The rift-related mafic dyke complex of the Rohkunborri Nappe, Indre Troms, northern Norwegian Caledonides

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Well-preserved dyke complexes are found within the Seve Nappe Complex, Upper Allochthon, in the easternmost part of Indre Troms, Norway. They form a separate thrust sheet, the Rohkunborri Nappe, and are best exposed in two low-strain units in the Rohkunborri and Njunis areas. In these areas the dolerite swarm intrudes a succession of carbonate rocks and subordinate sandstones, siltstones and quartzites. The sedimentary rocks, the Njunis Group, are supposed to represent the outermost part of the clastic wedge deposited during Neoproterozoic–earliest Palaeozoic time on the thinned outermost part of the Baltoscandian margin. A complex structural evolution can be recognized within the dyke complexes involving early block rotation during intrusion, rotation of both dykes and bedding due to simple shear deformation during thrusting and subsequent imbrication of the dyke complex. The Indre Troms dykes are part of the Neoproterozoic–Early Palaeozoic rifted Baltoscandian margin and represent the transition zone between the continent Baltica and the Iapetus ocean. The Rohkunborri Nappe can be correlated with the Vaivvancohkka Nappe and the Sarektjåkkå Nappe of the Seve Nappe Complex in the northernmost Swedish Caledonides.

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Introduction

Mafic dyke swarms are known from several parts of the Scandinavian Caledonides. They occur in the autochthon and lower thrust sheets in the northernmost parts of the mountain belt; further south, they occur only in the allochthons. According to a terminology introduced by Kulling (1972) and Gee & Zachrisson (1979), the allochthons can be divided into four major tectonostratigraphic units: Lower, Middle, Upper and Uppermost. The Lower Allochthon is dominated by Vendian and Lower Palaeozoic successions, the Middle Allochthon by thick Vendian and Upper Proterozoic strata, together with sheets of Precambrian crystalline rocks. The successions of the Lower Allochthon are readily correlated with those of the Baltoscandian Platform Autochthon; those in the Middle Allochthon are supposed to have been derived from the Baltoscandian miogeocline.

The uppermost tectonic units of the Middle Allochthon (Särv Nappe) were thrust from the outer part of the Baltoscandian miogeocline; they are extensively intruded by mafic dyke swarms (Strömberg 1969) related to Late Proterozoic rifting (Gee 1975; Solyom et al. 1979; Claesson & Roddick 1983), which extended more than 1000 km along the Baltoscandian margin (Andréasson 1987).

The lower part of the overlying Upper Allochthon, composed of the Seve Nappe Complex, is an imbricate stack of lithotectonic units (Andréasson 1986) characterized by tholeiitic metabasites (locally as dyke swarms) and psammitic schists. Its complexes are also inferred to be indigenous, and derived from the outermost part of the latest Proterozoic to Early Cambrian passive margin of baltica (Gee 1975; Andréasson 1987).

The tectonic units of the Köli Nappe Complex that overlie the Seve units locally are composed of a variety of terranes derived from outboard of Baltica (Stephens & Gee 1989). At least two episodes of mafic igneous activity related to the development of ophiolites and arc spreading are recorded within the Köli Nappe Complex. One is of Early Ordovician age and represented by the Karmøy and Leka ophiolite complexes (Furnes et al. 1988; Pedersen et al. 1988; Pedersen & Hertogen 1990); the other is Late Ordovician to earliest Silurian in age and represented by the Solund/Stavfjorden ophiolite (Furnes et al. 1980; Dunning and Pedersen 1988). Mafic complexes intruded during rifting of volcanic arcs and formation of marginal basins in the northern Scandinavian Caledonides, e.g. the Sulitjelma Igneous Complex (Pedersen et al. 1991) and the Råna Massif (Tucker et al. 1990), have a similar age to the Solund/Stavfjorden ophiolite.

As part of a more comprehensive study of the relationships between inboard and outboard terranes in northern parts of the Scandinavian Caledonides, this study deals with mafic dyke swarms occurring in the easternmost parts of Indre Troms, and focuses on their mode of occurrence and tectonostratigraphic position. Previous work, e.g. Gee et al. (1985a, b), has inferred a late Proterozoic age for the dykes and has correlated these units with those occurring in the Seve Nappe Complex in northern Sweden. The evidence presented here supports this hypothesis.

The Baltoscandian margin

In the central part of the Scandinavian Caledonides (Fig. 1) evidence from the Lower and Middle Allochthons provides constraints on the evolution of the Baltoscandian margin. Stratigraphic correlations (Kumpulainen & Nystuen 1985) of Late Proterozoic to Lower Cambrian sedimentary rocks within these thrust sheets have established three informal units: a thick lower mainly fluviatile unit, a middle glacial unit (Varangian) and an upper fluviatile and shallow marine unit of Late Vendian to Early Cambrian age. In northern areas, the upper unit dominates the autochthon and the middle unit is also locally preserved; further south all three units are generally allochthonous and the autochthonous strata are mainly Mid-Cambrian to Ordovician. The Vendian and Late Proterozoic successions can be readily correlated with sequences within the Middle Allochthon at least as far north as the Akkajaure area (Kumpulainen & Nystuen 1985).

Stratigraphical and sedimentological studies (Kumpulainen 1980; Kumpulainen & Nystuen 1985) indicate that the pre-Vendian successions were deposited in rift-related basins along the Baltoscandian margin. The extensive Late Proterozoic tholeiitic dyke swarms of the Särv Nappe suggest several tens of kilometres of passive margin extension. These dyke complexes have been recognized in Sweden as far north as central Norrbotten (Fig. 1). The more complexly deformed and highly metamorphosed Seve Nappe Complex, overlying the Middle Allochthon in Sweden, contains a similar, but somewhat more complex protolith, including both volcano-sedimentary Baltoscandian miogeoclinical successions (Andréasson 1987) and elements of the Proterozoic cratonic margin.

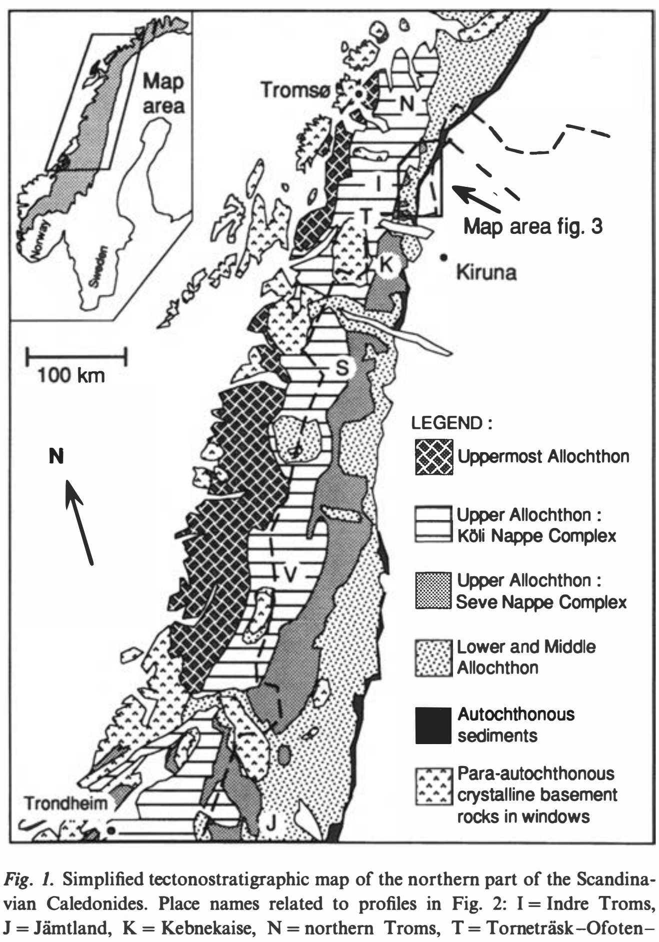

Fig. 1. Simplified tectonostratigraphic map of the northern part of the Scandinavian Caledonides. Place names related to profiles in Fig. 2: I = Indre Troms, J = Jämtland, K = Kebnekaise, N = northern Troms, T = Torneträsk–Ofoten–southern Troms, S = Sarek–Padjelanta (Norrbotten) and V = Västerbotten.

The lower part of the Seve Nappe Complex in Norrbotten, the Vaimok Lens (Fig. 2), contains a dolerite-intruded metasedimentary sequence, with similarities to the underlying Särv Nappe, but metamorphosed to eclogite grade. These units are overthrust by the Sarektjåkkå Nappe (Svenningsen 1987), which is dominated by Vendian mafic dykes (80%), occurring as sheeted complexes, with screens of quartzites, meta-arkoses and subordinate carbonates, showing similarities with the Tossåsfjellet Group of the Särv Nappes (Kumpulainen 1980).

Further north, in the Kebnekaise area, the nearly 100% dyke-dominated Kebne dyke complex (Andréasson & Gee 1989) can be correlated with the Sarektjåkkå Nappe. Near the Norwegian border in the Torneträsk area, Kathol (1989) mapped a sequence of dyke-intruded sandstones with cross- and graded-bedding in the Vaivvancohkka Nappe, overlying augen gneisses with eclogitized metabasite lenses. He included all these units in the Seve Nappe Complex. The high-grade Seve augen gneisses, together with units from the underlying Middle Allochthon, can be followed northwards from Torneträsk, via the area of Indre Troms, treated in more detail here, to Treriksrøysa (Stølen 1989), where the Seve units probably wedge out (c.f. Zachrisson 1986).

In northern Norway, mafic dyke swarms occur in units correlated (Gee et al. 1985a, b) with the upper part of Middle Allochthon and the overlying Vaddas (Köli) Nappe. In the upper Middle Allochthon, the dyke-intruded units are closely comparable with those in the Särv Nappe (and Seve in Norrbotten) and have been correlated with them (e.g. the Corrovarre Nappe of Zwaan & van Roermund 1990). In the Vaddas Nappe the mafic rocks occur both as dykes and as basalts in a Late Ordovician succession. Thus, in this part of the mountain belt, dyke complexes that were injected in the Vendian and in the Ordovician are juxtaposed.

The Corrovarre dykes have been dated to *c.* 580 Ma (Zwaan & van Roermund 1990) and correlated with those in the Seiland Igneous Province. The latter are thought to have formed during thinning and rifting of the Baltoscandian shield prior to Finnmarkian deformation (Roberts 1990; Zwaan & van Roermund 1990).

The Vaddas Nappe contains fossiliferous rocks of Late Ordovician or Early Silurian age (Binns & Gayer 1980) and Late Ordovician basalts. The lower part of the Vaddas Nappe is composed of interlayered marbles and schist overlain by a quartzite-dominated unit (Padget 1955). These units are overlain by a sequence of fossiliferous marble and mafic volcanics, locally pillow lavas. A monomictic conglomerate with quartzite clasts marks the

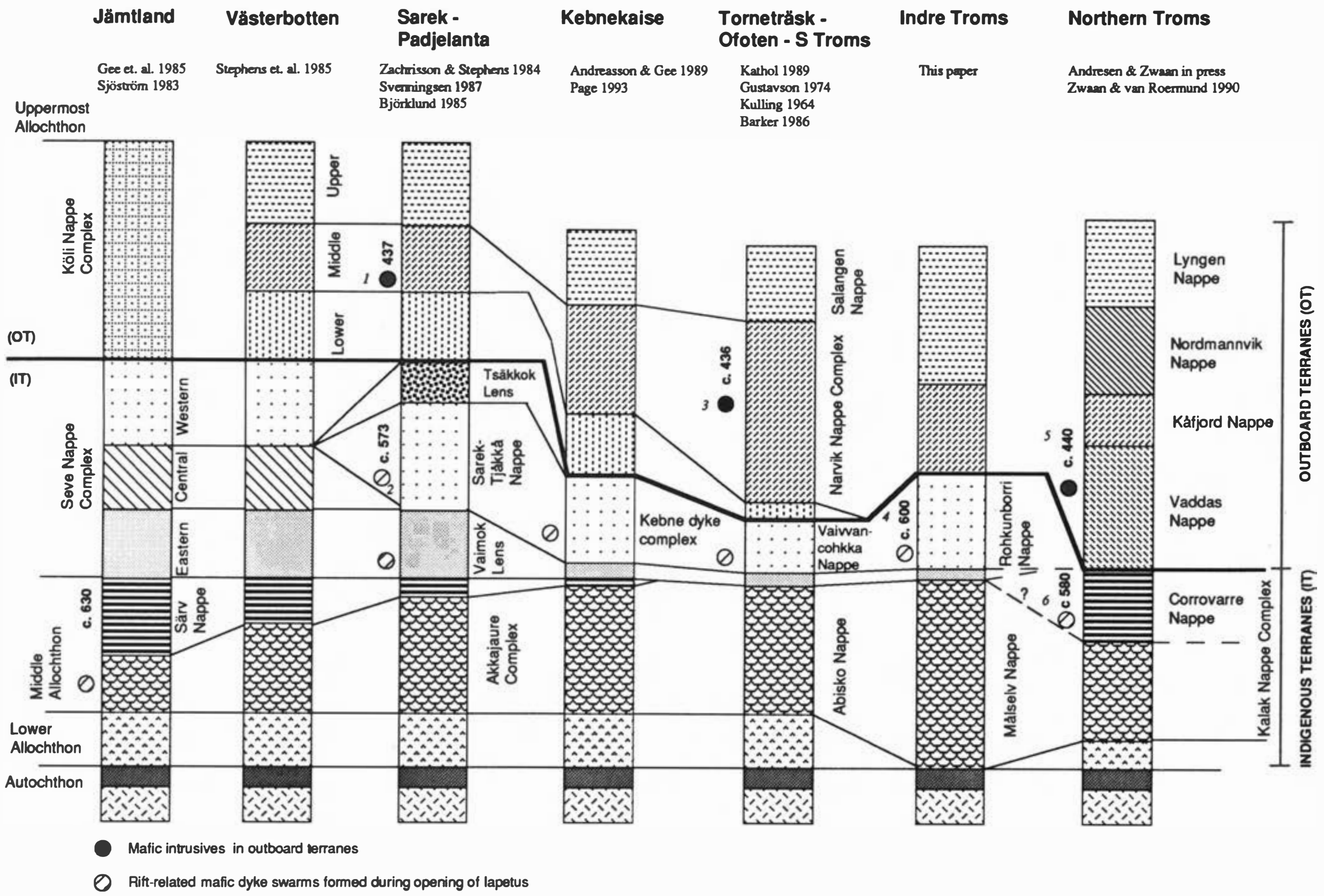

Fig. 2. Tectonostratigraphic correlations of mafic dyke complexes within the Middle and Upper Allochthon between Jämtland and northern Troms. Age data: 1. Pedersen et al. (1991), 2. Svenningsen in press (a), 3. Tucker et al. (1990), 4. Stølen unpublished, 5. Zwaan & Roermund (1990), 6. Binns & Gayer (1980).

base of a superimposed series of schists and psammites, representing distal turbidites (Andresen 1988); these rocks are overthrust by greenschists and amphibolites. A large mafic complex, the Vaddas gabbro (Lindahl 1974), intrudes lithologies in the upper part of the Vaddas Nappe. These units continue southwards towards the Treriksrøysa area (Figs. 1 and 2). None of the above mentioned units can be directly mapped into the Altevatn–Dividalen area (Fig. 3) where the dyke complexes, treated further below, are located.

The Altevatn–Dividalen area

The Indre Troms area is dominated by flat-lying thrust sheets underlain by the Late Vendian to Mid-Cambrian autochthonous sediments of the Divida1 Group, which were deposited unconformably on the mostly Late Archean granitoid gneisses of the northern part of Baltic Shield (Føyn 1967).

Kalsbeek & Olesen (1967) divided the allochthonous units in the Altevatn–Dividalen area into three units. Earlier workers had shown that the so-called 'Seve amphibolites' in the easternmost part of Indre Troms consisted of foliated amphibolites, commonly with relict igneous textures and containing lenses of marble and schist (Kalsbeek & Olesen 1967; Mortensen 1972; Gustavson 1974). However, primary features of the interior parts of these amphibolite massifs were not reported, and these provide the main topic of this paper.

Regional compilations (Gee et al. 1985a, b; Zachrisson 1986) correlated all the mafic dyke complexes of the Indre Troms area with the Seve Nappe Complex. Some workers (Krill et al. 1987, and Stephens & Gee 1989) correlated the southernmost one (Rohkunborri) with the Seve Nappe Complex and the rest (Kistefjell, Njunis and Jerta) north of this as part of the Köli Nappe Complex. The tectonic units exposed in the Altevatn–Dividalen area are described briefly below, prior to a more detailed treatment of the dyke complexes.

Middle Allochthon

The lowest tectonostratigraphic unit in the Altevatn–Dividalen area overlying the autochthonous Divida1 Group is the Målselv Nappe of the Middle Allochthon, consisting of various phyllites, quartzites, dolomites, mylonitic 'basement' rocks and tectonized clastic sedimentary rocks, the so-called 'hard-schists' of Pettersen (1878).

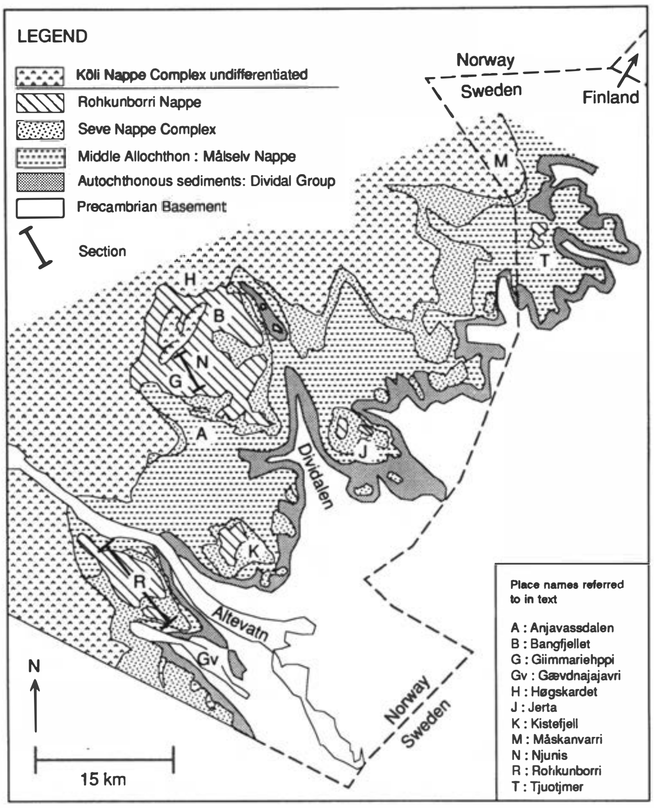

Fig. 3. Geological map of the Altevatn–Dividalen area (Indre Troms). Modified from Gustavson (1974) and Gustavson & Skålvoll (1977).

These units dominate the low-lying areas around Altevatn and in Anjavassdalen. A good marker horizon within the Målselv Nappe is the characteristic yellow Abisko dolomite (Kulling 1964), which can be recognized throughout the area. Granite mylonite derived from basement slices makes up the lowest part of the Målselv Nappe in the Jerta area. This rock unit, consisting of coarse mylonitic fractured granitoids, could be part of the Lower Allochthon, correlatable with similar units in the Rautas Nappe (Kulling 1964) in the Torneträsk area. However, the contact is poorly exposed and for the purpose of this paper it is regarded as an internal unit at the base of the Målselv Nappe.

Upper Allochthon: Seve Nappe Complex

The overlying Seve Nappe Complex is divided into three sub-units in the Altevatn–Dividalen area. The lowermost part is composed of partly phyllonitic pelitic to psammitic gneisses with quartz segregations and subordinate quartz $\pm$ garnet mica schists. These rocks are overlain by fine- to medium-grained dark-greenish foliated and often banded amphibolites; no igneous parageneses or textures are preserved. Above these, there is a characteristic kyanite-bearing augen gneiss with metabasic lenses and locally retrograded eclogites, in the area to the south of Gævdnjajavri. This unit is a good marker horizon that can be mapped through the whole Altevatn–Dividalen area northwards to Måskanvarri (Fig. 3), near Trerikrøysa. It is correlated with the Storglaciären gneiss (Andréasson & Gee 1989; Nilsson 1992) in the Kebnekaise–Abiskofjällen area.

The mafic dyke complexes described below are situated above the augen gneiss, separated from it by some tens of metres of mylonites. This thrust sheet, the Rohkunborri Nappe (Stølen 1989), is interpreted to compose the uppermost part of the Seve Nappe Complex in the Altevatn–Dividalen area.

Upper Allochthon: Köli Nappe Complex

The dyke complex is overthrust by garnet mica schists, locally with staurolite and kyanite, marbles, garbenschists and subordinate amphibolites of the Koli Nappe Complex. A more detailed description of the Köli Nappe Complex is found elsewhere (Stølen, unpublished).

Tectonothermal history

Four phases of deformation can be recognized within the various thrust sheets of the Altevatn–Dividalen area. Evidence for D1 has been observed only within the Seve Nappes, as shown by early isoclinical folds and inclusion trails in garnet prophyroblasts. The D2 deformation is related to development of the dominant schistosity in all the thrust sheets. D2, although similar in appearance in all thrust sheets, probably developed successively during emplacement of the nappes. F2 folds are recumbent isoclinal with NE–SW trending fold axes, and S2 as axial planes.

Early D2 growth of garnet and kyanite within the Seve Nappe Complex, and only of garnet within the Köli Nappes, took place at the peak of metamorphism. S-C mylonites and extensional crenulation cleavages are developed in thrust zones. The regional Caledonian transport direction in the area is to the ESE.

The third (D3) and fourth (D4) deformation phases post-date the thrusting; they fold thrust contacts in tight to open regional folds on N–S and NW–SE axes, respectively. F3 folds are inclined, close to tight. Locally the S3 crenulation fabric is penetrative. D4 deformation is dominated by mesoscopic open to box shaped, asymmetric folding with vergence towards SE. Kink banding and crenulation cleavages are commonly developed, and locally the crenulation cleavage is penetrative.

The Rohkunborri Nappe

The Rohkunborri Nappe has a tectonostratigraphic thickness of as much as 1000 metres in the Rohkunborri area and *c.* 800 metres in the Njunis area. Both areas have a number of glacial cirques that provide three-dimensional views of the internal parts of the nappe. More deformed parts of the Rohkunborri Nappe are exposed in the Kistefjell and Jerta areas.

Fig. 4. Part of the western wall in the Giimmariehppi glacier cirque. Screens of sedimentary rocks can be seen in between areas dominated by mafic rocks. Height of section is 350 m.

The Rohkunborri Nappe is dominated is dominated by mafic dykes, occurring in multiple sheeted complexes up to 100 metres wide (Fig. 4), or as single dykes, intruding a metasedimentary succession. The nappe occurs as a flat-lying klippen in the Rohkunborri area (Fig. 5), and in an open N–S trending synform in the Njunis area. In the northern part of the Njunis area, the nappe is refolded in a tight NE–SW trending synform. The central parts are particularly well preserved, and high-angle dyke-bedding relationships, chilled margins and dyke-in-dyke relationships can be observed (Fig. 6). The dykes are deformed and amphibolitized towards the roof and floor thrusts and in internal shear zones.

The Njunis succession appears to be imbricated, because a repetition of parts of the internal tectonostratigraphy has been found. At least two major internal thrusts have been mapped (Fig. 6) within the Giimmariehppi area. Small-scale thrust faults are common and all kinematic indicators show top-to-the-east movement. A late NW-dipping post-thrusting normal fault (Fig. 6) also occurs within the Njunis area.

Stratigraphy of the Rohkunborri Nappe

Although the Rohkunborri Nappe is made up of 65–70% dykes, a sedimentary succession, the Njunis Group, can be recognized (Fig. 7), with an estimated thickness of >2500 metres. The lower part of the succession in the Rohkunborri and Njunis areas can be correlated. In the latter, the stratigraphy is more complex in the upper part, and repetitions due to folding and thrusting (see below) of the dyke complex complicate the Njunis stratigraphy. The Njunis area has a more varied stratigraphy, containing more rock units in the upper part. Sediment screens that occur between multiple dykes can be thoroughly contact metamorphosed. Garnet–diopside–calcite scarns are frequently found near contacts to dykes. Usual textures are irregular vein systems and nests consisting of numerous garnet crystalloblasts. Back veining is common in these contact metamorphosed areas, with veins of melted sediments intruding the dykes. Most of the rocks are rusty owing to impregnation by pyrrhotite and pyrite. Bedding surfaces dip steeply to the SSE in the Njunis area and cross-bedding and graded bedding are found at a few localities in both areas, indicating that the sediments are younging towards the southeast. The Njunis Group can be divided into four formations:

(1) *Høgskardet formation:* The lowermost formation of the Njunis Group contains several horizons of graphitic and psammitic schists, interbedded with marble. Its lower boundary is a thrust contact to the Köli Nappes.

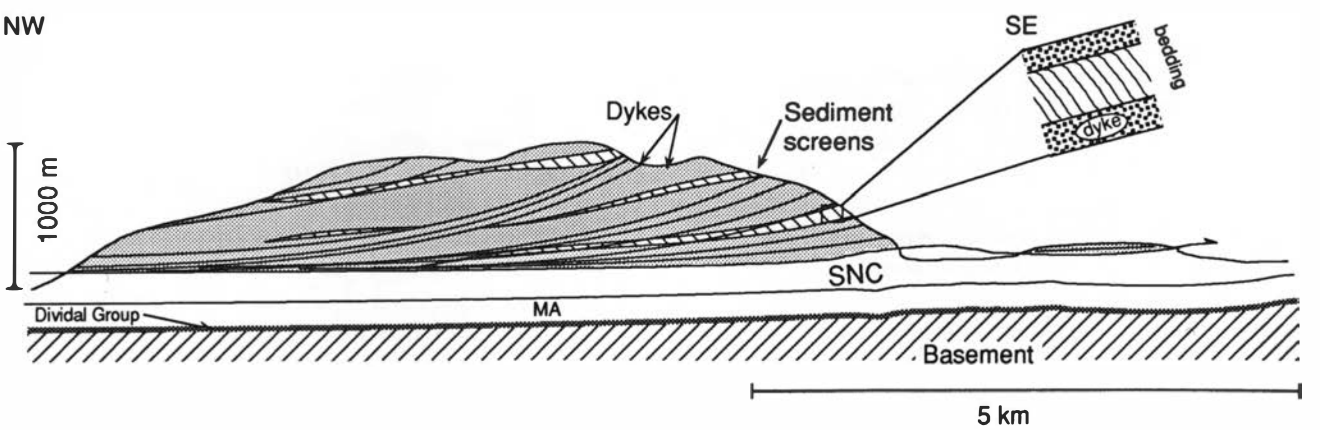

Fig. 5. Schematic profile through the Rohkunborri dyke complex. SNC = Seve Nappe Complex, MA = Middle Allochthon. Vertical scale is exaggerated.

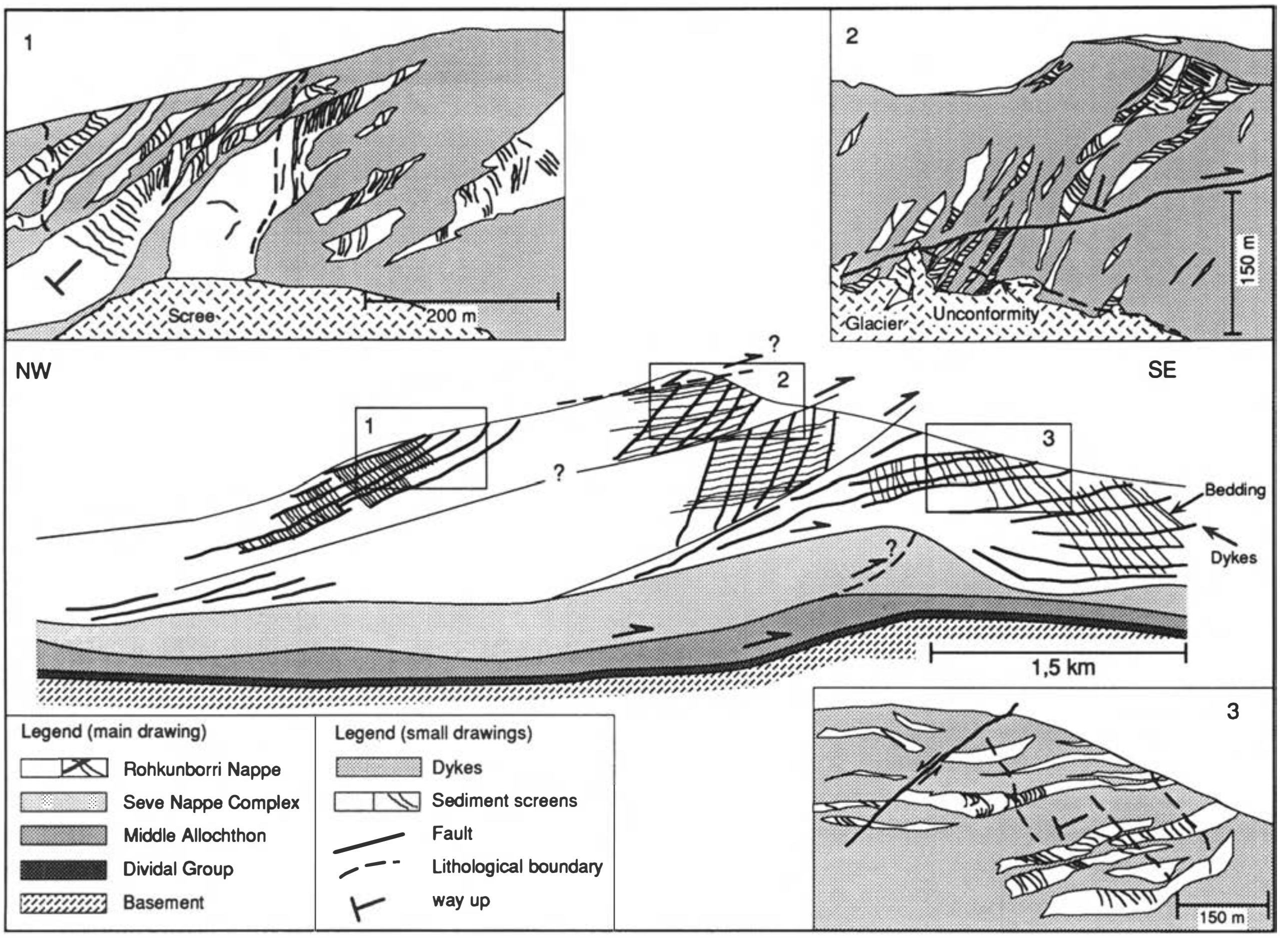

Fig. 6. Schematic profile through the central part of the Njunis dyke complex with inset detailed drawings of selected sections. Thrust faults are shown as thick lines within the main drawing. Drawing 1 shows shallowly NW-dipping dykes and sub-vertical bedding within the sediment screens. Drawing 2 shows steep dykes and horizontal bedding in the west wall of Njunis. The angular unconformity between limestones and overlying shales is marked with a dashed line. A thrust fault is shown as a thick line. Drawing 3 shows the same dyke-bedding relationships as in drawing 1. A NW-dipping post-thrusting normal fault is found within this section.

(2) *Bangfjellet formation:* The main outcrop is in the Bangfjellet area. The contacts are not exposed. This succession consists of yellow to grey dolomite several hundred metres thick, interbedded with 2–8 cm thick calc-silicate and scapolite layers. These layers make up more than 50% of the rock.

(3) *Sandfjellet formation:* A local angular unconformity (30°) between marble and underlying units represents the lower boundary to the Sandfjellet formation in the Njunis area. The lower contact is not exposed in the Rohkunborri area. Calcareous schists and impure marbles with calc-silicate bands form the major part of the succession in the Rohkunborri area. Marble layers are often recrystallized to grossular, diopside and calcite. A minor conglomerate horizon occurs in the lower part of the formation in the Njunis area, containing a few granitoid pebbles in a mudstone matrix.

(4) *Giimmariehppi formation:* This unit is made up of a medium- to coarse-grained grey marble, which makes up a large part of the eastern part of the Rohkunborri massif. Calc-silicate and scapolite bands are common within marble horizons.

A series of rusty quartzites, as subordinate concordant lenses within foliated amphibolites, occurs close to the floor thrust of the Rohkunborri Nappe, with an unclear relationship to the Njunis Group. No primary structures are found within these metasediments and the dyke-bedding relationships have been rotated into concordance.

Mafic dykes of the Rohkunborri Nappe

In the better-preserved parts of the nappe, medium- to fine-grained grey dolerites with ophitic to sub-ophitic textures, primary plagioclase phenocrysts and, locally, pyroxene are preserved. Early coarse-grained gabbroic dykes are found in a few places and coarse gabbroic xenoliths are also found at a number of localities in the dolerites. The width of the dykes follows a power law distribution, with most dykes varying from 0.5 m up to 3 m (Figs. 8, 9) and with a small number of thin dykes (cm wide) and large dykes (up to 10 m wide). The dykes generally strike NNE and dip slightly towards the NW. They cut the host metasediments at a high angle. Thin (cm wide) fine-grained dyke apophyses are found in parts

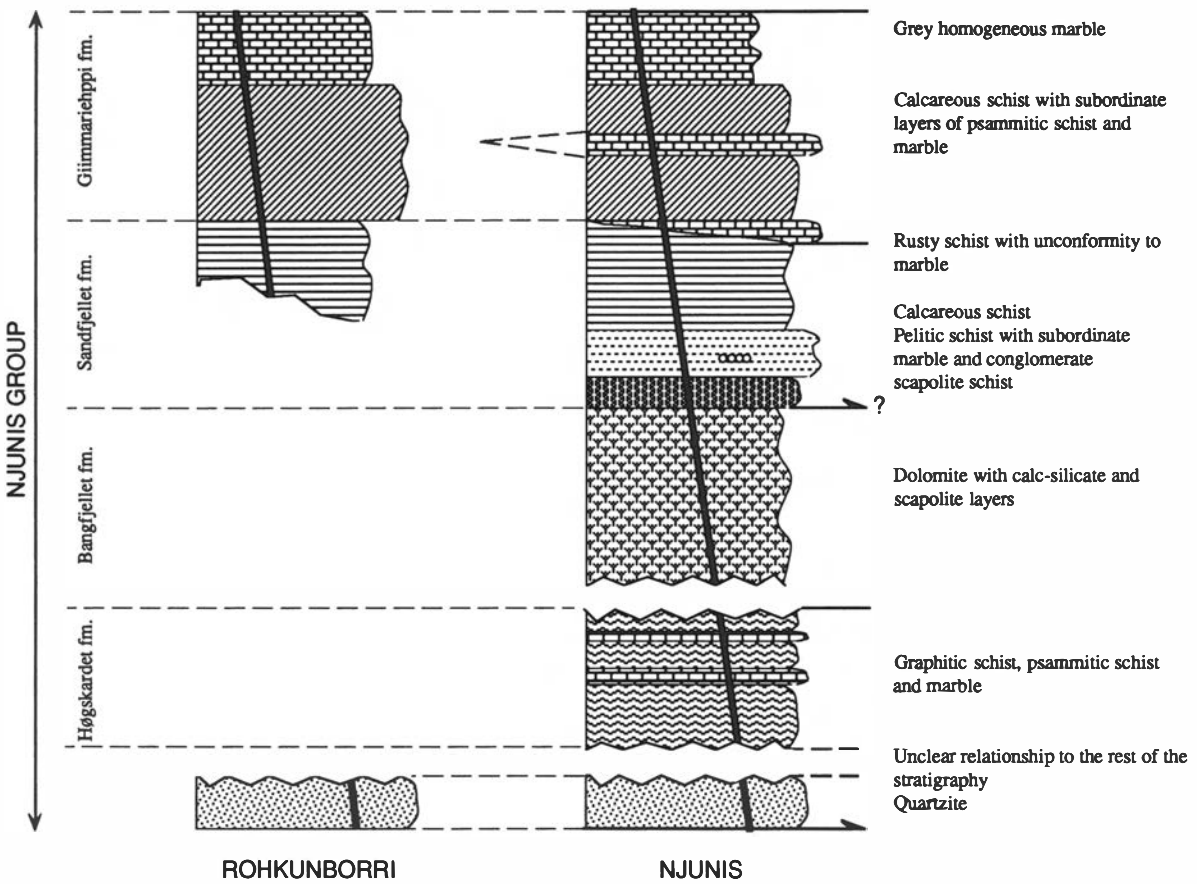

Fig. 7. Schematic internal tectonostratigraphy of the Rohkunborri Nappe in the Njunis and Rohkunborri areas.

of the Njunis area, some extending as much as 2 m away from the dyke. En echelon veins separated by bridge structures are found in areas where the country rock is calc-silicate rich or consists of marble.

Several dyke generations, based on cross-cutting relationships, are found, with younger dykes cutting older at angles of up to 40°, probably indicating dyke intrusion during active faulting. Late dykes have a width of 0.5–1.5 m. Single-sided chilling is commonly found, with younger dykes intruding the central parts of older dykes. Up to six single-sided chilled margins (dyke-in-dyke intrusions) have been found in the Rohkunborri area, comparable to multiple intrusions in sheeted dyke complexes. The chilling direction is always towards the screens of metasedimentary rocks.

Two generations of sills, intruding along calc-silicate layers in marbles, are observed at one locality in the Giimmariehppi glacier cirque (Fig. 10); they are cut by later dykes. Small sidesteps (Walker 1987), 1–2 m long, are observed at the lithological boundary between marble and schist at a few localities in the Njunis area.

Amphibolitization occurs close to the roof and floor thrusts and in internal shear zones. The amphibolites carry hornblende and plagioclase with minor amounts of quartz, zoisite and garnet. There are also a few examples of non-foliated dykes that are amphibolitized. One locality shows foliated dykes cut by later massive intrusions (Fig. 11a), indicating deformation during the intrusive history.

Composite and felsic dykes

Felsic dykes are rare within the dyke complexes and have been found only at three localities in the Rohkunborri area and at two localities in the Njunis area. One of the Rohkunborri dykes starts as a composite mafic–felsic dyke, with a gradational change from the mafic to the felsic components; it evolves into a granitoid dyke along strike and cuts the contact of the adjacent mafic dyke. The felsic dykes are medium grained and up to 2 m thick. The main minerals are quartz, plagioclase (partly altered to sericite) and K-feldspar (locally perthitic). Minor amounts of biotite, muscovite, chlorite, garnet and epidote are also found. Titanite, zircon and opaques occur as accessories. They can be followed for several hundreds of metres, clearly cutting the surrounding mafic dykes. A trondjemitic dyke occurs in the lower part of the Njunis succession, intruding the neighbouring mafic dykes at a small angle.

Pre- or syn-intrusion structures in the dyke complex

Extension structures that can be related to deformation prior to or contemporary to dolerite intrusion can be

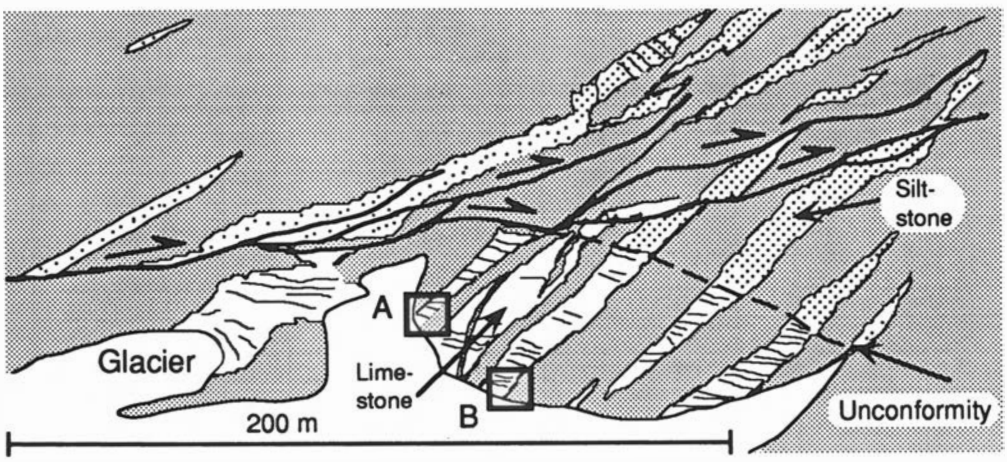

Fig. 8. Detailed drawing of the lower part of the Giimmariehppi west wall showing the unconformity and the thrust fault. A marks the location of Fig. 9 and B marks the location of Fig. 10.

Fig. 9. Mafic dykes several metres thick with thinner dykes cross-cutting banded calc-silicate limestone at the inner part of the Giimmariehppi glacier cirque in the Njunis area, UTM 34WDB382272.

found at a few localities. These structures include pull-apart boudinage of competent calc-silicate layers in a less competent marble (Fig. 11b) and small-scale faulting of sedimentary beds (Fig. 11c).

Most dykes occur in clusters with subparallel dykes intruded along the margins of or in the central parts of earlier dykes. Dykes constitute up to nearly 100% of the width of the clusters, with screens of metasedimentary rocks between. Sheeted complexes of dykes indicate that early dykes and their margins were planes of structural weakness offering easy paths for later intrusions. Later dykes, which cut earlier dykes at angles of up to 45°, might indicate tilting of crustal blocks during magmatic activity, suggestive of intrusion in an active rift environment, with block-faulting. Dykes with different orientations, but with the same or unclear age relationships, might have intruded along complementary sets of fractures related to normal faults in an extensional environment.

Single zircon $^{207}Pb/^{206}Pb$ dating by direct evaporation (L. P. Gromet, pers. comm.) of a felsic dyke in the Rohkunborri area and the felsic portion of a composite mafic/felsic dyke at Njunis provide evidence of composite zircons containing a varied Precambrian inheritance with minimum ages ranging from ≈780 to 1120 Ma (4 grains analysed) and ≈1510 to 1885 Ma (2 grains analysed), respectively. Several of the zircons displayed increasing $^{207}Pb/^{206}Pb$ ages with progressive evaporation, suggestive of core-overgrowth relationships. One zircon from the Rohkunborri sample displayed multiple early evapora-

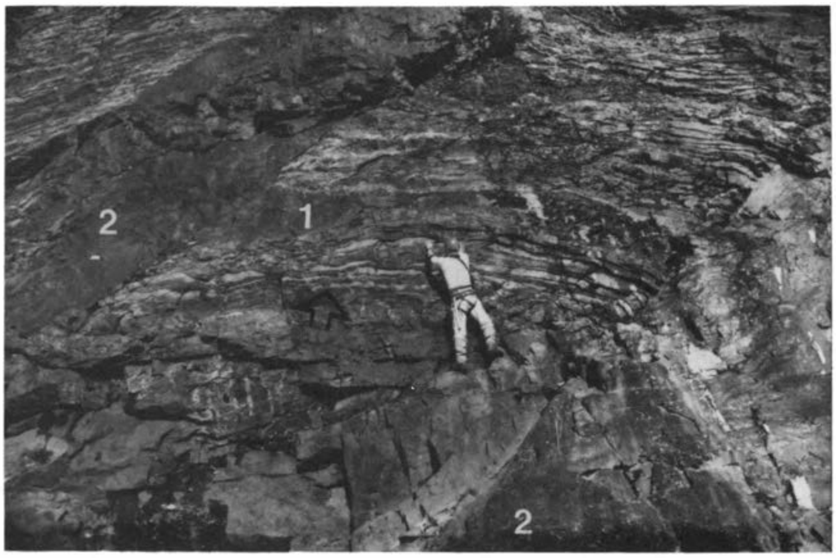

Fig. 10. Sill cut by later dyke generations in the inner part of the Giimmariehppi glacier cirque, UTM 34WDB382272. The numbers indicate the order in which the dykes intruded: 1. early sills, 2. later cross-cutting dykes. The arrow marks the location of pull-apart-boudinage shown in Fig. 11b.

Fig. 11a. Amphibolitized dyke cut by later intrusion (x), indicating that parts of the dyke complex were amphibolitized prior to later intrusive events. Scale 52 mm. UTM 34WDB388270.

Fig. 11c. Small-scale extensional faulting in primary calc-silicate layer. Scale 10 cm. Locality close to the summit area of Njunis, UTM 34WDB389271.

Fig. 11b. Pull-apart-boudinage of a more competent calc-silicate layer in limestone. Width of section 0.5 m. Locality in the inner part of the Giimmariehppi glacier cirque, UTM 34WDB382272.

tions of $\approx$600 Ma, which possibly represents the age of a magmatic overgrowth formed on inherited zircon, and therefore the age of dyke crystallization.

Although these data provide limited information on the age of the dykes, they provide very strong evidence for a Precambrian inheritance. The inherited zircons are interpreted to have originated by assimilation at deeper crustal levels, and indicate the presence at depth of Precambrian continental crust or its derivatives at the time of dyke emplacement. The Grenvillian and older ages for the inherited components favour a Baltoscandian rather than an outboard source.

Geochemically the dykes are tholeiites with MORB affinity and are interpreted to have formed by spreading-related magmatism, probably during the rift phase of the Iapetus Ocean. The geochemistry of the dykes is treated elsewhere (Stølen, unpublished).

Caledonian deformation of the dyke complex

Dyke-bedding relationships

Although the dyke complexes occur in low-strain zones, they are influenced by the same deformation phases as the rock units below and above – mainly structures related to the D2 and D3 deformation phases. The deformation of the dyke complexes involves rotation, shearing and folding.

The following section contains a description of this deformation and an interpretation of its mechanism. There are systematic relationships between dyke attitude and the types of structure formed at the dyke margins (Fig. 12).

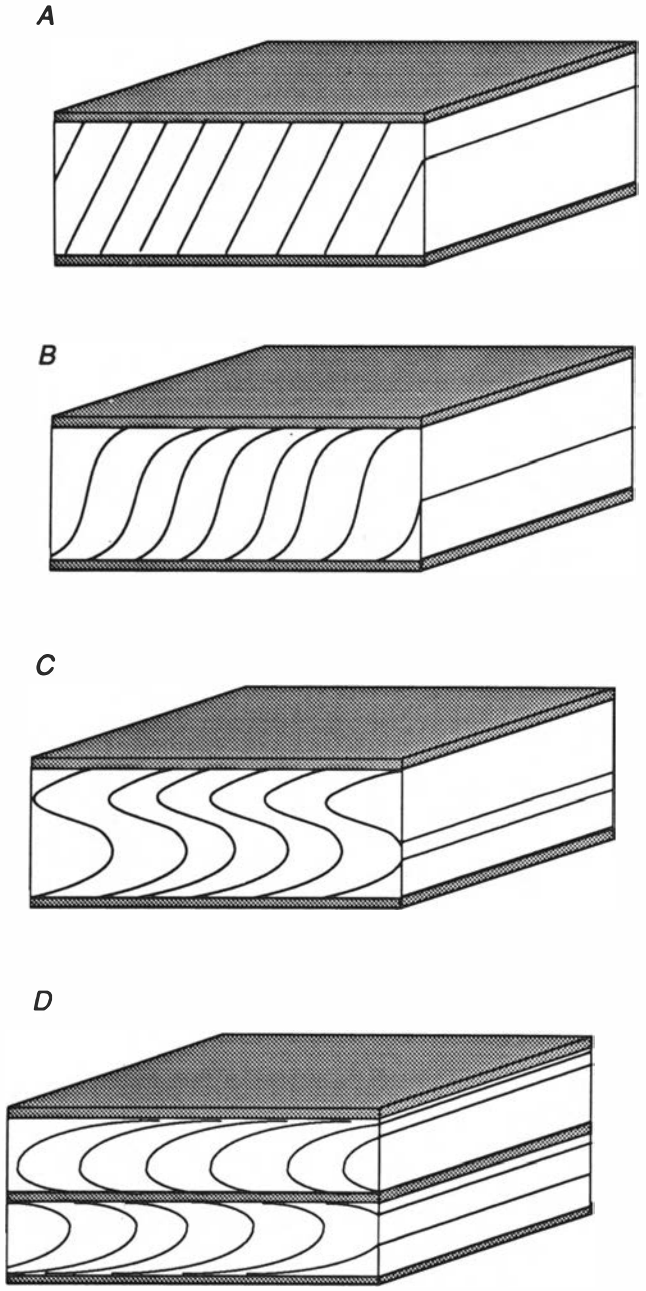

Fig. 12. Examples of fold structures developed at the margins of dykes. Thick lines = dykes, thin lines = bedding surfaces. A: type A dyke-bedding relationship; B: type B dyke-bedding relationship; C: evolved version of type B; D: type C dyke-bedding relationship.

Dyke relationship A. – These dykes (Fig. 12a) cut bedding at angles between 90° and 75°. Igneous textures and commonly primary minerals are preserved and no foliation is developed. The dyke-bedding contact is planar (Fig. 13) except for very thin dykes, where the contact is irregular. The chilled margin may be up to 5 cm wide. The contact-metamorphosed zone at the margins of the dykes varies from 2–4 cm up to several dm depending on dyke thickness and number of dykes. This dyke-bedding relationship is found mainly in central parts of the dyke complex, but also in low-strain zones close to the margins of the complex.

Dyke relationship B. – In this case the angle between dyke and bedding is between 75° and 30° (Figs. 12b, 12c). Folds have formed adjacent to the dykes and an axial plane (S3) foliation is developed within dyke margins. Relict igneous textures can be found in the central parts of the dykes. Both symmetric and asymmetric folds are formed adjacent to dyke margins; symmetric folds are more common in the less deformed parts of the dyke complex and asymmetric folds occur in parts of the dyke complex with higher shear strain. An oblique foliation within dykes is observed at a few localities.

Dyke relationship C. – This relationship is found close to the roof and floor thrusts and near internal shear zones. The angle between dykes and bedding is smaller than 30° (Fig. 12d) and commonly the dykes and bedding are parallel to subparallel with a penetrative foliation developed both in the dyke and in the surrounding metasediments. Shear strain is more or less homogeneous throughout the dykes, except along the margins where a strain concentration can be found following the earlier chilled margin (Fig. 14). Folds against dyke margins occur as sheared out isoclinal folds, with a mylonitic zone up to 5 cm wide close to the dyke margin often following the earlier contact-metamorphosed zone (Fig. 14). Boudinage involving both dykes and metasediments

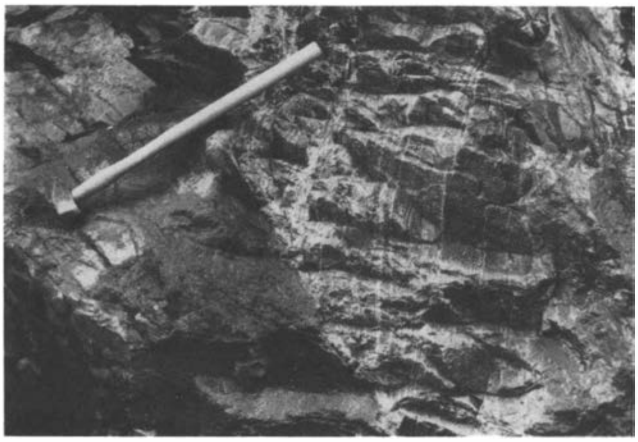

Fig. 13. Bedding cut by mafic dyke at a high angle. The dyke-bedding contact is planar. Scale 0.55 m. Locality on the southern side of Njunis, UTM 32WDB379258.

Fig. 14. Folds developed at the margin of mafic dyke. A Mylonitic zone following the earlier contact-metamorphosed zone (marked with X). The dyke margin is also penetratively foliated, possibly along earlier chilled margin (marked with Y). Scale 0.5 m. Locality SW part of Giimmariehppi glacier cirque, UTM 34WDB378259.

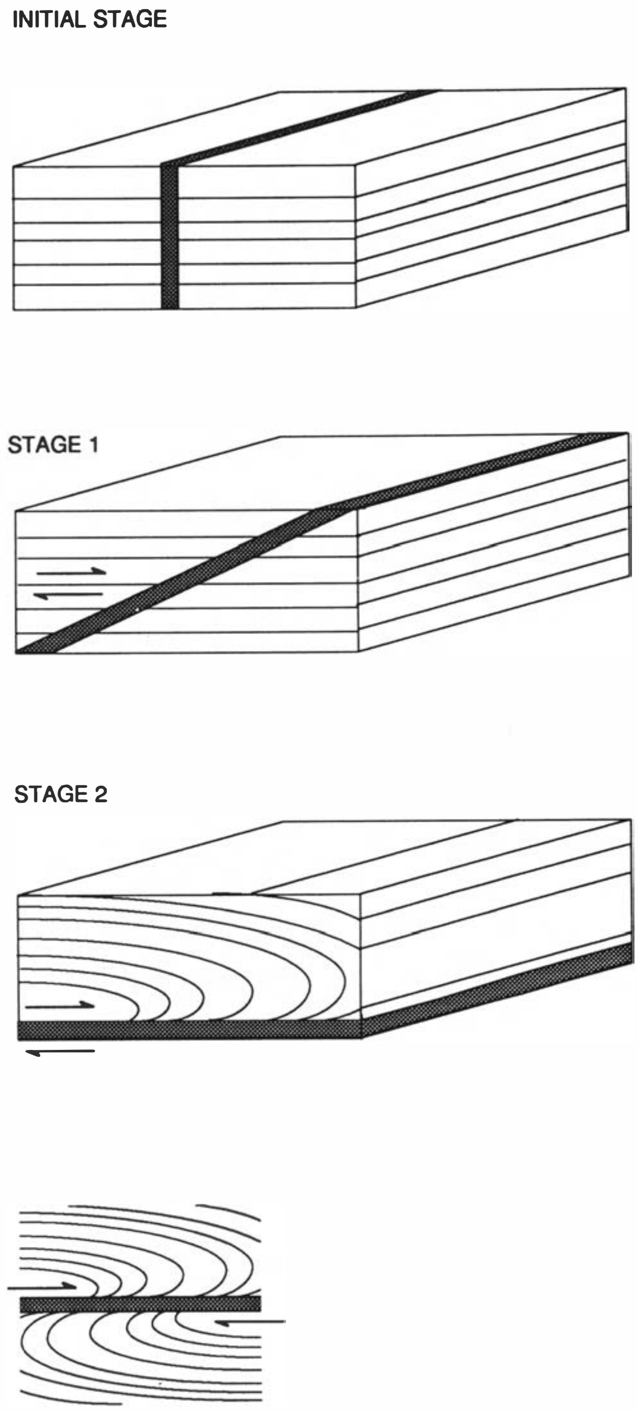

Fig. 15. Sketch of deformation relationships and formation of folds at dyke margins. Initial stage: inferred dyke-bedding relationship prior to deformation. Stage 1: dykes rotate owing to simple shear parallel to sedimentary bedding. Stage 2: dykes cannot be rotated further and start acting as shear planes. Folding of bedding adjacent to dykes. Development of foliation in dyke margins. Folds form on both sides of dykes. Dyke-bedding relationships suggest dykes were intruding along axial plane, but folds are formed after intrusion.

is found in the lower part of the dyke complex in both the Rohkunborri and Njunis areas. The dykes are almost completely amphibolitized, igneous textures are rare and no primary minerals are found.

Structural evolution

In order to establish the structural evolution of the dyke complexes, an estimate of the original orientation (pre-deformational) of the dykes in relationship to the sedimentary bedding is necessary. Evidence from the best-preserved parts of the dyke complexes indicates that the initial dyke-bedding relationship was orthogonal to suborthogonal.

Rotation of dykes and bedding. – The rotation of the dykes and the bedding and subsequent folding of the latter involve at least two deformation phases (D2 and D3). During the first stage of deformation, the dykes acted as competent layers owing to the ductility contrast between the dykes and the surrounding metasediments. The initial rotation of the dykes was due to simple shear parallel to the sedimentary bedding (Fig. 15) until D2 shear strain was unable to rotate the dykes and the dykes started acting as planes of weakness (Fig. 15), with most of the strain localized along dyke margins. The following D3 deformation resulted in folding of the sedimentary bedding adjacent to the dyke margins. The folding started as symmetric folds, which were rotated into asymmetric folds with increasing shear strain.

The above sequence of deformation is one explanation of the dyke-bedding relationships observed in field. A different possibility is that the dykes intruded parallel to the axial planes of previously formed folds. If the folds were formed prior to dyke intrusion, one would expect to see the same bed cut by the dykes on both limbs of the fold in a single section normal to the fold axis (Rice & Reiz 1993); no such relationships have been observed within the Rohkunborri Nappe.

The sequence of deformation of dykes of bedding within the Rohkunborri Nappe is in agreement with fold formation at the margins of dykes in mafic dyke swarms in the central (Krill 1986) and northern (Gayer et al. 1978; Rice 1986) Scandinavian Caledonides. This statement does not, however, exclude the possibility that dykes cutting earlier folds exist in this part of the northern Norwegian Caledonides.

Tectonostratigraphic correlations

Correlation of the Rohkunborri Nappe with other dyke-intruded tectonic units in Troms (Figs. 1, 2) as well as the Norrbotten area in Sweden has been mentioned above. Other potential correlations should be considered.

The most likely northward correlative of the Rohkunborri Nappe is the Corrovarre Nappe (Zwaan & van Roermund 1990), although the latter is more psammite dominated than the Rohkunborri Nappe.

The host rocks of the mafic dyke swarms of the Rohkunborri Nappe show similarities with the Sarektjåkkå Nappe (Svenningsen in press b), the Tsäkkok Nappe (Kullerud et al. 1990) and the Vaivvancohkka Nappe (Kathol 1989) in Norrbotten. The Tsäkkok Nappe includes carbonate platform rocks and is thought to have originated at the outermost part of the Baltoscandian margin; these rocks have suffered high-P metamorphism during the Late Cambrian–Early Ordovician (Kullerud et al. 1990), an event that is not observed in the Rohkunborri Nappe.

The nature of the screen rocks within the dyke complexes (see above), new geochemical (Stølen in prep) and isotopic data (see above) on the mafic dykes, together with tectonostratigraphic correlations with similar mafic dyke complexes within the Seve Nappe Complex, suggested a correlation with the Seve Terrane – suggested earlier as a working hypothesis (Andréasson et al. 1988; Stølen 1989) – rather than a correlation with the exotic Vaddas/Sulitjelma Terrane (Roberts 1988) equivalent to Terrane 12 of Stephens & Gee (1989) as abstracted earlier (Stølen 1991).

Conclusions

Two groups of mafic dyke swarms occur in the northern part of the Scandinavian Caledonides. One was part of the rifted Baltoscandian margin, the other was in an outboard setting related to opening of back-arc/marginal basins. The mafic dykes in the Indre Troms area are inferred to be part of this first group of dyke swarms on the basis of tectonostratigraphic correlations, preliminary age data and similarities in the lithologies of the host rocks and the lithologies of the Baltoscandian miogeocline succession. The dykes are excellently preserved in low-strain zones in the Rohkunborri and Njunis occurrences of the Rohkunborri Nappe, and more deformed parts of the dyke swarm can be mapped throughout the area between Gævdnjajavri in the south and Treriksrøysa in the north.

An internal stratigraphy has been mapped out for the dyke-intruded sediments, the Njunis Group succession, dominated by calcareous sediments and dolomitic marble. Sedimentary, extensional and magmatic structures are common. The sedimentary rocks are supposed to represent the outermost part of the clastic wedge deposited during Neoproterozoic–earliest Palaeozoic time on the thinned outmost part of the Baltoscandian margin.

A complex structural evolution can be recognized within the dyke complexes involving early block rotation during intrusion, rotation of both dykes and bedding due to simple shear deformation during thrusting and subsequent imbrication of the dyke complex.

The Indre Troms dyke swarm, the Rohkunborri Nappe, is correlated with similar mafic intrusive events, related to the opening of the Iapetus Ocean, within the Seve Nappe Complex in the Sarek, Kebnekaise and Torneträsk areas in northernmost Sweden.

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