formations are the dykes well preserved. There they form a swarm of NNW-SSE trending dykes locally truncating, or in places truncated by, granitic pegmatites. The dykes are discordant and cut the foliation of the metasediments at high angles. They are only locally dilational. Twenty dykes occur over a distance of 500m in the most densely intruded area. The dykes are up to 10m thick with an average of 5m, indicating about 20% extension in this particular area. They range in length from 50 to 1000m but were originally longer.

Petrography: The dyke rocks are fine- to medium-grained (1-3mm), mainly equigranular and some display a porphyritic microstructure with large pyroxene and feldspar crystals. Chilled margins can be found, mostly outside the area of migmatites (contact aureole), but they are not common (Fig. 5).

Two microstructural end-member types have been recognised with all stages in between. The general type is an intergranular "dolerite" structure (McKenzie et al. 1982); anhedral pyroxene crystals occupying spaces between lath-shaped euhedral plagioclase. The rocks are mostly medium-grained (0.8mm) but some idiomorphic crystals of pyroxene and plagioclase up to 3mm in length are also present. The other type, an equigranular, more coarse-grained (3mm) 'gabbroic' structure, is found only in the thickest dykes, but this has not been investigated systematically. The feldspar crystals are less markedly elongated. A 1 m-thick dyke displays various types of basaltic inequigranular microstructures, from seriate to porphyritic and glomeroporphyric (McKenzie et al. 1982) with euhedral laths of plagioclase and euhedral equant pyroxene crystals floating in a matrix composed of the same minerals and opaques. The crystals are 3mm in size, with slightly corroded surfaces; the grain size of the matrix is 0.01 mm. The mafic dykes contain about 60 % plagioclase and 30 % pyroxene. The plagioclase has around 60% An (optical determination) and is either unzoned or only slightly normally zoned. It displays exsolution in the form of a brownish dust of unidentified minerals. The most common pyroxene is clinopyroxene; orthopyroxene is rare. Both pyroxenes display several exsolution types; a dust of unidentified opaque minerals, fine-grained parallel-oriented brown minerals, possibly rutile, and pyroxene lamellae oriented parallel to (001) of the host.

Metamorphic textures: Commonly the dykes are more or less altered. Two phases of regional metamorphism were recognised (see below) but an earlier (M1 see below), static (corona) alteration typical for the mafic to ultramafic bodies in the lower tectonic unit (see below) is also observed locally, although it is only weakly developed. The felsic pegmatites are a minor constituent; they have the same mineralogy as the neosome of the surrounding migmatites. In the contact zone with the host rocks the crystals in the pegmatite have grown perpendicular to the contact, depicting crystallisation from a liquid.

Mafic to ultramafic bodies

Besides dykes, the lower tectonic unit contains mafic to ultramafic lens-shaped bodies up to 1km in length. Due to the intense deformation the original shapes and contact relations with the host rocks could not be determined. The petrological composition of the bodies ranges from gabbroic with 50% plagioclase and 50% pyroxene (mainly cpx) to olivine-bearing varieties containing spinel. Troctolites, commonly wehrlites, clinopyroxene-rich lherzolites and dunites are also present.

Petrography: Gabbroic varieties have a mainly subophitic microstructure with clearly elongated feldspar crystals, and are equigranular and coarse-grained (1-1.5cm). In gabbroic rocks the (clino)pyroxene is anhedral and colourless (in thin-section); in the olivine-rich rocks it is euhedral, twinned and has a pale yellowish colour with brownish sectors. Plagioclase is mainly labradorite, as in the dykes, but in the olivine-rich rocks it grades up to bytownite. As in the dykes, pyroxene and plagioclase display different types of exsolution features.

Metamorphic textures: The gabbroic to ultramafic rocks and the older mafic dykes with gabbroic microstructure in the two tectonic units have been metamorphosed at high grade with the formation of granulite-facies minerals (M1, see below). Index minerals, formed as a reaction between the mafic minerals and plagioclase, are clino- and orthopyroxene, plagioclase (50/60% An) and spinel. The new clino/orthopyroxenes occur in the internal corona rims around the crystals of the original mafic minerals (opx, cpx and ol) as fibres, fine-grained, strain-free polygonal mosaics or as symplectitic intergrowths. The rocks were subsequently deformed (D1, see below) with further granulite-facies recrystallisation. The igneous minerals and their coronas are partly strained, and the plagioclase is strongly twinned and annealed into a core-and-mantle microstructure. By further deformation the coronas became elongated into irregular tongue-shaped clusters of highly strained porphyroclasts and annealed recrystallised mafic minerals forming a rough foliation, embedded in a fine-grained groundmass comprising a strain-free polygonal mosaic of untwinned feldspars (Fig. 8) ("cluster foliation", Oosterom 1963; "layer-parallel flaser texture", Gardner & Robins 1974). Due to dynamic recrystallisation, porphyroclasts of plagioclase and pyroxene contain optically strain-free inclusions, composed of one single grain or clusters of grains of the same mineral. It is therefore inferred that the metamorphism was synchronous with deformation ("incipient plastic deformation", Oosterom 1963; "annealing recrystallisation", Robins 1982; "high-temperature solid-state flow", Vernon et al. 1989). The same features are seen in thin (0.1 mm) shear zones in the olivine-rich rocks. The olivine and the (brownish) clinopyroxene porphyroclasts, both with strained coronas of clino/orthopyroxene, are embedded in a ground mass of recrystallised

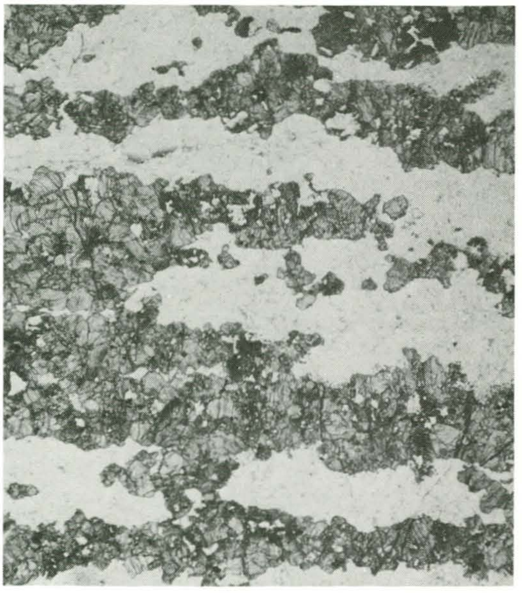

Fig. 8. Optical micrograph of 'Cluster'-foliated metagabbro. Dark grey bands consist of equigranular grains of ortho- and clinopyroxene. Whitebands with equigranular foam-textured labradoritic plagioclase. Sample taken from foliated metagabbro fragment in migmatite of the Skartasvagge Formation. Plane-polarised light, 'clusters' 1-2mm thick. Locality: 2565 4655.

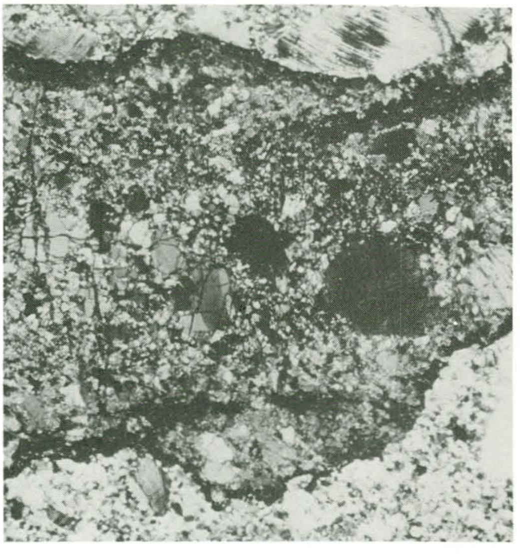

Fig. 9. 'Cluster'-foliated metagabbro with incipient D2 deformation features. The dark grey central cluster consists of partly recrystallised grains of clinopyroxene, yellow pleochroic amphibole and minor olivine. The cluster is rimmed with yellow/green/blue pleochroic amphibole, yellow/brown pleochroic biotite and idioblastic garnets (black outer rim). Strained and recrystallised, originally foam-textured oligoclase/andesine occurs outside the cluster. Crossed nicols. Cluster 4mm thick. Locality: 2720 4625.

	'CONTACT' METAMORPHISM Superimposed on supposed burial metamorphism		REGIONAL METAMORPHISM			
			Prograde			Retrograde. Also in basal rocks of Vaddas Nappe
	M1		M2			M3
	early	late		early	late	
Textures	cluster foliation, corona, migmatites	alteration, corona	inclusion trails in prograde zoned garnets	blastomylonite		spaced foliation/cleavage polygonisation
Olivine	---					
Clinopyroxene	---			---		
Orthopyroxene	---			---		
Plagioclase	--- labradorite	---		--- andesine	- - oligoclase	--- albite ---
Spinel	---	---				
Garnet				---	---	---
Biotite		- - yellow - -		--- red/brown	---	yellow/brown ---
Amphibole		- - yellow - -		--- blue/green	---	yellow/green ---
Kyanite				---	---	
Sillimanite	--- ?	? ---				
K-feldspar	---	---		---		
Staurolite					---	---
Muscovite				---	---	---
Chlorite						---
Epidote group						---- mainly zoisite ----

Table 2. Paragenetic diagram of the Corrovarre Nappe.

foam-textured clinopyroxene. Spinel forms intergrowths with the recrystallised pyroxene but it is not present in the early coronas. The cpx-porphyroclasts contain exsolution lamellae but these have not been seen in the truncating corona minerals. Mafic dykes are found in the lower tectonic unit truncating this cluster foliation (Fig. 7). Typically the dykes have rarely, and then only weakly, been affected by this alteration. However, fragments of dykes floating in the 'flow-foliated' neosome of the anatectic rocks contain a strong cluster foliation.

Retrogradation (late M1, see below) commenced in the waning stages of the intrusion history after formation of the cluster foliation. Yellow/brown pleochroic hornblende ± magnetite ± spinel forms an outer rim around the previously described pyroxene coronas, or on the contact between the groundmass pyroxene and plagioclase. During later regional metamorphism (M2, see below), blue/green pleochroic hornblende was formed. With incipient deformation this mineral, red biotite and garnet form a rim of idioblastic minerals along the contacts between the earlier strained (also yellow hornblende) minerals (Fig. 9). After more severe deformation the rocks were transformed into garnet-hornblende schists.

Metamorphism

The metamorphic evolution of the Corrovarre Nappe is plurifacial and polymetamorphic. This complicated metamorphic history is difficult to recognise in the quartzofeldspathic rocks but can be detected in suitable rock compositions such as mafic rocks, ultramafites, metapelites/gneisses and the calcareous rocks of the Skartasvarri Formation. A synoptic diagram of the metamorphic evolution is given in Table 2. Characteristic for the Corrovarre area is the strain-shielding effect of the Corrojavrre tectonic lens which forms a window for the earliest metamorphic imprint on the host rocks by the emplacement of the mafic to ultramafic igneous rocks. This first period is labelled M1 and is only tentatively called 'contact' metamorphism because it had a wide and penetrative influence; the later periods are labelled M2/M3 and have a regional metamorphic character.

'Contact' metamorphism (M1)

A migmatitic aureole has been mapped out (Plate 1), restricted to the neighbourhood of the mafic dykes and gabbroic and ultramafic intrusions. In the upper tectonic unit, the lower part of the Loddevaggi Formation and the whole of the Skartasvarri Formation were affected. The youngest dykes transect the migmatite structures as well as earlier dykes. Neosome, formed by partial melting of the psammitic rocks, intruded both the sedimentary rocks and the mafic intrusive rocks. The psammitic rocks are strongly migmatised and the sedimentary rocks of the Skartasvaggi Formation are totally converted into hornfelses. This metamorphism is recognised both in the field and under the microscope by its granoblastic microstructure in the psammitic rocks and hornfelsic microstructure in the Ca-rich pelitic rocks. The foliation is generally non-schistose in outcrop i.e. on the microscopic scale the minerals forming the foliation are randomly orientated; however, deviations from this general rule do occur.

In the lower tectonic unit a relationship between migmatitic structures and mafic to ultramafic intrusions could not be detected due to the severe, post-intrusion, regional deformation. However, late dykes cut foliated, olivine-plagioclase-bearing, meta-igneous rocks (Fig. 7). In such cases, the foliation (S1) consists of dynamically recrystallised orthopyroxene, clinopyroxene, plagioclase and spinel, while porphyroclasts of primary olivine, plagioclase and clinopyroxene are still preserved, indicating that we have crossed the olivine + plagioclase → two-pyroxene + spinel reaction curve (Fig. 10).

Elsewhere, the migmatites contain two pyroxenes, spinel, plagioclase, biotite, brown amphibole, potash feldspar and quartz (Table 2). One sample possibly contains sillimanite extensively replaced by secondary kyanite. Pressure-sensitive minerals are absent. If, however, we accept a syngenetic relationship of all intrusive rocks in the Corrovarre Nappe, a maximum intrusion depth of around 35km, corresponding to 9kb (Fig. 10), is indicated by the coexistence of olivine and plagioclase (Ito & Kennedy 1971). The primary plagioclase and olivine are dynamically recrystallised into a two-pyroxene + spinel assemblage. Microprobe analyses of recrystallised adjacent ortho- and clinopyroxenes are given in Table 3. We applied the geothermometers of Wells (1977) and Wood & Banno (1973) to the composition of the recrystallised pyroxenes, and obtained a temperature of 850± 50°C. This indicates that the cooling trajectory crosses the olivine + plagioclase → two-pyroxene + spinel boundary at around 850± 50°C. By assuming an isobaric cooling trajectory for the intrusive rocks, the maximum intrusion depth is reduced to about 20km corresponding to 6 kb (Fig. 10). Both Rietmeyer & Champness (1982) and Synnøve Elvevold (pers.comm. 1990) have criticised the use of the applied geothermometers of Wells (1977) and Wood & Banno (1973). They found that Fe-rich pyroxenes from granulites give less accurate and lower temperature estimates. The most important feature, however, is that the temperature regime defined by the cooling trajectory

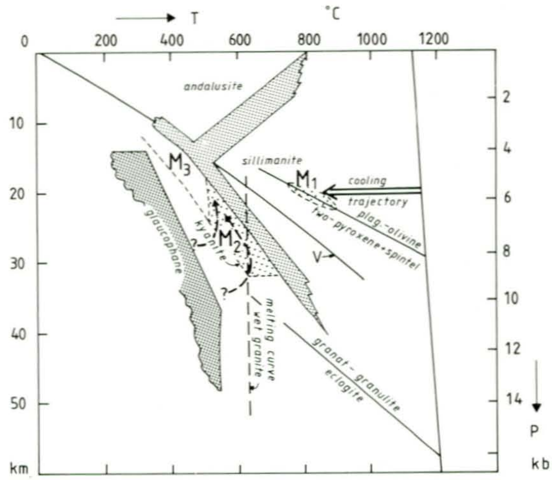

Fig. 10. P-T diagram with cooling trajectory of the olivine gabbroic rock and M1 crystallisation range of opx and cpx out of olivine between 814 C and 878 C based on two-pyroxene thermometry. — inferred PT paths of M2 regional metamorphism in the Corrovarre Nappe.

Table 3

Clinopyroxene				Orthopyroxene			
SiO_2	52.07	Si	1.946	Si_2	52.56	Si	1.952
Al_2O_3	2.76	Al	0.122	Al_2O_3	1.95	Al	0.085
TiO_2	0.37	Ti	0.010	TiO_2	0.07	Ti	0.002
Cr_2O_3	0.19	Cr	0.006	Cr_2O_3	0.09	Cr	0.003
Fe_2O_3	+0.24	Fe^{3+}	+0.007	Fe_2O_3	0.17	Fe^{3+}	0.170
FeO	7.44	Fe^{2+}	0.233	FeO	20.79	Fe^{2+}	0.646
MnO	0.18	Mn	0.006	MnO	0.54	Mn	0.017
MgO	13.88	Mg	0.773	MgO	22.83	Mg	1.264
CaO	21.94	Ca	0.878	CaO	0.51	Ca	0.020
Na_2O	0.46	Na	0.033	Na_2O	0.05	Na	0.004
Sum	99.06	Sum	4.000	Sum	99.56	Sum	4.000

Temperatures
Wood & Banno 814.4°C Wells 878.4°C

Table 3. Microprobe analyses of clinopyroxene and orthopyroxene forming a corona around olivine grain. The analyses, including the Wood & Banno and Wells calculations, were carried out by Herman van Roermund, 1988, at the Microprobe Lab. of the Institute of Earth Sciences, Free University, Amsterdam.

(Fig. 10) clearly exceeds the maximum value of a relaxed geotherm (V in Fig. 10) even during post-collisional uplift (England & Thompson 1984, Thompson & England 1984). This means that the heat source which produced the abnormal heat supply must have been related to the upwelling of the asthenosphere associated with the intrusion of the magmatic complex. This indicates that the cooling trajectory cannot have been established during subduction and/or collision processes and their associated uplift histories. A high geothermal gradient is inconsistent with processes of crystal thickening. Moreover, the development of LP/HT metamorphism during extensional tectonics has been widely discussed (Vielzeuf 1984, Wickam & Oxburg 1986, Brodie & Rutter 1987). We therefore conclude that the M1,LP/HT metamorphism could have been related to extensional tectonics. In our synoptic diagram (Table 2) we have called this metamorphic event M1, which contrasts clearly with the second metamorphic event (M2) interpreted to be related to the Caledonian Orogeny.

Regional metamorphism (M2 and M3)

M2 is easily recognised in the field by the occurrence of muscovite, garnet and kyanite. Additional minerals are listed in Table 2. The growth of M2 minerals is commonly related to a marked grain-size reduction associated with the formation of the regional foliation. In all cases, M2 mineral assemblages overprint and replace those of M1. The M2 mineral assemblage typically reflects intermediate amphibolite-facies conditions in a Barrovian facies sequence.

The maximum M2 regional metamorphic grade is, however, not constant throughout the Corrovarre Nappe. In the Goattegielas lens of the lower tectonic unit (Plate 1), granulite-facies rocks are found; they contain the M2 mineral assemblage garnet-clinopyroxene-plagioclase (Table 2). The surrounding gneisses are slightly migmatitic and contain the kyanite-K-feldspar mineral assemblage. In the mylonites overlying the lens, kyanite and twinned K-feldspar clasts are found which could be remnants of such gneisses. This suggests that rocks of the upper and middle parts of the lower tectonic unit underwent upper amphibolite to granulite-facies metamorphism in a Barrovian to Saxonian facies sequence. The Corrovarre Nappe is thus metamorphically zoned.

The M2 peak-metamorphic mineral assemblages cannot be correlated with M1 since the two metamorphic events reflect quite different physical conditions. This is illustrated in the PT diagram of Fig. 10. The M2 resembles the characteristic features of the regional metamorphism in the Seve Nappe Complex (Zwart 1974, Van Roermund & Bakker 1984, Van Roermund 1989). Future age-determination studies on M2 minerals may help to strengthen the correlation of the Corrovarre Nappe with the Seve Nappe Complex.

Possibly in a late stage of this metamorphic period, the peak M2 minerals in the deformed rocks became replaced by intermediate amphibolite-facies mineral assemblages typified by muscovite-kyanite and amphibole-plagioclase-garnet minerals which define the mylonitic foliation. It is inferred that the early M2 zonation is due to thrusting in this period.

The *M3* is mainly restricted to the enveloping shear zones and is best investigated in the rocks of the Luovusskaidi Formation and lower part of the lower tectonic unit. The M3 was a retrograde process, in which early M3 amphibolite-facies mineral assemblages gradually became transformed and replaced by minerals of the greenschist facies. This is a mineral assemblage similar to that found in the directly overlying rocks of the basal thrust zone of the Vaddas Nappe. A further difference from that of M2 is that the M3 porphyroblastic minerals staurolite, zoisite and amphibole occur as 'garben', forming garbenschists, which is characteristic for the correlative basal thrust zone of the Köli Nappe in Sweden (Andreasson & Gorbatschev 1980). It thus seems likely that the M3 is related to the juxtaposition of the Vaddas Nappe upon the Corrovarre Nappe during the Scandian orogeny in Silurian times (see Lindahl et al. in prep). Gayer et al. (1985) have argued for their M3 too represent the final stage of the M2. Future age determination studies will tell us in which period the Corrovarre M3 mineral assemblages were formed. The M2 mineral assemblages and fabrics, which are an integral part of the Corrovarre Nappe, are truncated by the (see below) Vaddas basal thrust zone in the Quolasjavri area (see Fig. 1) 50 km to the south. The M2 therefore represents the earliest Caledonian regional metamorphic event.

Deformation

Using the above-described metamorphic history as a base, three generations of structures have been identified (see Table 2). All structures cut by dykes are grouped together as D1 structures. The structures in the contact aureole of the dyke swarm are of highly ductile and anatectic character. The two later generations of structures (D2/3) are of regional character. The D3 is inferred to be responsible for the formation of the Corrojavrre tectonic lens.

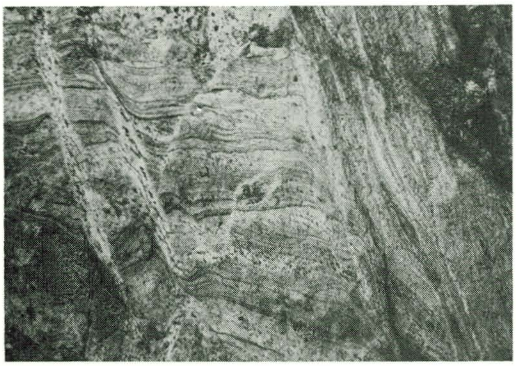

Fig. 11. Shear zones in anatectic meta-arkose of the Loddevaggi Formation. A 'viscous' migmatitic foliation has developed along the shearzones. The width of photograph = 90cm. Locality: 2450 4745.

Fig. 12. Relatively symmetrical folding (D1) in anatectic meta-arkose of the Loddevagge Formation cut by vertical neosome veins (which are parallel to cross-cutting dykes). The width of photograph = 60cm. Location:2490 4815.

D1 structures (F1, S1)

As the rocks are traced into the centre of the upper tectonic unit (Table 1, Plate 1), the incidence of the later deformation (D2/D3) diminishes rapidly. There, sedimentary structures and primary features related to the intrusions are preserved in the 'strain shadows' of the numerous dykes (Fig. 4). The metasediments display a granoblastic texture with varying grain size in the lighter and darker depositional mineral banding. The sedimentary structures locally display a 'weak' deformation which pre-dates the dyke intrusion. It is uncertain if this is synsedimentary, due to burial deformation or an example of extensional tectonics.

Fig. 13. Anatectic cross-bedded meta-arkose, with neosome intruding along a shear zone. Note the local random overgrowth of anatectic minerals. Loddevaggi Formation. The width of the photograph = 60cm. Locality: 2450 4750.

Fig. 14. 'Viscous' disharmonic D1 folding in anatectic meta-arkose of the Loddevagge Formation. The marker is 14cm in length. Locality: 2495 4830.

The rocks of the Loddevaggi Formation were progressively migmatised towards the centre of the dyke swarm. Parallel with the trend of migmatisation, the host rocks are deformed (D1) by mesoscopic monoclinal folds

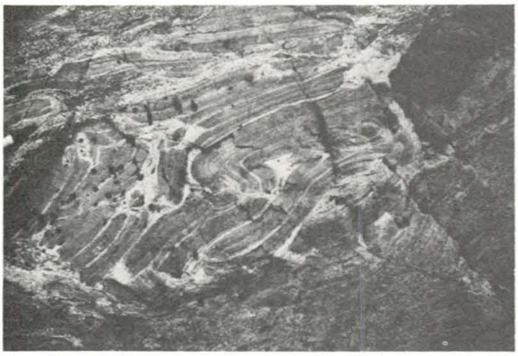

Fig. 15. 'Viscous' foliated neosome flowing around and intruding hornfelsed sedimentary rock of the Skartasvaggi Formation. A 15cm-thick truncated mafic dyke is present in the upper right side of the photograph. Locality: 2490 4820.

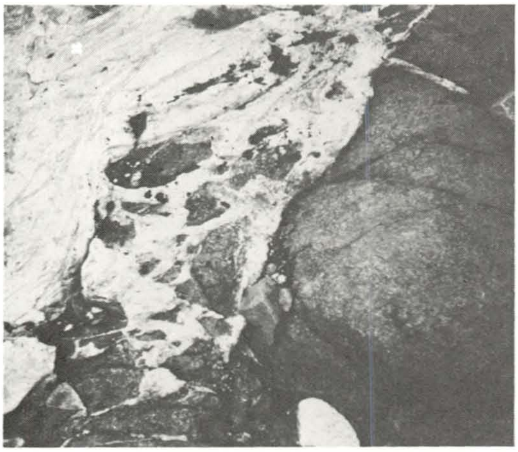

Fig. 16. Rafts of mafic dyke in the central part of the photo, floating in foliated 'viscous' neosome, are fragments torn off the dyke to the right. The dyke is back-veined by neosome. Loddevagge Formation. The width of photograph = 1m. Locality: 2495 4830.

(Fig. 11) grading into high-angle faults locally concentrated in narrow shear zones. Symmetrical folds (Fig. 12) with a NW-SE axial trend also occur. The psammite beds became mobilised, generating neosomes which intruded along the faults. In the paleosome, represented by the semipelitic bedding which is slightly richer in dark minerals, granoblastic recrystallisation mimicked the sedimentary structures (Fig. 13).

As there was little difference in composition between the beds, lower down the entire rock sequence became migmatitic and a new foliation formed together with an intense disharmonic folding (Fig. 14). The folds (F1) are irregular in wavelength, amplitude and orientation, suggesting a lowering of the viscosity of the rocks (viscous folding, McLellan 1984). The folded compositional layering consists of biotite seams and quartz-feldspar aggregates.

When crossing the boundary to the underlying Skartasvaggi Formation a different reaction to the metamorphism is seen. The metapelitic calc-silicate-rich layers have a fine-grained granoblastic hornfelsic texture. They are only locally partially melted, possibly because they have a higher melting temperature. The layering is locally broken up, folded and fragmented by the penetration of felsic neosome (Fig. 15; rheomorphic brecciation, Robins 1982).

The same features are seen in the mafic dykes. In one case a dyke was disrupted and the fragments drifted aside (Fig. 16) in a melt-dominated migmatite which back-veined the dyke. Close by, another dyke intruded the migmatite with rafts of disrupted and partly contaminated early mafic dyke and hornfels with compositional layering. The neosome flowed around the xenoliths forming a new 'viscous' (S1) foliation (Fig. 17). In many cases the shape-preferred orientation of the rafts help to define the new foliation.

The highly ductile behaviour of the marbles is quite different from that of the marbles of the Kvænangen Group in the overlying Vaddas Nappe (Table 1). In the same way as with the neosome in the migmatites the marble locally became mobile. It intruded the adjacent rocks (both sediment and mafic dyke) and detached fragments became part of the viscous foliation (Fig. 18).

D2 and D3 structures (F2, S2 and F3, S3)

The structures overprinting the minerals and structures related to the 'contact' metamorphism are separated into two generations labelled D2 and D3. In the field, the *D2* structures are most evident when such structures are deformed by later folds (Fig. 19). Microstructures in the D2-deformed rocks display a complicated tectonometamorphic history but are labelled D2 because they have a common M2 mineral paragenesis. The main D2 structure is that of a continuous foliation, S2, defined

Fig. 17. Foliated 'viscous' migmatite with elongate rafts of an early mafic dyke (thin, dark, boudinaged layer to the left of the marker, which is 14 cm long) and anatectically fragmented hornfelsed layer (lower end of marker) truncated by a younger mafic dyke. Locality: 2490 4820.

by M2 mineral assemblages. Garnets with snowball-type inclusion patterns are commonly optically zoned, which may reflect a chemical zoning. This is illustrated by their deep red-coloured core which is surrounded by a more pink-coloured rim, most likely indicating their prograde metamorphic origin. The rocks are coarse-grained with randomly orientated minerals depicting a granulitic microstructure. The S2 is an early-D2 foliation because this is converted into a blastomylonite foliation in the upper shear zone of the lower tectonic unit between the Goattegielas lens and the overlying rocks of the Skartasvarri Formation of the upper tectonic unit. The fine-grained mylonitic foliation envelops clasts in which the early-S2 foliation is preserved. This late S2 foliation is recrystallised in the same, or slightly lower, metamorphic grade indicated by the assemblage kyanite-muscovite and garnet-hornblende-plagioclase. This mylonite zone, with its characteristic coarse-grained clasts and pinkish glassy garnets, is of regional importance and can possibly be correlated with the 'Eidvågeid gneiss' some 90km to the north-east on NE Seiland which there forms the basal part of the Sørøy Nappe (Akselsen 1982).

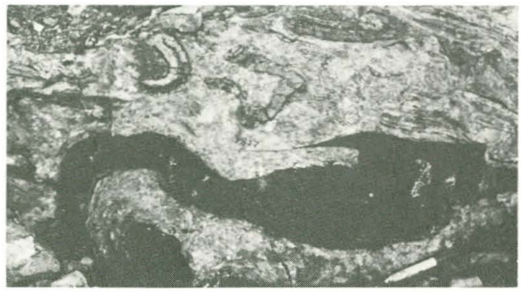

Fig. 18. Anatectic marble with rafts of metasediment and (black) mafic dyke. The marker is 14cm in length. Locality: 2520 4735.

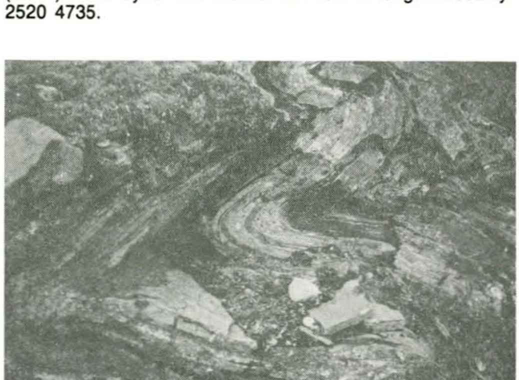

Fig. 19. D2 blastomylonitic foliation (S2) deformed by D3 folds. The width of photograph = 50cm. Locality: 2530 4765.

Fig. 20. Deformed intrusive contact between mafic dyke and meta-arkose of the Loddevaggi Formation. To the right of the dyke, the psammite is only weakly folded and sedimentary structures are preserved close to the contact. To the left, the metasediment is transposed into a blastomylonitic foliation parallel to the deformed dyke contact. The width of photograph = 360cm. Locality: 2660 4070.

Fig. 21. Northern extension of the main dyke seen in Fig. 17. An undisturbed foliated (S1) 'viscous' migmatite is present below the dyke. On the upper side the migmatite is converted into a foliated garnet-kyanite-muscovite-bearing blastomylonite with the foliation (S2) bending around the dyke remnant. The width of photograph = 90cm. Locality: 2490 4820.

The *D3* is characterised by grain-size reduction of the M2 minerals in anastomosing spaced foliations. This is the typical microstructure in the rocks forming the mylonitic foliation in the shear zones enveloping the Corrojavvre lens. In outcrop this structure finds its expression in the D3 pinch-and-swell structures of up to 10m magnitude. It is therefore concluded that the Corrovarre Nappe acquired its lens shape during this period. The lens is asymmetric and within its northwestern part the upper shear zone cuts discordantly through the Corrovarre Nappe, truncating the two highest formations. The dykes and the banding in the metasediments are here deflected to the NNE into parallelism with the mylonitic foliation. The upper tectonic unit, away from the basal thrust zone of the Vaddas Nappe is little disturbed and cut only by a system of E-W and NW-SE high-angle faults separating blocks with slightly different dyke orientation (see Plate 1 and Fig. 2). These faults are D3 structures and thus related to the formation of the lens, because here the D2 mylonitic foliation is deformed by D3 folds (Fig. 19).

The occurrence of dykes has played an important role in the character of the deformations and the styles of folds. Such features have been described by, e.g. Gayer et al. (1978), Rice (1986) and Krill (1986) from other parts of Norway. In the Corrovarre area the degree of deformation changes within some tens of cm from undeformed, granoblastic rocks with sedimentary structures into strongly schistose rocks (Fig. 20). That this also happened in the late-D2 phase is demonstrated by the rocks of the Skartasvagge Formation close to the D2 shear boundary with the underlying lower tectonic unit. On the upper side of one particular dyke the migmatised rock underwent a grain-size reduction, forming a new foliation which bends around the dyke (Fig. 21).

In the lower tectonic unit, starting with the rocks of the Goattegielas lens and the underlying rocks down to the basal shear zone above the Nabar Nappe, the anastomosing S3 spaced foliation is the dominant structure in fine- to coarse-grained garnet-mica schists and fine-grained mylonites. The metamorphic textures display the same D2-D3 deformation sequence.

Geochemistry

The dominance of clinopyroxene in both the mafic dykes and the olivine-bearing gabbroic rocks points towards a tholeiitic composition of the original magma. This is consistent with the geochemistry of the dykes (Zwaan & Roberts 1981, Roberts 1990). A reconnaissance geochemical investigation of 4 samples of gabbroic rocks from the lower tectonic unit reveals a comparable picture (Fig. 22). The compositions are less uniform than those of the dykes but 3 of the 4 analyses fall within the 'ocean floor basalt' field on the Ti-Zr-Y diagram. This suggests that the gabbros and dykes are probably related. Since dykes are found truncating foliated gabbros it is probable that the latter were intruded slightly earlier

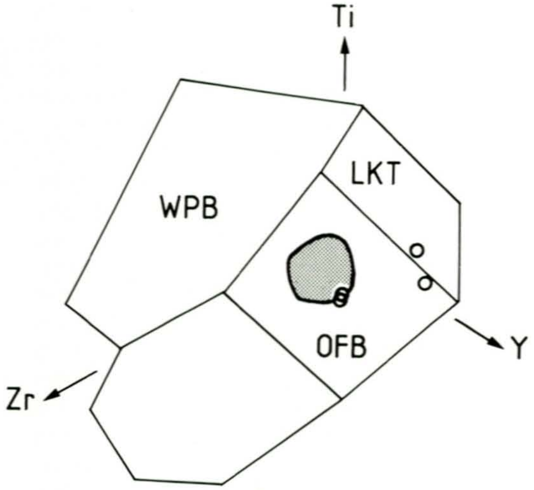

Fig. 22. Simplified Ti-Zr-Yi diagram showing the plots of 4 analysed gabbro samples (circles) from the lower tectonic unit. The field with grey ornament embraces samples of mafic dykes from the upper tectonic unit (Zwaan & Roberts 1981, Roberts 1990). The gabbro analyses were carried out in 1987 at NGU using a Philips PW1404 XRF spectrometer. The complete analytical data from the gabbro samples can be obtained from the first author upon request.

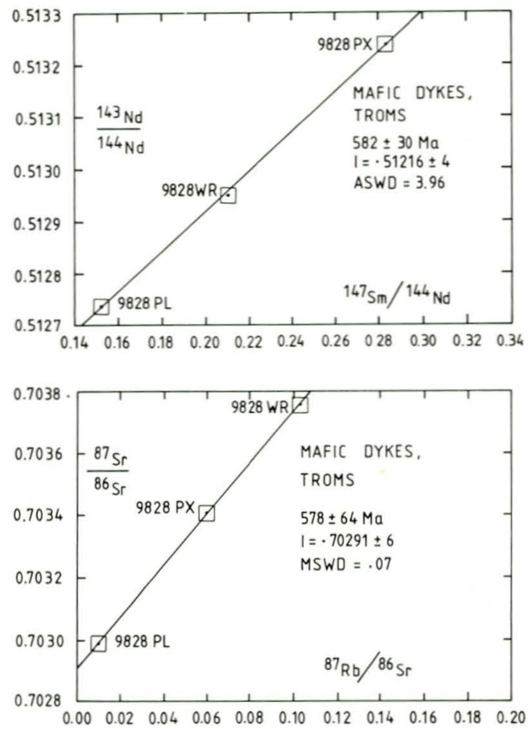

Fig. 23. Sm-Nd and Rb-Sr isochron diagrams for clinopyroxene (CPX), plagioclase (PL) and whole rock (WR). Sample 9828 (2485 4745) of mafic dyke. Data in Table 4.

and deeper in the crust. Subsequently, the rocks were brought up to higher levels during which they cooled, altered, obtained their viscous foliation and were intruded by the dykes. This history is in agreement with the ridge scenery described by Hall (1987). The geochemistry of the mafic dykes is treated in more detail in another paper in this same volume (Roberts 1990).

Rb-Sr and Sm-Nd Age determinations

A reconnaissance Rb-Sr and Sm-Nd age determination study of the mafic dykes was carried out on samples 9828 (2485 4745) and 9967 (2455 4745). Mineral separates of clinopyroxene and labradoritic plagioclase were prepared at NGU by Harald Hatling. The analyses were carried out by Bjørn Sundvoll at the Mineralogisk-geologisk Museum, Tøyen, Oslo. Sample 9828 yielded both Rb-Sr and Sm-Nd isochrons, despite minor exsolution features in cpx. The results are presented in Fig. 23 and Table 4. For this sample, the Sm-Nd isochron age is 582±30 Ma (MSWD = 3.96) and the Rb-Sr age 578±64 Ma (MSWD = 0.7). Sample 9967 gave errorchrons for both types of analysis, possibly because it is situated close to the upper shear zone enveloping the lens. In this case the data show the Sm-Nd age as 538±72 Ma (MSWD =13.8) and the Rb-Sr age as 458±70 Ma (MSWD= 6.9). These errorchron results are not considered to have any

Table 4

Sample/ fraction	Rb ppm	Sr ppm	Rb/Sr	SE	^{87}Sr/^{86}Sr	SE	^{87}Rb/^{86}Sr	SE
9828 WR2	3.06	85.86	.036	0	.10337	103	.70376	30
9828 PX	.31	15.43	.021	0	.05960	060	.70341	50
9828 PL	1.25	333.34	.033	0	.00976	010	.70299	30
9967 WR	4.27	70.88	.060	1	.17439	174	.70423	30
9967 PX	1.55	18.69	.083	1	.24023	240	.70455	30
9967 PL	2.17	342.35	.006	0	.01836	018	.70313	30

Sample/ fraction	Rb ppm	Sr ppm	Rb/Sr	SE	^{87}Sr/^{86}Sr	SE	^{87}Rb/^{86}Sr	SE
9828 WR	23.93	11.38	.346	1	.21044	53	.512351	4
9828 PX	1.80	3.88	.465	1	.28310	71	.513239	40
9828 PL	.59	2.40	.249	1	.15173	38	.512738	4
9967 WR	4.31	12.45	.346	1	.21077	53	.512942	4
9967 PX	3.58	9.38	.382	1	.23259	58	.512996	4
9967 PL	.68	2.94	.234	1	.14242	36	.512686	4

Table 4. Rb-Sr and Sm-Nd analytical data for samples 9828 and 9967.

geological significance. The ^{87}Rb decay constant used is $1.42 \times 10^{-11}a^{-1}$.

Discussion and conclusions

The synorogenic nature of the SIP has recently been challenged by Krill & Zwaan (1987), Andreasson (1987) and Gee (1988). Sturt & Roberts (1989) referred to it as "syntectonic rift- or transform-related magmatism". As a result of this and on account of recent U-Pb zircon dating of nepheline syenite pegmatites from Seiland (531 and 523 Ma; Pedersen et al. 1989), the original definition of the Finnmarkian orogenic phase is no longer applicable (Krill & Zwaan 1987, Roberts 1988). The period prior to c.523 has been reinterpretated by Krill (1990) as a long-lasting taphogenic period effectively characterised by some form of extensional tectonics, including rift magmatism.

Subduction, suggested by dates of c.505 Ma (Mørk et al. 1988) from eclogite boudins (van Roermund 1982, 1985, Stephens & van Roermund 1984), is now regarded as a first event in the history of the Caledonian orogenesis. Several authors include subsequent rapid uplift and thrusting, dated to c. 490 Ma (Dallmeyer & Gee 1986) and c. 460 Ma (Dalmeyer & Gee 1988) from retrograde, amphibolite-facies selvages around these eclogite boudins in the Corrovarre Nappe correlatives, and ophiolite obduction to this event. They consider it to be a major Caledonian orogenic phase restricted largely to the period c. 520-460 Ma. They transfer the name Finnmarkian to this phase. However, Krill & Zwaan (1987) consider this event as an integral part of the Caledonian evolution and not as a major separate orogenic (Finnmarkian) period in this part of northern Scandinavia.

Critical for the interpretation of the geology of the Corrovarre area is the observation of the mutual coexistence of rocks which were either affected by, or escaped, one or more phases of deformation and metamorphism (Krill & Zwaan 1987). It is possible to investigate the earliest, tectonothermal event (M1) and follow, step by step, the influence of later ones representing the Caledonian orogenic history. For the first event a mutual relationship was found between the intrusion of the mafic dykes and gabbro bodies, and the earliest non-compressive deformation, HT-LP metamorphism and associated migmatisation of the sedimentary host rocks. This has been confirmed by studies of metamorphic textures, mineral assemblages and metamorphic conditions during intrusion using geothermometric methods. This event is therefore considered to be earlier than, and unrelated to, the Caledonian orogeny. Sedimentary facies interpretations and radiometric age determination studies, respectively, placed the intrusion in the time period after the deposition and consolidation of the host rocks but before the onset of the Caledonian orogeny. Regional mapping makes it probable that the intrusions belong to the SIP. In this part of the Middle Allochthon, evidence of the formation for an actual ocean floor has not been found and we therefore prefer the idea of Andreasson (1987) of a continental rift situated close to the Baltoscandian continent/Iapetus ocean-floor interface. However, based on the geochemistry of the Corrovarre mafic dykes and the Sm-Nd isochron age reported here, Roberts (1990) has argued that the mafic dykes probably intruded in the very final stages of continental rifting just prior to seaflcor spreading.

The second and third tectonothermal events are of regional character and are considered to represent two phases in the evolution of the Caledonian orogeny. The first one (M2/D2) occurred under intermediate to high-pressure/temperature conditions. These conditions are not equally distributed throughout the Corrovarre Nappe, a feature which is characteristic for the earliest Caledonian regional metamorphic event, around 500 Ma, recognised in the Seve Nappe Complex and there related to subduction. The second phase (M3/D3) occurred under retrograde conditions and can be related to (1) thrusting of the Vaddas Nappe on to the Corrovarre Nappe and is thus associated with the juxtaposition of the Upper Allochthon onto the Middle Allochthon in Silurian time, or (2) it represents the waning stages of the 'Seve' (see below) event.

In summary, Late Precambrian-Early Cambrian continental rift phenomena and Late Cambrian-Early Ordovician short-lived collision-related metamorphism are restricted to the uppermost part of the Middle Allochthon of the Caledonian Orogen in North Troms. In the southern correlative of this uppermost part, the Seve Nappe Complex, the collision takes the form of subduction and initial thrusting. Even if they are unrelated in time, a palaeogeographic relationship may exist. Further to the west the Iapetus Ocean existed into the Silurian. Thus, it may be concluded that the 'Seve' collision/ subduction was located in approximately the same position as the earlier rifting and magmatism.

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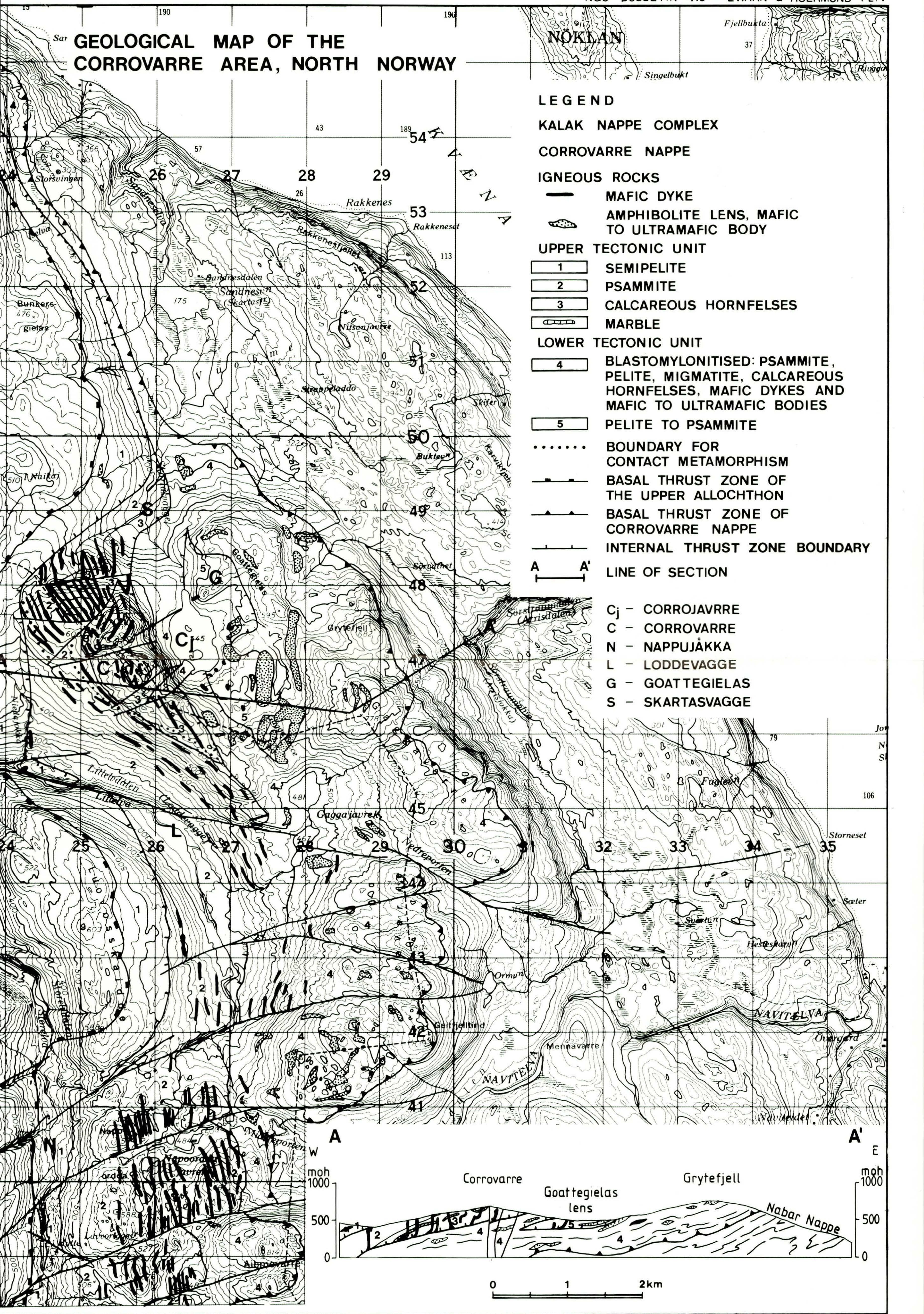
GEOLOGICAL MAP OF THE CORROVARRE AREA, NORTH NORWAY
LEGEND
KALAK NAPPE COMPLEX
CORROVARRE NAPPE
IGNEOUS ROCKS
MAFIC DYKE
AMPHIBOLITE LENS, MAFIC TO ULTRAMAFIC BODY
UPPER TECTONIC UNIT
1 SEMIPELITE
2 PSAMMITE
3 CALCAREOUS HORNFELSES
MARBLE
LOWER TECTONIC UNIT
4 BLASTOMYLONITISED: PSAMMITE, PELITE, MIGMATITE, CALCAREOUS HORNFELSES, MAFIC DYKES AND MAFIC TO ULTRAMAFIC BODIES
5 PELITE TO PSAMMITE
BOUNDARY FOR CONTACT METAMORPHISM
BASAL THRUST ZONE OF THE UPPER ALLOCHTHON
BASAL THRUST ZONE OF CORROVARRE NAPPE
INTERNAL THRUST ZONE BOUNDARY
A A' LINE OF SECTION
Cj – CORROJAVRRE
C – CORROVARRE
N – NAPPUJÅKKA
L – LODDEVAGGE
G – GOATTEGIELAS
S – SKARTASVAGGE
NÖKLAN
Fjellbukta
Singelbukt
Rakkenes
Rakkeneset
Rakkenesfjellet
Sandnesdalen
Sandnesfjellet
Nilsaanjavrre
Bunkersgielas
Naikai
Storsvingen
Grytefjell
Gaggajavrek
Littelvdalen
Lilleelva
Loddevaggi
Vedreporten
Geitfjelltind
Mennavarre
NAVITELVA
Navitdalen
Fugleberg
Storneset
Sæter
Hesteskarvatn
Øvergård
Ormvatn
Nappoporten
Aibmovarre
Buktevatn
Sørstraumdalen
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Corrovarre
Goattegielas lens
Grytefjell
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