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ånes Area, Rana,

SVEIN GJELLE

Gjelle, S. 1978: Geology and structure of the Bjøllånes area, Rana, Nordland. *Norges geol. Unders. 343,* 1–37.

The field relationships of rock groups of three tectonic units from the area west of the Lønsdal basal massif are outlined and the lithologies and mineral assemblages are described. Chemical analyses of marbles and amphibolites are presented and discussed in relation to analytical data from neighbouring areas of the Caledonides. Most of the amphibolites are shown to be of igneous origin and subalkaline, but their precise nature is uncertain.

The structures recorded suggest four phases of Caledonian deformation. The F_1 phase probably had axes orientated roughly E–W which is also the axial trend of the F_2 phase. The first deformation produced minor isoclinal folds, the main foliation and one possible thrust zone. The second phase gave rise to relatively tight mesoscopic and macroscopic folds. The F_3 phase, approximately N–S oriented, deforms the earlier structures and is responsible for the main lithological outcrop pattern. The thrusting of the middle and the upper unit is thought to be connected with this deformation phase.

Possible correlations of the Bjøllånes rocks with those from neighbouring areas of the Caledonides in Norway and Sweden are proposed. There would seem to be good evidence that the Rödingsfjäll Nappe is situated at a tectonically higher level than the Gasak Nappe which previously was supposed to be in an identical tectonic position.

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Introduction

The Bjøllånes area is situated in the county of Nordland, Northern Norway, about 40 km north-east of Mo i Rana (Fig. 1). Topographically the area is characterized by a series of north-south trending valleys with mountains in between reaching altitudes of 1000–1400 m. Outcrops are generally good except in the valley bottoms. Quaternary terraces in Bjøllådalen make this valley one of the most covered areas in the district. During the summers of 1970–72 the author carried out field investigations in the Bjøllånes area for a cand. real. thesis at the University of Oslo (Gjelle 1974). This paper summarizes the results of these investigations. The earliest work in the Rana district includes that of Vogt (1890, 1894), Rekstad (1913) and Oxaal (1919). This was followed by Holmsen's (1932) 1:250 000 map description while parts of the present area have been discussed in papers by Bugge (1948), Strand (1972) and Rutland & Nicholson (1965). Wilson & Nicholson (1973) have carried out Rb-Sr dating of granitic gneisses from basal massifs of the central parts of Nordland, and the Nasafjäll massif, which crops out in the eastern part of the area, was included in their study. In addition, it should be mentioned that the area south-west of Bjøllånes has been described by Søvegjarto (1972) in a cand. real. thesis.

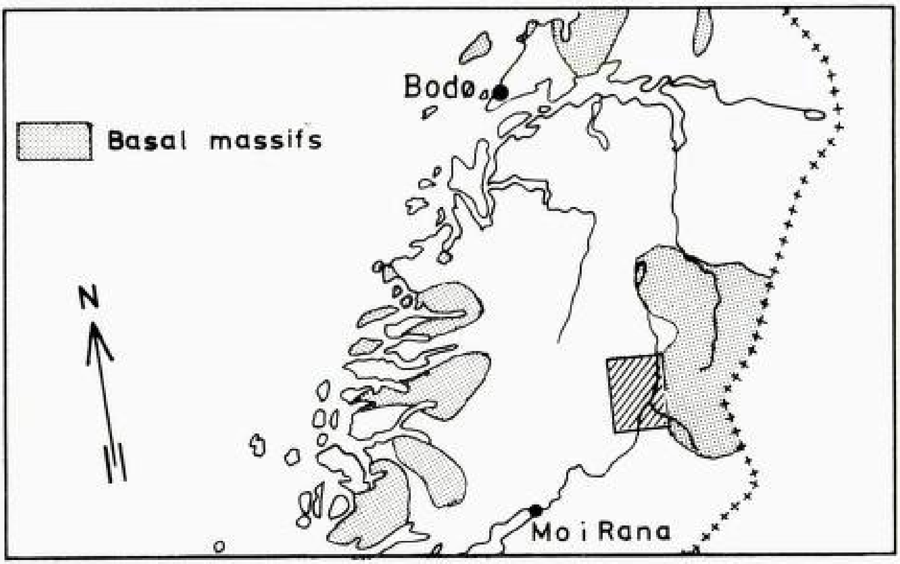

Fig. 1. Simplified map of the central part of Nordland showing the location of the area.

GEOLOGICAL SETTING

A characteristic feature of the geology in this central part of the Scandinavian Caledonides is that the basal massifs which in the west were strongly deformed in Caledonian time whereas those in the east towards and beyond the Swedish border appear almost undeformed (Rutland & Nicholson 1965). Previously, many geologists considered the western 'granite' massifs to be Caledonian intrusives, but more recent investigators have established that they represent Precambrian basement rocks (Hollingworth et al. 1960; Rutland & Nicholson 1965).

Overlying the basal massifs are thick metasedimentary sequences consisting of pelitic to psammitic rocks and limestones with metavolcanics as a subordinate constituent. Caledonian intrusives are relatively uncommon, except in the southern part of Nordland.

Structurally the Bjøllånes area is rather complicated. Lack of fossils has made it almost impossible to establish a stratigraphy which can be readily correlated with successions in other parts of the Caledonides. Correlations must be based on lithostratigraphy and tectonostratigraphy and are therefore not very reliable.

A series of nappes has been described from both sides of the international border. In Sweden the nappes are generally discordant and easily distinguished as nappes, whereas on the Norwegian side of the border most of the allochthonous units are of the conjunctive type (Rutland & Nicholson 1965), particularly in the western areas. Both the continuation of the Swedish nappes on to Norwegian territory and their actual origin have been much debated. Most geologists seem to prefer the theory of nappes rooting off the Norwegian coast, while some hold the opinion that the site of deposition of the Seve–Köli rocks could possibly have been in Nordland above the now exposed basement areas (Nicholson & Rutland 1969).

Tectonostratigraphic succession

The rocks of the area can be subdivided into three allochthonous units lying above the Precambrian Lønsdal (or Nasafjäll) basal massif. Each unit is further divided informally into groups comprising a series of different rock formations. The tectonostratigraphic succession is presented in Table 1 and the distribution of the groups shown in Fig. 2.

Table 1. Tectonostratigraphic succession

Upper Thrust Unit (The Rödingsfjäll Nappe)		DUNDERLAND GROUP	Marbles, mica schists, amphibolites
		ØRTFJELL GROUP	Mica schists, quartzites, various igneous rocks
		KJERRINGFJELL GROUP	Gneisses, quartzites, various igneous rocks
		GILA COMPLEX	Gneissic granite, mica schists, amphibolites
	Thrust zone	— — — — — — — —	
Middle Thrust Unit		TESPFJELL GROUP	Mica schists, quartzites, marbles, various igneous rocks
	Thrust zone	— — — — — — — —	
Lower Thrust Unit		BJØLLÅDAL GROUP	Mica schists, marbles, amphibolites, metaperidotites
		RAUDFJELL GROUP	Mica schists, marbles, quartzites
	Thrust zone	— — — — — — — —	
		LØNSDAL BASAL MASSIF	with autochthonous cover

LITHOLOGIES OF THE VARIOUS ROCK GROUPS

The Lønsdal basal massif. – The Precambrian Lønsdal basal massif is exposed in the eastern part of the area around Saratuva (Fig. 2 and Plate 1). Only a small part of the massif has been surveyed. The rock exposed here is a porphyritic granite with gneissic structure defined by a foliation which is parallel to the schistosity in the overlying metasediments. The foliation gradually diminishes away from the contact. The uppermost part of the Precambrian massif seems to consist of a metasediment derived from the granite itself; the thickness

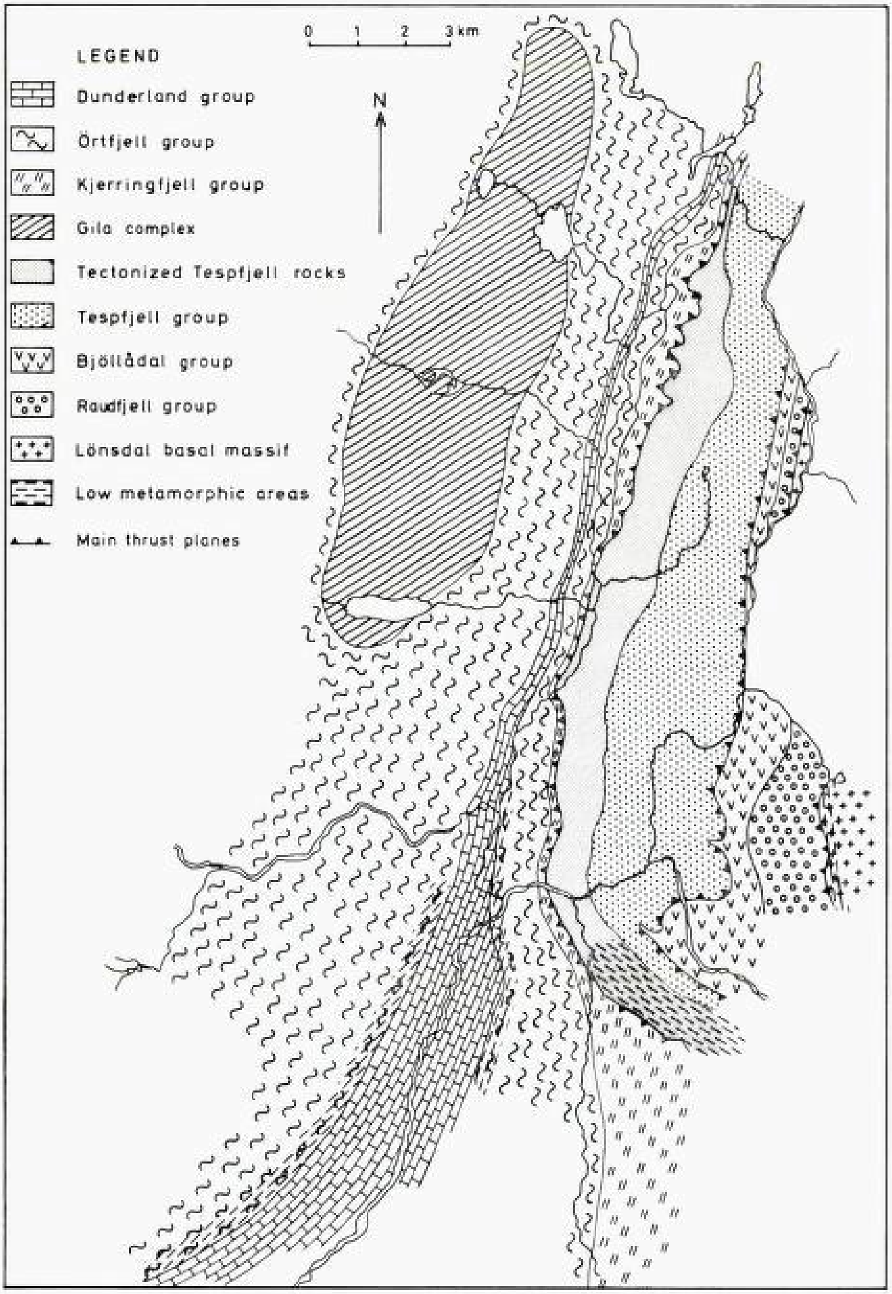

Fig. 2. Map showing the principal rock units and zones of low metamorphic grade.

of this is usually less than one metre. Above this is a brown-coloured, finely laminated, quartz-rich, graphitic mica schist with a thin quartzite horizon, which possibly represents an autochthonous/parautochthonous sequence. The total thickness of this schist sequence is generally less than 10 m. It has not been possible to determine whether or not this schist really constitutes an autochthonous cover. It could conceivably be part of the overlying Lower Thrust Unit, but no discordance or traces of cataclasis have been found here. The only indications of thrusting are that the overlying sequence, the Raudfjell group, has a higher metamorphic grade than the granite and its in situ sediment cover, and that the basement granite is foliated parallel to the contact. Geologists who have been working in neighbouring areas both to the north and to the south have, however, described thrust planes occurring immediately above a graphite schist lying directly upon the basal massif (Steenken 1957; Marklund 1952). Another possible indication of thrusting is provided by granulated quartz grains in the quartz-mica schist and in the overlying calcareous schist and limestone. For these reasons the graphitic quartz-mica schist is not regarded as part of the Lower Thrust Unit.

The Lower Thrust Unit

The Raudfjell group. – The tectonically lowermost group in the Lower Thrust Unit is the Raudfjell group, which consists predominantly of quartz–mica schists with calcareous mica schists and a few layers of calcite marble, 4 to 10 m thick. At the bottom there is a metalimestone which in part is richly contaminated by pelitic material. The total tectonic thickness of the Raudfjell group succession is somewhere between 500 and 800 m. (The tectonic thickness is taken as the thickness measured between the upper and lower boundaries of the succession disregarding the possibility of repetition of strata.)

No igneous rocks have been found within the sequence, but as only a small part of it has been investigated and the degree of exposure is poor, they may well be present locally.

The Bjøllådal group. – The Bjøllådal group has a very characteristic rock association, distinguishing it very clearly from the other groups. It consists mainly of a sequence of different types of calcareous mica schists rich in thin amphibolite layers and a few thin marble horizons (both dolomite and calcite marble) of limited extent. In addition to this there is a string of stratabound metaperidotite bodies varying in size from a few metres to about 750 metres in length. It has not been possible to establish an internal stratigraphy for the group, the tectonic thickness of which varies between 300 and 500 m.

The Middle Thrust Unit

The Tespfjell group and rocks of the tectonized zone beneath the Rödingsfjäll Nappe. – The Middle Thrust Unit consists of only one rock group here called the Tespfjell group, but rocks occurring in a strongly tectonized zone directly beneath the basal thrust of the Rödingsfjäll nappe are also thought to belong to this succession. The lithostratigraphy of this group can be well demonstrated in a traverse across Tespfjell.

Top	Marble
	Mica schist, metaquartzites, meta-arkoses
	Amphibolite
	Calcite marble
	Calcareous mica schist with amphibolite
Bottom	Dolomite marble

Two horizons of metamorphosed quartz–andesite occur as layers within the uppermost marble (the Hjartås marble). They have a maximum thickness of 4–5 m and can be traced for a distance of at least 1 km. At the southern end of Tespfjell a similar rock type is found within the marble sequence of the tectonized zone, such that it is likely that these two marbles are one and the same.

In addition to rocks similar to those of the Tespfjell group, the tectonized zone beneath the Rödingsfjäll Nappe also includes a hornblende schist and a pink, pure calcite marble with a thickness of about 1 m. A typical feature of these rocks is their more or less strongly developed cataclastic character.

The Upper Thrust Unit

The Gila complex. – The Upper Thrust Unit has been divided into four rock groups: the Gila complex, the Kjerringfjell group, the Ørtfjell group and the Dunderland group. The Gila complex, which consists predominantly of a gneissic granite with some layers of metasediment, forms the lowermost part of a rather large dome structure. The boundaries towards the superposed sequence of metasediments seem to be concordant wherever they have been observed, and no sign of tectonic movements has been found. As the eastern nappes are reported to wedge out westwards (Nicholson & Rutland 1969, Zachrisson 1969) this complex could represent the pre-Caledonian basement with a recrystallized slide contact towards the metasediments above and thus not belong to the Upper Thrust Unit. Another possible explanation is that the granite is an early intrusion pre-dating the Caledonian deformation or associated with the earliest Silurian deformation phase. Evidence supporting this view include discordant igneous contacts between mica schist and granite *within* the massif, xenoliths of varying sizes and lack of contact metamorphism in the surrounding metasediments.

The tectonic position at the core of a large antiformal structure appears to indicate that it is a basement granite remobilized during the Caledonian orogenesis.

The Kjerringfjell group. – This sequence, which occurs directly above the Rödingsfjäll Nappe thrust, is dominated by gneisses of different types and also includes a variety of igneous rocks. The principal lithologies are paragneisses, orthogneisses and diorites with minor occurrences of amphibolite, serpentinite (one small body recorded so far) and quartzite. In the south the group covers a considerable area around the Kjerringfjell massif, while to the north the group can be traced as a thin zone of heterogeneous gneissic rocks which are markedly different from the adjoining mica schists. Orthogneisses present at the base of the Kjerringfjell group may represent a slice of Precambrian basement.

No continuous thrust plane beneath the group can be demonstrated, but cataclastic rocks ranging from protomylonites to ultramylonites and blastomylonites can frequently be found along the zone where the thrusting is believed to have taken place. The northernmost outcrop of true cataclastic rocks within this zone is approximately 1 km north of Storbekken (O–12, Plate 1) and exposes an ultramylonite of a few metres thickness. Further north it is very difficult to establish the precise boundary between the Kjerringfjell group and the underlying Tespfjell group because of minor differences in lithology and equal grade of metamorphism. The thrust plane is here tentatively placed beneath a quartzite which usually shows strong cataclasis.

The Ørtfjell group. – The Ørtfjell group has its main outcrop extent in the western and south-western parts of the region. On the map it is divided into a western and an eastern zone by a strip of Dunderland group lithologies. To the west it is tectonostratigraphically underlain by the Steinfjell group and to the east by the Kjerringfjell group. Wherever the boundaries between either of these groups are exposed they are concordant and show no traces of thrusting.

The internal lithostratigraphy of the western and eastern parts of the group is shown in Table 2. The main lithologies are mica schists (or locally, mica gneisses) of different types and with a composition which indicates a similarity to metamorphosed greywacke or subgreywacke. In addition, the sequence also includes quartzites, marbles, amphibolites and acid igneous rocks. The marble formation is quite heterogeneous while the lowermost mica schist formations show the same characteristic features over large areas. Small discordant pegmatites are fairly abundant in the Ørtfjell area. At Kvitvasselv (Plate 1, K, L, M –13) the total tectonic thickness of the group is about 2 km.

The upper part of the Kjerringfjell group is possibly equivalent to the lowermost formations of the Ørtfjell group, the only difference being that the former is much more intruded by igneous rocks than the latter.

Table 2. Camparison of the lithostratigraphical sequence of the eastern and western parts of the Ørtfjell group

West	East
Quartzite and garnet–mica schist	Quartzite and garnet–mica schist
Marble	Marble
Garnet–mica schist with metarhyolites	
Calcareous garnet–mica schist	Garnet–mica schist
Garnet–mica schist	
The Steinfjell group	The Kjerringfjell group

The Dunderland group. – The structurally highest part of the Upper Thrust Unit, the Dunderland group, consists of a lower marble formation including both dolomite and calcite marbles, calcareous mica schists, garnet–mica schists and amphibolites, and an upper garnet–mica schist formation comprising quartzites and amphibolites. The lithologies of the upper formation are very similar to those of the Ørtfjell group, and Søvegjarto (1972) has in fact ascribed them to this group. Two different iron ore horizons are associated with the marble formation. These ores are mined by A/S Rana Gruber in Dunderlandsdalen south-west of the area investigated by the author. This is also the main outcrop area of this group. The rocks have been described in great detail by Bugge (1948) and Søvegjarto (1972).

Petrography

The petrographical descriptions which follow are relatively brief and generalised although the amphibolites and metaperidotites are given a more thorough treatment than the other rock-types. Detailed descriptions are given by Gjelle (1974). In order to avoid repetition only the principal lithological types are distinguished and reference made to variations from group to group where necessary.

MARBLES

Marbles are fairly abundant within the mapped area. They vary in tectonic thickness from less than 1 m up to the 250 m calculated for the dolomite of the Dunderland group south-west of Bjøllånes (Plate 1, K–20). A range in composition is found from pure marbles to metalimestones containing a variable amount of terrigeneous material, and to calcareous mica schists. The clastic material is mostly concentrated in thin layers alternating with the marble. Partial chemical analyses are presented in Table 3 (some modal analyses are given in Gjelle (1974)).

In dolomite marbles, dolomite comprises usually more than 90% of the rock. Calcite crystals are evenly distributed throughout and have a smaller grain-size than the dolomite crystals (0.05–0.1 mm for calcite compared with 0.2–0.3 mm for dolomite). This situation is reversed for the calcite marbles. Some marbles are finely banded or laminated with 1 mm to 1 cm thick calcite-rich bands alternating with dolomite-rich layers. The bands have sharp non-gradational boundaries. All observations point to a pre-metamorphic, pre-deformational origin for the dolomite, but whether it was formed by primary precipitation from seawater or as an early metasomatic product in unconsolidated sediments is impossible to decide.

In a discussion of the origin of dolomite marbles in the Kongsfjell area about 40–50 km south of Mo i Rana, Ramberg (1967) considered the alteration between calcite and dolomite layers to be due to small stratigraphical differences in the grade of dolomitization of primary calcite-rich layers, and that the minor differences thus formed were enhanced by later metamorphic processes.

Table 3. Partial chemical analyses of the marbles

Specimen		Weight percentage CaO	Weight percentage MgO	Amount of insoluble*) components (Weight percentage	Calcite–dolomite ratio based on the chemical anlysis	Calcite–dolomite ratio based on the mode (Gjelle 1974)
Tespfjell group	d 11	31.1	20.8	0.1	4.1 : 95.9	–
	d 12	30.8	20.0	2.3	5.5 : 94.5	–
	k 13	49.3	2.3	5.1	88.7 : 11.3	–
	k 17	39.2	8.7	9.8	54.9 : 45.1	82.7 : 17.3
	k 16	52.1	0.7	3.9	96.6 : 3.4	99.5 : 0.5
	k 14	49.0	2.4	5.4	88.1 : 11.9	87.4 : 12.6
Ørtfjell group	k 1	53.3	1.0	1.5	95.3 : 4.7	
	k 2	43.0	2.1	15.8	88.2 : 11.8	
	k 7	52.3	0.9	4.7	95.7 : 4.3	
	k 8	32.3	4.4	26.6	69.9 : 30.1	77.2 : 22.8
	d 9	47.9	6.1	1.0	71.6 : 28.4	
Dunderland group	d 4	28.9	18.6	8.1	6.0 : 94.0	6.0 : 94.0
	k 5	50.3	2.3	4.0	88.9 : 11.1	
	k 6	51.3	1.0	3.5	95.1 : 4.9	92.0 : 8.0

*) Not soluble in HC1

Analyst E. Sletten, A/S Norsk Jernverk, Mo i Rana.

Specimen localities: *Tespfjell group:* d 11: Lowermost dol. horizon (Q–12). d 12: Upper dol. horizon (Q–12). k 13: Calcite marble above d 12 (Q–12). k 17: Hjartåsen railway station (O–20). k 16: Road-cut east of Messingåga ,Storvoll (N–20). k 14: Railway cut west of Messingåga (N–20). *Ørtfjell group:* k 1: Central marble horizon 2.5 km SSW of Svarttj. (D–27). k 2: Southern marble horizon 2.5 km WSW of Svarttj. (D–27). k 7, k 2, k 9: Railway cut at Storvoll, 1.25 km west of Messingåga (M–20). *Dunderland group:* d 4: Dolomite marble from the southeastern side of Ørtfjell, 2 km south of Bredek (K–19). k 5: Calcite marble beneath the dolomite marble 2 km south of Bredek (K–19). k 6: Railway cut 2–2.5 km west of Messingåga (L–21).

QUARTZITES

Quartzites, including feldspathic quartzites, are of minor importance in the area, but are useful as stratigraphic marker horizons. A combination of limited thickness and sparse exposure, however, has made them difficult to map.

The quartzites are fine-grained, weakly to distinctly foliated, and the colour varies from light pink to greenish blue and dark greyish blue. They are usually thin-bedded. Quartz, plagioclase, muscovite and sometimes biotite can be identified in hand specimens.

Among the accessory minerals are garnet, apatite, sphene, zircon, rutile, tourmaline (schorl), pyrite, ilmenite and hematite. The plagioclase ranges in composition from An_{20} to An_{30} (U-stage determinations). The texture of the quartzites is dominantly granoblastic, although some tectonically disturbed varieties show dimensionally oriented fabrics. The more mica-rich varieties show lepidogranoblastic textures. Strong granulation occurs especially in the quartzite near the thrust plane of the Rödingsfjäll Nappe. Sometimes feldspar porphyroclasts occur as augen in the quartzite.

Table 4. Modal analyses of the mica schists

Specimen	355	309	137	357	024	389	343	14E45	156	224	1A65	54	166	359
Quartz	33	37	39	44	30	53	54	60	39	36	33	24	41	48
Plagioclase	36	8	6	22	1	2	20	2	29	12	22	22	10	3
Microcline	–	–	–	–	–	–	–	–	1	–	–	–	–	–
Calc./dol.	13	2	–	–	–	–	1	–	1	–	16	–	–	1
Muscovite	tr	8	35	12	46	43	17	20	29	20	7	2	3	11
Biotite	24	42	10	16	2	tr	7	–	–	20	16	3	26	20
Chlorite	tr	tr	tr	1	11	1	–	–	–	tr	tr	22	tr	3
Amphibole	–	–	–	–	8	–	–	–	–	–	tr	2	–	6
Kyanite	–	–	–	–	–	–	–	–	–	–	2	–	–	tr
Garnet	1	–	8	3	tr	–	–	–	–	6	2	–	2	2
Epidote	3	–	–	–	tr	–	tr	1	–	1	–	17	17	2
Staurolite	–	–	–	–	–	–	–	–	–	3	–	–	–	–
Other acces.	tr	3	2	2	2	1	1	17	1	2	2	8	tr	4

tr = traces
– = not observed

Localities: *Bjøllådal group*: 355: Bjøllådalen (S–9). 309: 0.5 km E of railway (R–20). *Tespfjell group*: 137: Central Tespfjell (P–14). 357: Northern Tespfjell (R–8). 024: Road cut E of Messingåga (N–20). 389: 2 km S of Hjartåsen st. O–22). *Ørtfjell group:* 343: Northeastern ridge of Ørtfjell (I–21). 14E45: Strandjordelv 0.5 km SW of Svartjern (F–27). 156: At trig.point 568 N of Bredek (L–17). 224: Bredekfjell, 2 km S of Kvitvann (J–15). 1A65: Stormdalen (H–19). 54: E of Tespa/Stormdalselv (L–18). *Dunderland group*: 166: 0.5 km SSW of Stormdalshei (L–20). 359: Road cut at Messingslett bridge (J–23).

META-ARKOSES

Meta-arkoses occur interbedded with mica schists and quartzites, especially in the Tespfjell group, and are of minor importance in the area. They are usually well banded, foliated and of grey-white coloration. Modal feldspar contents vary from 23 to 56% with plagioclase (An_{25}–An_{28}) predominating over microcline (Gjelle 1974).

Accessory minerals include muscovite, garnet, hornblende, apatite, sphene, rutile, zircon and opaques. The meta-arkoses show fine-grained, lepidogranoblastic matrix textures with plagioclase porphyroblasts up to 3–4 mm across.

MICA SCHISTS

The mica schists constitute the most abundant rock-type in the area and occur in all groups. The Ørtfjell and Raudfjell groups consist almost exclusively of different types of mica schist. According to their mineralogy the most frequent types are garnet–mica schist, calcareous mica schist, calcareous garnet–mica schist, horneblende–mica schist and biotite–muscovite schist. Table 4 shows that the mineralogy varies within wide limits.

The accessory minerals include apatite, sphene, tourmaline (dravite and schorl), zircon, rutile and ore minerals (pyrite, in fact, is a major constituent of specimen 14E45). The textures of the schists are usually lepidoblastic, often with porphyroblasts of garnet or amphibole. Plagioclase composition varies from $An_{35\text{-}37}$ in the Bjøllådal group, to $An_{16\text{-}24}$ in the Tespfjell group and to $An_{17\text{-}47}$ in the Ørtfjell group (but one example from Spruttjønn in the Ørtfjell group was determined at An_5). In the Gila complex schists plagioclases fall in the range An_{18} to An_{26}. Schists of the Dunderland group show oligoclase compositions according to the refractive indices observations relative to quartz. Normal zoning in some plagioclases of the Ørtfjell group is encountered.

MICA GNEISSES

Gradual transitions occur between the mica schists and the mica gneisses. The gneisses are more massive and less homogeneous and display lithological banding. They occur mainly in the upper part of the Kjerringfjell group. Mineralogically they are similar to the schists. Plagioclases show a compositional range from An_{19} to An_{35}. Accessory minerals include apatite, tourmaline, sphene, rutile and pyrite.

Textures in the mica gneisses vary from porphyroblastic to lepidogranoblastic; the porphyroblasts are of feldspars, hornblende, garnet and sometimes muscovite.

ORTHOGNEISSES

The orthogneisses, which are poorly foliated and almost white, occur predominantly in the lower part of the Kjerringfjell group. The structurally lowermost gneisses have been affected by cataclasis during nappe emplacemen. The principal minerals are plagioclase, quartz and epidote/clinozoisite/zoisite which together constitute about 80–90% of the rock. The major part of the epidote family minerals originates from saussuritization of plagioclase. These gneisses also have about 10% of white mica, some of it formed by sericitization of plagioclase while some is primary muscovite.

Biotite, apatite, sphene, rutile and ore minerals are included among the accessories. Chlorite is a secondary mineral after biotite.

Textures of the orthogneisses vary from porphyroblastic to lepidogranoblastic with plagioclase forming the porphyroblasts. In one specimen these plagioclases from 2 km north of Storvoll were determined as having an An content of 28% while in another an outer rim of plagioclase gave An_5 with the core showing An_{18} (U-stage determinations). In this case the outer rim represented a late growth zone. Likewise, a composition of An_5 has been determined in a narrow zone around inclusions of clinozoisite crystals in plagioclase, a feature thought to be associated with saussuritization. Sericitization and saussuritization of plagioclases are commonly observed phenomena in the southern part of the Kjerringfjell group.

GNEISSIC GRANITES

Granites displaying a gneissic texture occur in two main areas: in the east in the basement complex and in the north-west in the Gila complex. Only a very small area of the granite belonging to the Lønsdal basal massif has been investigated. The granite here is greyish white with a faint pink coloration which gradually disappears towards the boundary against the overlying metasediments. K-feldspar phenocrysts about 1 cm across and a faint but distinct foliation give the rock an appearance similar to that of augen gneiss. This foliation seems to

Table 5. Modal analyses of the gneissic granites

	LØNSDAL BASAL MASSIF			GILA COMPLEX		
Specimen	149	313	314A	145	254	257
Quartz	30	37	39	32	38	44
Plagioclase	17	14	14	12	18	10
Microcline	46	44	37	40	28	32
Muscovite	3	1	3	6	14	13
Biotite	3	4	4	9	1	–
Accessories	1	–	3	1	1	1

Localities: 149: West–northwest of Saratuva (S–18). 313: Southwest of Saratuva 50 m from the boundary (S–19). 314A: 1 m from the boundary, southwest of Saratuva (S–19). 145: At the western boundary ca. 1.5 km north of Kvitvann (I–11). 254: At the eastern boundary at the northern end of Midtvann (N–5). 257: Near the eastern boundary ca. 0.5 km north of Midtvann (N–4).

gradually disappear towards the interior of the massif. Quartz, microcline and plagioclase are the main minerals constituting more than 90% of the rock. The usual texture is porphyritic. The plagioclase is an albite with 3–4% of the An component. The microcline phenocrysts show patch–perthites and are situated in an anhedral–granular groundmass of quartz, microcline and plagioclase. The grain-size of the matrix ranges from 0.1 mm up to 1 mm while the phenocrysts range up to 1 cm. Muscovite and green and dark brown, almost black, biotite are common minerals. The biotite often shows alteration to chlorite. Accessory minerals include sphene, apatite and magnetite.

The gneissic granite of the Gila complex is strongly foliated, almost white and carries occasional dark, irregular, mica-rich inclusions which resemble xenoliths. Microcline and plagioclase crystals about 2–3 mm across are evenly distributed in a fine-grained matrix sometimes with an anhedral–granular texture and sometimes with a lepidogranoblastic, gneissic texture. The plagioclase composition varies from An_{29} to An_{36} (4 U-stage measurements). This granite contains more muscovite than the former (ca. 10% versus 3%) and a few accessory minerals such as garnet, epidote, clinozoisite, orthite and zircon. Three growth zones are recorded in some of the epidote minerals and always the core is an orthite. The mineralogical composition of these granites is compared in Table 5.

METARHYOLITES

At two different levels in the Ørtfjell area (Ørtfjell group) a greyish white, poorly foliated, fine-grained rock is found concordantly interbanded with the mica schists. The principal minerals are microcline and quartz; subordinate amounts of plagioclase, biotite and muscovite are present, while accessory minerals include epidote, sometimes with an orthite core, clinozoisite, apatite, sphene and ore minerals. The average grain-size is about 0.1–0.3 mm and the texture is allotriomorphic–granular. U-stage determination of the plagioclase seems to indicate a volcanic origin as the $2V_x$ value is as low as 79° and the An content is about 26% (Burri et al. 1967). Based on the characteristics of the plagioclase and the field occurrence, the rock is considered to be of extrusive origin and probably representative of rhyolitic lava or tuff.

Table 6. Chemical composition of amphibolites from the Bjøllånes area and some other areas in Nordland

Sample no.	225	260	305	326	352	367	387	388	397
SiO_2	52.25	48.87	46.90	50.14	50.06	48.74	47.82	47.86	43.98
TiO_2	2.13	1.15	4.38	0.67	2.15	1.93	2.45	1.83	4.81
Al_2O_3	14.89	15.19	13.69	15.18	14.06	14.78	15.67	15.71	14.23
Fe_2O_3	5.00	5.37	7.70	2.23	2.79	1.72	2.44	1.84	4.75
FeO	8.40	5.01	7.96	9.04	10.49	9.87	9.02	8.16	10.85
MnO	0.20	0.28	0.23	0.19	0.23	0.18	0.22	0.16	0.26
MgO	5.64	7.99	5.77	8.28	6.37	8.82	8.64	8.41	6.47
CaO	8.27	13.48	8.42	11.59	10.01	11.05	10.05	10.74	10.41
Na_2O	2.67	0.74	3.15	1.46	2.01	1.05	2.35	2.72	1.61
K_2O	0.27	0.48	0.52	0.39	0.36	0.31	0.33	0.20	0.30
P_2O_5	0.19	0.16	0.71	0.07	0.23	0.29	0.35	0.28	0.67
CO_2	–	0.99	–	–	–	–	–	2.04	–
H_2O+	1.20	1.30	1.20	1.93	2.16	2.23	1.78	1.06	1.47
	101.14	101.01	100.63	101.17	100.92	100.97	101.12	101.01	99.81

Table 6. Contin.

	405	407	409	a	b	1a	2a
SiO_2	48.32	46.67	45.12	49.34	49.40	48.53	49.66
TiO_2	1.26	2.09	2.88	1.28	1.88	1.42	1.56
Al_2O_3	14.30	12.44	15.72	12.89	11.05	15.48	15.66
Fe_2O_3	2.18	4.80	4.32	2.74	4.72	0.75	2.36
FeO	10.51	8.89	8.91	8.78	8.89	10.64	7.27
MnO	0.20	0.27	0.28	0.13	0.24	0.25	0.17
MgO	8.15	9.17	8.40	9.90	8.11	6.68	7.53
CaO	9.41	8.45	8.25	9.93	11.50	10.84	10.57
Na_2O	2.08	2.36	2.96	2.43	2.55	2.79	2.77
K_2O	0.49	0.52	0.22	0.31	0.50	0.66	0.46
P_2O_5	0.09	0.20	0.41	0.11	–	0.21	0.15
CO_2	2.13	1.63	0.64	–	–	0.15	0.38
H_2O+	1.32	2.35	2.32	1.99	1.57	1.34	1.35
	100.44	99.84	101.43	98.83	100.42	99.74	99.89

Localities: *Bjøllådal group*: 305: Møllebekken (Q–20). 405: Railway cut south of Møllebekken (Q–21). 407: Ca. 1.5 km southeast of Hjartåsen (P–21). *Tespfjell group*: 397: Central eastern Tespfjell (Q–12). *Kjerringfjell group*: 326: 2.5 km northwest of Kjerringvann (N–26). 367: 1 km southwest of Storburtj. (O–24). *Gila complex*: 260: Near the northwestern boundary of the complex (M–20). *Ørtfjell group:* 225: Bredekfjell 1.5 km south of Kvitvann (I–15). 352: Messingen at the western boundary of the marble (M–23). 387: Ca. 1 km northwest of trig.point 1284 m, Ørtfjell (G–22). 388: Ca. 3 km northwest of Rundtind (E–21). *Dunderland group:* 409: North of Stormdalshei (L–20). a, b: Kongsfjell (Ramberg 1967). 1a, 2a: Ofoten (Gustavson 1969).

AMPHIBOLITES

Amphibolites are abundant in the Bjøllådal group and occur less frequently in the other groups. In the Raudfjell group, no amphibolites have so far been observed by the author. Their thickness usually varies from a few decimetres to less than 10 m, although an amphibolite in the Bjøllådal group about 2 km south-east of Hjartåsen railway station has a possible maximum thickness of about 40 m. Exposure is poor, however, so that we might in fact be dealing

Table 7. The origin of the amphibolites

Method	Igneous	Sedimentary	Unclassified
1) (Al+Fe+Ti)/3–K versus (Al+Fe+Ti)/3–Na (Moine & de la Roche, 1968)	326, 387, 388 352, 405, 407		225, 260, 305, 367, 397, 409
2) Al+Fe+Ti versus Ca+Mg (Moine & de la Roche, 1968)	225, 260, 305, 326, 352, 367, 387, 388, 405, 407		397, 409
3) Niggli parametres after Leake (1964)	All fit the Karroo trend		
4) MgO, FeO, CaO triangle after Walker et al. (1960)	225, 305, 352, 367, 387, 388, 397, 405, 407, 409	260	326
5) Discrimination formula after Shaw & Kudo (1965)	225, 305, 352, 367, 387, 388, 397, 405, 407, 409	260, 326	
6) Oxidation ratio $(2Fe_2O_3 \cdot 100)/(2Fe_2O_3 + FeO)$ after Chinner (1960) and Elliott & Cowan (1966)	intrusive: 326, 367, 387 388, 405, 352, extrusive: 225, 397, 407, 409 tuffaceous ? 305	260	

with several thin amphibolite layers. The same applies for an amphibolite in the Dunderland group west of Storvoll; here the maximum thickness is about 20 m. All the amphibolites observed in the area have concordant boundaries with the adjacent metasediments. The amphibolites are mostly foliated, usually with parallel-oriented amphibole crystals. The rocks are commonly massive and of dark greenish colour. The texture usually is nematoblastic, sometimes also porphyroblastic with hornblende crystals up to 2–3 mm long in a fine-grained matrix. Plagioclase compositions are from An_{17} to An_{26} in the Bjøllådal group amphibolites, and between An_{20} and An_{30} in the Kjerringfjell and Ørtfjell groups. Accessories are ore minerals such as pyrite, pyrrhotite, ilmenite and magnetite as well as apatite, rutile, sphene and, rarely, muscovite. In an attempt to determine the origin of the amphibolites an X-ray fluorescence analysis programme was carried out, giving the main element compositions of a selected number of specimens. Several other methods were also adopted for the same purpose; for descriptions and discussions of these methods the reader is referred to Walker et al. (1960), Leake (1964), Shaw & Kudo (1965), Elliott & Cowan (1966), Moine & de la Roche (1968) and Gjelle (1974).

The chemistry of selected amphibolites is presented in Table 6: modes, mesonorms and catanorms may be found in Gjelle (1974). In addition, the likely origins of the amphibolites — igneous or sedimentary — as suggested by the above mentioned methods are summarized in Table 7 from which it is evident that specimen no. 260 is clearly different from all the others. One of

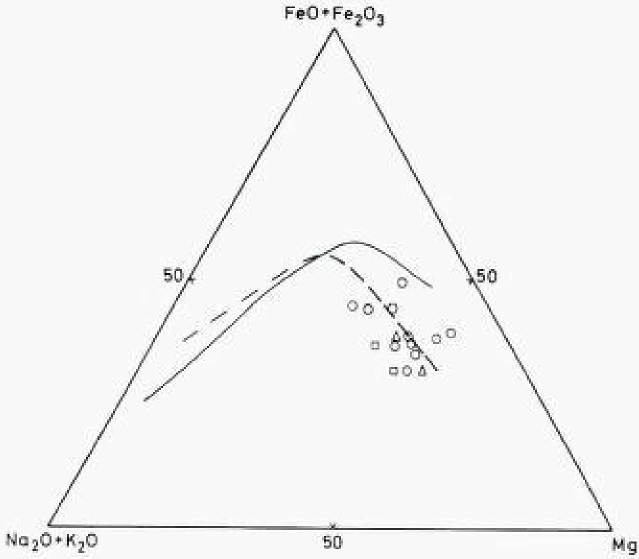

Fig. 3. The amphibolites plotted on an AFM diagram. Solid line after Kuno (1968), dashed line after Irvine & Baragar (1971). Dots - Bjøllånes area: squares - Ofoten area; triangles - Kongsfjell area.

Table 8. The suite index of Rittmann applied to the amphibolites

Specimen	Rittmann's index $S = \frac{(Na_2 + K_2O)^2}{SiO_2 - 43}$
225	1.0
305	3.5
326	0.5
352	1.0
367	0.5
387	1.5
388	2.0
397	3.5
405	1.0
407	2.5
409	5.0
Kongsfjell a	1.2
Kongsfjell b	1.5
Ofoten 1a	2.2
Ofoten 2a	1.6

the methods described by Moine & de la Roche (1968) indicates an igneous origin; the others point towards a sedimentary or in one case unclassified origin. Specimen no. 326 is identified as a metasediment by Shaw & Kudo's (1965) discrimination formula while the other methods, except that of Walker et al. (1960) indicate an igneous mode of formation. Compared with the other samples specimen no. 326 has an unusually low TiO_2 value, but at the same time the Fe oxidation ratio is very low. Considering all the available evidence an

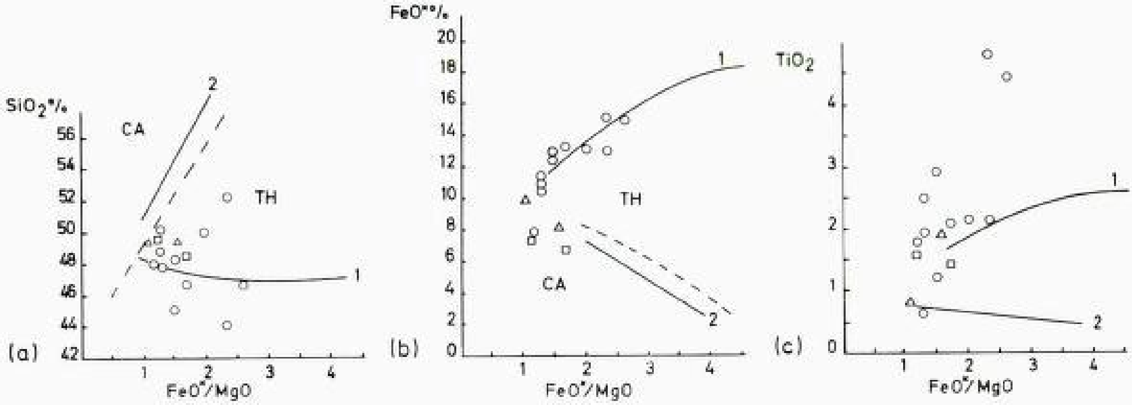

Fig. 4. Variation diagram after Miyashiro (1974) showing the tholeiitic character of the amphibolites. Solid lines showing typical tholeiitic (1) and calc–alkaline (2) trends. The dashed lines in (a) and (b) separate the fields of the tholeiitic (TH) and calc–alkaline (CA) series. $FeO^x = FeO + 0.9\ Fe_2O_3$. Symbols as in Fig. 3.

igneous origin is suggested for this sample. All the other analysed samples are considered to have had an igneous derivation.

An attempt to classify the igneous amphibolites based on the major elements has been carried out. The suite index of Rittman (1962) shows that the amphibolites have a calc–alkaline character (Table 8). On an AFM diagram (Fig. 3), following Kuno (1968) all of the amphibolites fall into the calc–alkaline field whereas Irvine & Baragar's (1971) subdivision is less definitive. Fig. 4 shows the ratio total FeO to MgO versus SiO_2, total FeO and TiO_2, respectively (Miyashiro 1974). All these diagrams show that the amphibolites have a tholeiitic nature.

A comparison with published major element data on basic igneous rocks from other areas in Nordland reveals that the amphibolites of the Ofoten area (Gustavson 1969) and the amphibolites of the Kongsfjell area (Ramberg 1967) have similar chemistries (Table 6 and Figs. 2 and 3). From this one can conclude that these rocks seem to have a tholeiitic affinity rather than a calc-alkaline, but as only main element chemistry is available it is difficult to reach a safe conclusion.

METAPERIDOTITES

Apart from one small body in the Kjerringfjell group all ultramafic rocks occur in the Bjøllådal group. They vary in size from small lenses of a few metres to the largest body measuring about 750 m × 250 m in outcrop.

A few kilometres north of the area described here a series of ultramafic bodies are found, all of them belonging to the Bjøllådal group. The rocks are situated in calcareous mica schists, but because of lack of exposure the actual contacts could not be studied in detail. One of the small lenses shows an exposed contact, however, and here an intense shearing and crushing of the rocks can be demonstrated. No contact aureole has been found in the surrounding mica schists. Most of the bodies consist predominantly of serpentine with relict crystals of olivine (forsterite, $2V_z = 85°–90°$) and/or orthopyroxene (nstatite/bronzite). Usually the serpentine constitutes more than 50% of the mode. The forsterite and the enstatite interdigitate with serpentine flakes. Talc and magnetite are common.

One of the biggest of the ultramafic bodies, namely that occurring west of Bjøllåga in Bjøllådalen (Plate 1, R–9/10), has a more complex mineral composition. Its interior part is composed almost exclusively of clinopyroxene, the optical data indicating this to be an augite. The structure of the pyroxenite is porphyroclastic. Augite crystals 1–3 mm across are surrounded by smaller grains (less than 0.3 mm across) of the same mineral, the latter having been formed by crushing and recrystallization of the former. Secondary growth of Mg–chlorite (Albee 1962) is limited. It is found along fractures in the rock and also in a rew randomly distributed aggregates where it seems to have replaced another mineral, probably orthopyroxene. Other secondary minerals in the fractures also include dolomite and magnesite.

Another rock-type in this body consists of augite, hornblende, epidote and a green spinel (pleonaste?). This is a fine-grained rock where most of the minerals are 0.1 mm or less across except the hornblende and epidote which measure up to 0.5 mm. Other minerals present are apatite, sphene, magnetite an chalcopyrite. Mg–chlorite and tremolite occur in fractures within this particular body. This rock would correspond to the hornblende–spinel–peridotite facies of O'Hara (in Wyllie 1967). In the western part of this ultramafic body a garnet amphibolite has been found, measuring 20–30 m × 6—8 m. It is a dark greenish rock with red-brown garnets and displays a porphyroblastic–nematoblastic texture with traces of cataclasis. The garnet is usually less than 1 cm across and xenoblastic. It has a refractive index of 1.755; lattice constant a = 11.62 Å and 11.67 Å (a double peak on the diffractometer), and a chemistry indicating: Alm. 34.3 – Andr. 21.2 – Gross. 18.5 – Pyr. 24.8 – Spess. 1.2 determined by electron microproble work.

The clinopyroxene of this amphibolite has optical data consistent with both diopside and omphacite. Electron microprobe determination gives a chemical composition where Ca, Mg and Fe^{II} are the dominant cations. Subordinate amounts of Al, Na and Ti are also present. It is always mantled by an amphibole with optical properties signifying hornblende and this in turn is partly converted to Mg–chlorite. Epidote is present as aggregates of fine-grained crystals associated with hornblende. Only small traces of talc are found. Accessory minerals are rutile, sphene, ilmenite, chalcopyrite and (?)chalcostibite. Dolomite or magnesite occurs in fractures. Originally this ultramafic body would appear to have consisted of garnet and clinopyroxene. Later it has been affected by cataclasis possibly simultaneously with its emplacement into the surrounding mica schist. Access of water caused the pyroxene partly to change to hornblende. Subsequently secondary chlorite was formed and this sometimes shows kink zones indicating a later phase of tectonic movements. The latest mineral growth is that of carbonate minerals in fractures. The marginal zone of the ultramafic bodies in most cases consists of serpentine with minor relics of olivine and–or pyroxene, and in a few cases it consists of Mg–chlorite and tremolite. The latter assemblage, however, is usually found in megascopic fracture zones through the rock.

In the observed parageneses, listed below, the minerals in parentheses are believed to be of a late metamorphic origin.

Clinopyroxene + garnet + (hornblende + epidote).
Clinopyroxene + spinel + (hornblende + epidote).
Forsterite + orthopyroxene + (serpentine).
Clinopyroxene + orthopyroxene (only as minor relics) + (Mg–chlorite).
Orthopyroxene + (serpentine + magnesite (?) + talc).
Forsterite + (serpentine + magnesite (?) + talc).
Forsterite + orthopyroxene + (magnesite (?) + talc + Mg–chlorite).
(Tremolite + Mg–chlorite).

A later publication will consider the problems posed by these exotic parageneses.

OTHER IGNEOUS ROCKS

Of minor importance are a few other rock-types of igneous origin. Modal analyses of most of these are given in Gjelle (1974). In the Bjøllådal group (Plate 1, P–21), a rock of andesitic composition occurs together with an amphibolite identified as a basaltic lava.

In the Tespfjell group within the upper marble at Tespfjell (Plate 1, O–14) two different levels of a quartz andesite of about 4–5 m thickness are found and at Hjartåsen railway station (Plate 1, O–20) two levels of 2–3 m thickness of another igneous rock-type, a meta-basalt, are found within the same marble.

In the tectonic zone beneath the Rödingsfjäll Nappe, an alkali granitic intrusive occurs as a lens-shaped body about 500 m in length. Within the Kjerringfjell group igneous rocks of granitic, quartz dioritic and dioritic composition are found in addition to the orthogneisses.

Metamorphism

The granite gneiss of the *Lønsdal basal massif* shows a mineral assemblage of quartz, albite, microcline, muscovite and biotite – a typical 'granite' paragenesis. A slight chloritization of the biotite indicates a lower greenschist facies metamorphism. The paragenesis of the autochthonous metasediment of residual character is:

quartz + albite + muscovite + biotite/chlorite

which indicates the Bl. 2 subfacies of Winkler (1967). Areas of low-grade metamorphism (i.e. greenschist facies) are depicted in Fig. 2.

The parageneses of the *Raudfjell group* include the:

quartz + calcite + oligoclase (An_{28}) + muscovite + biotite

assemblage of the calcareous mica schists and the:

quartz + oligoclase + garnet + muscovite + biotite

assemblage of the garnet–mica schists. A metamorphic grade corresponding to somewhere near the boundary between the upper greenschist facies (B 1.3) and the lower amphibolite facies (B 2.1) would satisfy these parageneses. One can thus conclude that there is a sharp metamorphic discontinuity between the autochthonous basal cover and the Raudfjell group, thus providing evidence for the existence of a late thrust zone at this level.

The calcareous mica schists of the *Bjøllådal group* show the assemblages listed below:

quartz + calcite + oligoclase + epidote + hornblende + muscovite
+ biotite
quartz + calcite + andesine (An_{35-37}) + epidote
+ garnet + muscovite + biotite

The amphibolites have:

quartz + oligoclase + epidote + hornblende ± garnet + biotite

as the typical paragenesis. According to Winkler (1967) these should correspond to the lower amphibolite facies, B 2.1 or B 2.2. A slight chloritization of garnet and biotite is attributed to a later retrogressive metamorphic phase observed almost everywhere in the mapped area. The relict paragenesis of one of the metaperidotites discussed earlier represents the P–T conditions to which the rocks have been exposed prior to the regional metamorphism of the area and prior to its emplacement into its present position.

Parageneses of the metasediments belonging to the *Tespfjell group* include:

quartz + oligoclase (An_{25}) ± clinozoisite ± garnet + muscovite
+ biotite
quartz + oligoclase + clinozoisite + muscovite + biotite
+ K-feldspar
quartz + oligoclase (An_{25}) + clinozoisite + hornblende ± garnet
+ muscovite + biotite
quartz + andesine (An_{36}) + clinozoisite + garnet + muscovite
+ biotite

These also correspond to the B 2.1 or the B 2.2 subfacies of the amphibolite facies of Winkler (1967). In addition, a late chloritization of the ferromagnesian minerals is recorded.

Typical mineral assemblages of the rocks belonging to the *tectonized zone* beneath the Rödingsfjäll nappe are listed below:

(1) quartz + zoned plagioclase (An_{16}–An_0) + epidote + hornblende
+ biotite
(2) quartz + plagioclase (An_{25}) + epidote + hornblende + garnet
+ muscovite + biotite
(3) quartz + plagioclase (An_{20}) + epidote + hornblende + garnet
(4) quartz + garnet + muscovite + biotite + chlorite
(5) quartz + plagioclase (albite ?) + muscovite + chlorite (mylonite)

The mylonite assemblage (5) has recrystallized in the lower greenschist facies, B 1.1. The other assemblages could all well belong to the lower amphibolite facies (B 2.1), although (4) would seem to have been a stable B 1.3 assemblage. The latter, from the area south of Hjartåsen, possibly provides evidence of a metamorphic gradient with increasing metamorphic grade northwards for the thrust zone rocks. Strand (1972) and Øines (pers. comm. 1973) have reported low-grade rocks at the corresponding tectonic level at Krokstrand about 4 km south-east of the Bjøllånes area, and in the northern part of the area only amphibolite facies rocks have been observed except where the mylonites are present. South of Bjøllånes no unambiguous traces of amphibolite facies rocks have been found at this level. The cause of his could be either the above-mentioned metamorphic gradient combined with the later B 1.1 subfacies (chloritization phase), or that the rocks in this area have been slowly exposedt to lower pressure and temperature conditions after the metamorphic peak of B 2.1/B 2.2 so that stable B 1.3 parageneses have been developed. Later, all parageneses have been exposed to lower greenschist facies giving the chloritization of Fe–Mg minerals.

The assemblages:

quartz + andesine ($An_{29\text{-}36}$) ± epidote ± garnet + muscovite
+biotite + microcline

of the granite gneiss and

quartz + oligoclase ($An_{17\text{-}26}$) + epidote ± garnet ± hornblende
+ muscovite + biotite

of the mica schists, both belonging to the *Gila complex*, correspond to the lower amphibolite facies.

A special mineral assemblage from one of the mica schist horizons in the Gila complex is composed of:

quartz + calcite + plagioclase (low R.I., albite?) + epidote
+ amphibole (probably actinolite) + muscovite + biotite

This could represent either a B 1.3 paragenesis or a relict albite–epidote– hornfels facies (Winkler 1967) connected with the granitic intrusion. The last possibility seems to be the most likely one. As no traces of a contact metamorphism have been found anywhere else around the granitic gneiss the conclusion must be that regional metamorphism was the later of the two.

The typical parageneses:

quartz + plagioclase (An_{19-38}) + epidote + garnet ± hornblende
+ muscovite + biotite
quartz + oligoclase (An_{25-28}) + epidote + muscovite + biotite
+ microcline
quartz + epidote + muscovite + kyanite (?)

of the *Kjerringfjell group* can all be attributed to the B 2.1 or the B 2.2 subfacies of the amphibolite facies.

The usual chloritization of Fe–Mg minerals is recorded and in addition strong saussuritization and sericitization of the feldspars has been observed in the gneisses in the southern area, especially in the lower part of the group. This phase is either post-deformational or contemporaneous with the thrusting.

Mineral assemblages typical for the metasediments of the *Ørtfjell group* are listed below:

(1) quartz + albite ± epidote + garnet + muscovite + biotite
(2) quartz ± calcite + plagioclase ± epidote + muscovite + biotite
(3) quartz + plagioclase ± epidote + garnet + muscovite + biotite
(4) quartz + plagioclase + epidote + garnet + staurolite + muscovite + biotite
(5) quartz + plagioclase ± epidote + garnet + kyanite + muscovite + biotite
(6) quartz + plagioclase + epidote + garnet + hornblende + biotite

The plagioclase is varying in composition from oligoclase to a Ca-rich andesine. All parageneses except (1) and (2) are in agreement with a metamorphic grade corresponding to the B 2.1 or the B 2.2 subfacies of the amphibolite facies (Winkler 1967). Paragenesis (5) from southwestern Ørtfjell just off the map indicates B 2.2. conditions. The parageneses (3), (4) and (6) belong to the B 2.1 subfacies. Parageneses (1) and (2) from the border zone towards the Dunderland group west of Dunderland railway station suggest B 1.3 subfacies conditions. These greenschist facies assemblages are confined to a narrow zone about 15 km long and less than 300 m wide (usually much less) along the boundary between the two groups, extending from the southwestern part of the area to west of Bjøllånes. This zone has not been investigated further north. Along the eastern side of the Dunderland group outcrop, at the top of the Ørtfjell group there is a similar zone of low metamorphic grade. This stretches from the southern boundary of the mapped area to east of Bredek. The thickness of the zone is less than 150 m in the south, diminishing northwards; its extension further north has not been investigated. The chloritization in this eastern zone is particularly prominent, giving the mica schists a distinctive green colour. Chlorite pseudomorphs after garnet are common. The reason for the occurrence of this low-grade zone is not clear. It might be that the boundary between the two groups is a tectonic one, representing a thrust plane at least earlier than the F_3 deformation phase. On the other hand, this phenomenon could also be due to minor movements between the groups accompanied by a

Fig. 5. Isoclinal F_1 fold in the marble at the Hjartåsen railway station (O–20).

new metamorphic episode of lower grade or retrogression of the main one. Small movements between the main rock units after the peak of metamorphism (for instance during the F_3 phase) could have provided an easier access for aqueous solutions along these boundaries than elsewhere, thereby producing a stabilized greenschist (B 1.3) subfacies paragenesis; subsequently the garnet and biotite were chloritized.

In the mica schists of the *Dunderland group* the following mineral assemblages have been found:

quartz + anthophyllite + garnet + muscovite + biotite
quartz + garnet + staurolite + muscovite
quartz + oligoclase + epidote + hornblende + muscovite + biotite
quartz + oligoclase + garnet + kyanite + muscovite + biotite

These parageneses belong to the B 2.1 subfacies of the amphibolite facies.

Tectonic structures

MINOR STRUCTURES

Only the main features of the structural geology of the Bjøllånes area are considered in this paper. For a more detailed discussion, see Gjelle (1974).

Based on fold interference relationships four phases of folding have been recognized. The oldest phase, F_1, gave rise to isoclinal, similar folds in quartzites and marbles, and rootless intrafolial folds (Turner & Weiss 1963) of thin quartzite layers in mica schists and gneisses (Fig. 5). Folds of F_1 age deform

Fig. 6. F_2 folds with axial-plane cleavage S_2 developed as a fracture cleavage. Ørtfjell group, Rundtind area (H–22).

the primary bedding, S_0. Where the deformation has been extremely intense the bedding has been transposed into a new foliation, S_1, coincident with the axial-planes of the F_1 folds. S_1, which is the principal schistosity in the rocks, generally appears to be parallel to the bedding, but at the hinges of the F_1 folds it is clearly intersecting S_0. Only few observations of F_1 axes have been made, these showing an east-west orientation. The peak om metamorphism was reached during this deformation phase.

The S_1 foliation is affected by at least two later phases of folding, designated F_2 and F_3. The F_2 generation has a roughly E–W axial trend, although the small-scale fold-axes and axial-planes show considerable variations in orientation. The folds are relatively tight, and only occasionally is an axial-plane cleavage, S_2, developed (Fig. 6).

Fig. 7 depicts the main structural elements at the Hjartåsen quarry. The S_1 poles define a girdle axis approximately coincident with the axis defined by the S_2 pole girdle. Both girdle axes are taken to represent the F_2 axial trend. The F_2 axes and L_2 lineations are orientated with a sharp maximum around the girdle axis (the F_2 axis). As the L_1 lineations are disposed at an extremely acute angle to the E–W F_2 axes this could be regarded as an indication that the original orientation of the F_1 axes was also approximately E–W. The structural relationships east of Hjartåsen (Fig. 8) also suggest an E–W to SW–NE orientation of the F_1 lineations. The S_1 pole girdle axis defines the F_2 plunge at 30° towards 255–260°.

The F_3 generation of folds is responsible for the main distribution of lith-

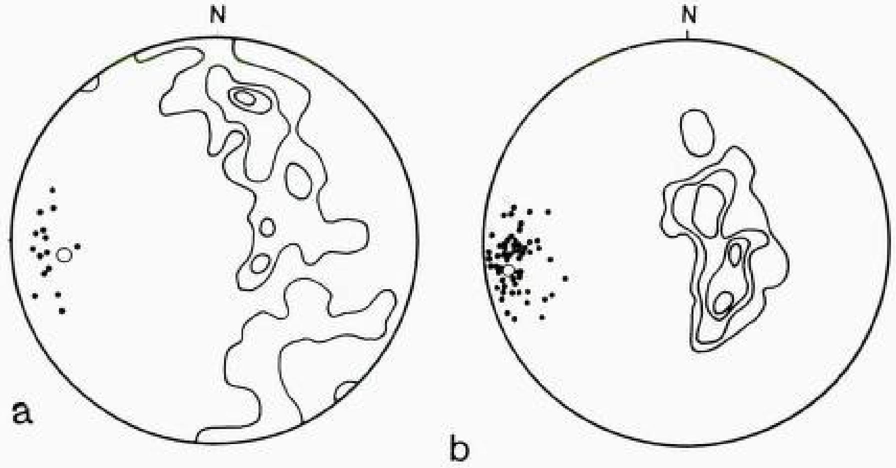

Fig. 7. Structural elements at the Hjartåsen quarry (O–20). Dots – lineations; circle – axis to pole-girdle.

a) L_1 lineations and S_1 poles (52 poles contoured).

b) L_2 fold axes/lineations and S_2 poles (23 poles contoured).

Contour intervals at 0, 5, 10 and 15%. All stereograms are equal-area lower hemisphere projections.

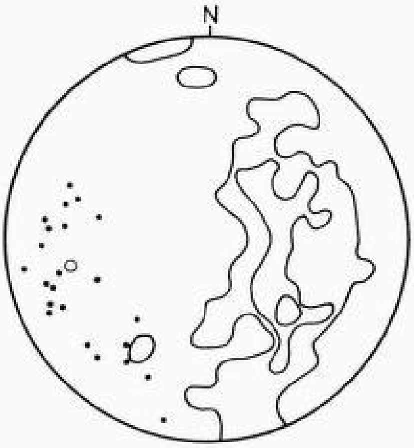

Fig. 8. Structural elements east of Hjartåsen (R–19). 22 L_1 lineations (dots); 63 S_1 poles contoured. Contour intervals at 0, 5 and 10%. Circle: girdle axis.

ologies on the map. This deformation produced large N–S trending folds with axial-planes dipping vertically or steeply towards the west.

Structural elements in the southern and northern parts of the dome structure in the Steinfjell area are shown in Fig. 9. The axes to the S_1 pole girdle parallel the F_3 axial trend; and the mesoscopic F_3 fold-axes and lineations recorded show pronounced maxima around these axes. One or two of these folds could possibly be of F_2 age since it is often difficult to differentiate between the mesoscopic F_2 and F_3 structures in the field.

In the Tespfjell area the F_2 and F_3 folds interfere with each other in such a way that only restricted areas of a few hundred square metres show structural homogeneity with respect to the S_1 foliation and to the F_2 or the F_3 linear structures. One such area due west of the trigonometrical point 1099 m on Tespfjell is illustrated by the stereogram of Fig. 10. Here the S_1 poles define a girdle axis, F_2. Two intersecting lineations are plotted; one roughly N–S orientated,

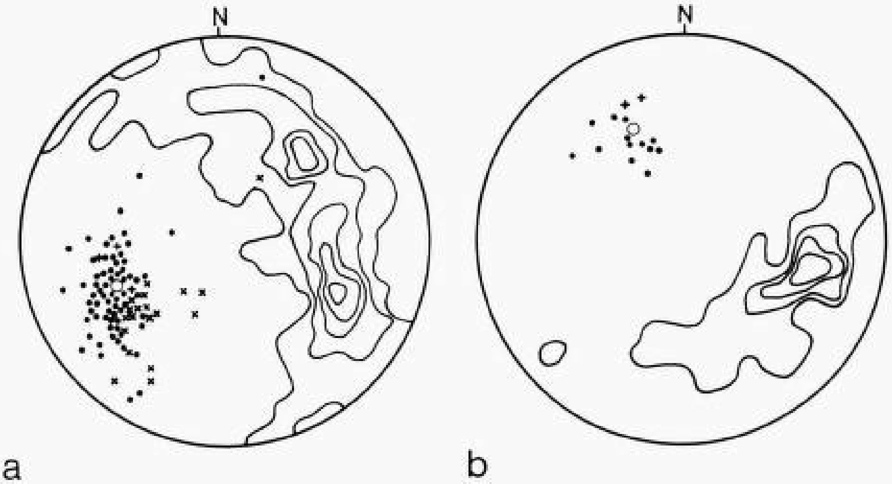

Fig. 9. Structural data from the southern (a) and northern (b) Steinfjell area. Dots – L_3 lineations; crosses – F_3 axes; circle – girdle axis.

a) 22 F_3 axes; 66 L_3 lineations; 184 S_1 poles contoured. Contour intervals: 0, 2.5, 5, 7.5, and 10%.

b) 2 F_3 axes; 13 L_3 lineations; 40 S_1 poles contoured. Contour intervals: 0, 5, 10, and 15%.

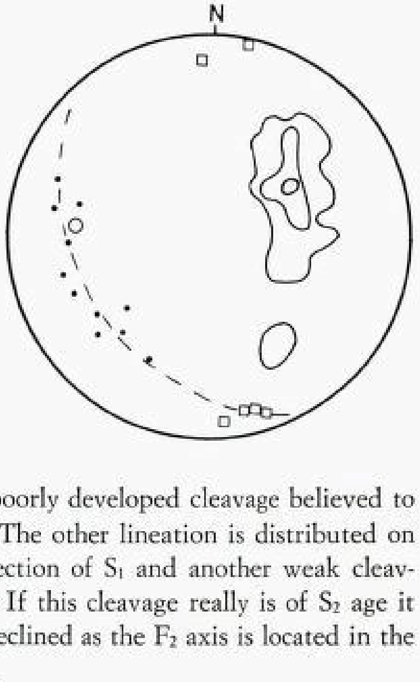

Fig. 10. Structural elements from a small area on central Tespfjell (P–9). 6 L_3 lineations (squares); 12 L_2 lineations (dots); and 16 S_1 poles contoured. Contour intervals at 0, 12.5 and 25%. Circle – girdle axis.

stems from the intersection of S_1 with a poorly developed cleavage believed to be of F_3 age, and is thus an L_3 lineation. The other lineation is distributed on a great circle and results from the intersection of S_1 and another weak cleavage defined by parallel-orientated biotite. If this cleavage really is of S_2 age it would imply that the F_2 folds are almost reclined as the F_2 axis is located in the foliation-plane with a pitch of about 60°.

Structural relationships in the southern Tespfjell area are illustrated by Fig. 11. The F_3 phase is dominant in this area, but the rather broad S_1 pole belt is mainly due to the interference from the F_2 phase. The strong concentration of poles in the eastern half of the stereogram is a result of the vergence of the F_3 folds towards the east. The attitude of the axial-planes varies from approximately vertical to dipping steeply towards the west. A small flexure in the axial-plane of the major F_3 structure causes the F_3 axial trend to swing from SSW–NNE to N–S and then to SSE–NNW when going from north to south. Within small areas of up to a hundred square metres one can find F_2 axes which are distributed on great circles. An example is shown in Fig. 11b from a locality

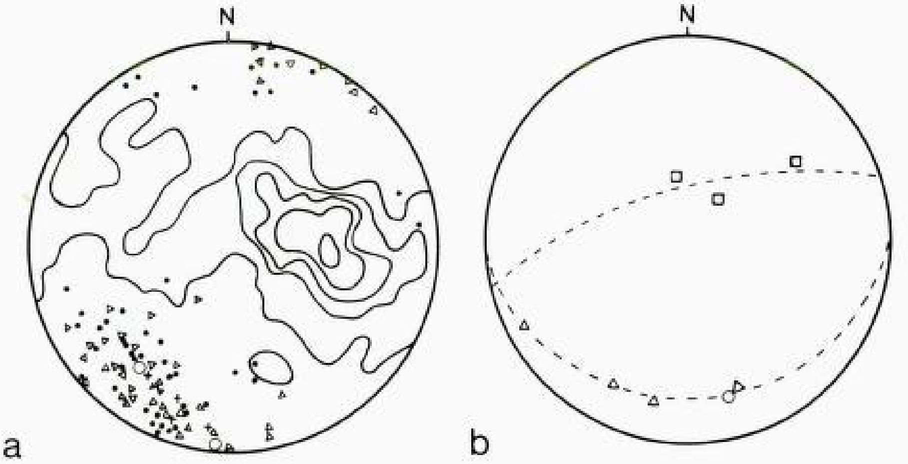

Fig. 11. Structural data from the southern Tespfjell area.

a) 4 F_3 axes (crosses); 44 F_2 axes (triangles); 48 L_3/L_2 lineations (dots); 142 S_1 poles contoured. Contour intervals at 0, 2.5, 5, 7.5, and 10%. Circle – girdle axis.

b) 4 F_2 axes (triangles); 3 S_2 axial-planes (squares).

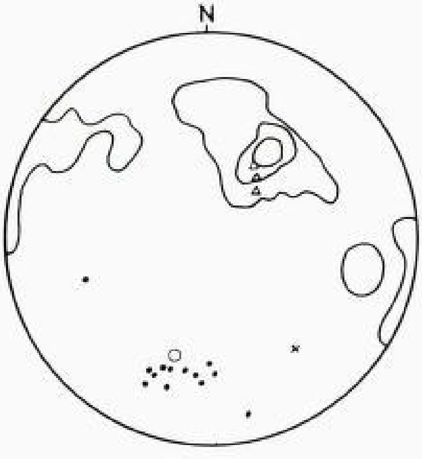

Fig. 12. Structural elements at the front of the Rödingsfjäll Nappe south of Hjartåsen (P–23). 12 F_4 axes and lineations (dots); 1 F_3 axis (cross); 3 S_3 poles (triangles); 21 S_1 poles contoured. Contour intervals at 0, 10, and 20%. Circle – girdle axis.

on southern Tespfjell about 1.5 km north of Bjøllånes. Four axes of F_2 folds are distributed along a great circle, and their axial-planes have attitudes which indicate that the orientation of the folds results from their deformation by the SSW–NNE orientated F_3 folds. Most of the fold axes and lineations measured in this area are older than F_3. Only four mesoscopic folds have been identified as being of certain F_3 age in the entire southern Tespfjell area.

A younger phase of deformation is recorded in the south-eastern area where F_4 structures fold of the F_3 axial-planes in wide open folds. The axial trend of the F_4 folds is approximately perpendicular to the thrust front of the Rödingsfjäll Nappe. Fig. 12 shows the structural elements in a small area at the thrust front of the Rödingsfjäll Nappe south-southeast of Hjartåsen. The S_1 poles define a girdle axis plunging at 40° towards 200° which represents the latest deformation phase, F_4.

The thrust zone in Bjøllådalen between the Tespfjell and Bjøllådal groups exposes rocks which show phyllonitic and mylonite textures (Higgins 1971) in thin-section. In addition to this there is a pronounced break of slope along the zone on the western side of the Bjøllådal valley. Another thrust zone is located southeast of Kjerringvann within the Kjerringfjell group. Its regional extent is not clear; quite likely it represents only a local thrusting, with imbrication, within the group. Paragneisses are displaced towards the northeast relative to the underlying orthogneisses and mylonite occurs along the thrust plane.

All these thrust zones are considered to be of F_3 age. The postulated thrust beneath the Raudfjell group around the Lønsdal basal massif must be older than the regional metamorphism in view of the metamorphic discontinuity beneath it. This boundary is also affected by F_2 structures north of the mapped area, so that this thrusting must have occurred either during or immediately following the F_1 deformation phase.

It is tempting to correlate the deformation phases F_1, F_2 and F_3 with those described by Rutland & Nicholson (1965) from the coastal district between Mo i Rana and Bodø. The orientation of the fold axes seems to be roughly the same and the F_1 phase produced minor isoclinal folds with a penetrative axial-plane schistosity in both areas. Major isoclines are not found in the Bjøllånes area. The only possible F_1 nappe structure here is the one immediately above the Lønsdal basal massif. The possibility that the Rödingsfjäll Nappe boundary in the north has been affected by the F_2 phase while in the south it seems to be connected with the F_3 movements may be an indication that deformation has been more or less continuous from one phase to another, as described by Rutland & Nicholson. Another possibility is that the Rödingsfjäll Nappe is originally a conjunctive F_1 nappe reactivated during the F_3 phase in the southern part of the investigated area, where it is now disjunctive.

The fold phases described by Ramberg (1967) from the Kongsfjell district include an F_1 episode with isoclinal similar folds with axes showing two principal trends, SSW–NNE and WNW–ESE, an F_2 phase with SSW–NNE trend and an F_3 phase recorded only at the front of the Helgeland Nappe (Ramberg, in a lecture at Det Nordiske Geologiske Vintermøte i Åbo, 1966). The axial-plane traces from the Kongsfjell area seem to indicate that the F_1 phase was axially oriented roughly E–W and the F_2 phase roughly aligned N–S. The F_1 phase could then possibly be identical in the two areas while the F_2 phase of Ramberg (1967) would correspond to the F_3 phase in the Bjøllånes area. The F_4 folds observed in the southern part of the investigated area and with an orientation roughly perpendicular to the nappe front would appear to be identical to similar structures observed further south by Ramberg (pers. comm. 1976). Folds of this phase always seem to be perpendicular to the nappe front regardless of the orientation of the front itself.

MAJOR FOLDS AND THRUSTS

The profile shown in Fig. 13 depicts an interpretational section through the study area. The Gila gneissic granite forms the core of a large, dome-shaped, elongated structure with an axial-plane striking at 020° and dipping west at about 60°. In the southern part of the area the axial-plane is vertical and strikes almost east-west (080°). The axis plunges about 25° west in the south-

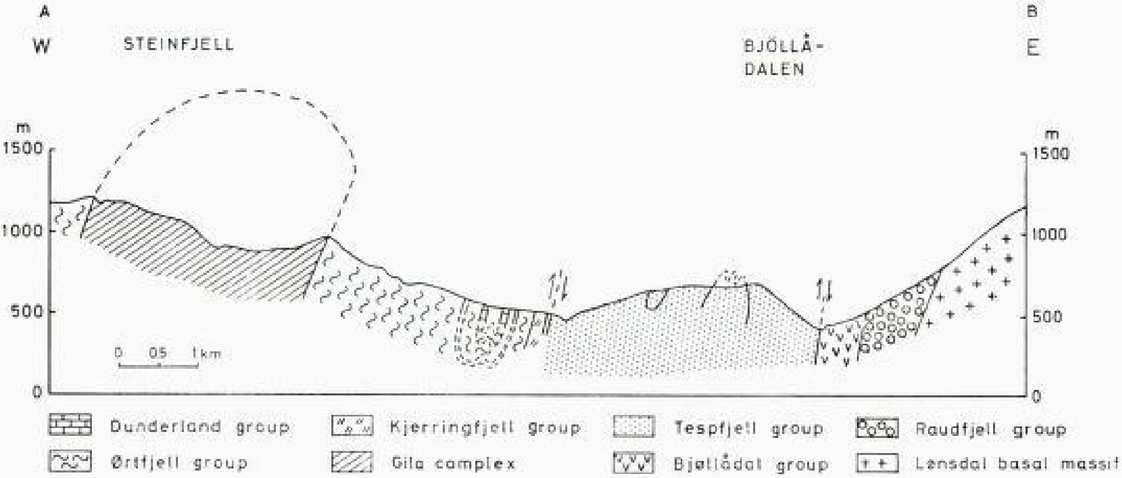

Fig. 13. Simplified profile along the line A–B on the map, Plate 1.

ern Ørtfjell area, increasing to 40° in the northern Ørtfjell–Bredek area. In the northern Steinfjell area the axial plunge is about 40° to the NNW.

East of the antiform is a synform directly involving rocks of the Ørtfjell and Dunderland groups, which follows the valley of the Tespa river. Exposure here is poor. The mica schists in the core of the synform have been interpreted as Ørtfjell group rocks by Søvegjarto (1972), but the present author distinguishes them as an upper mica schist formation in the Dunderland group. This latter interpretation seems to fit the profiles of Søvegjarto (1972) better than other interpretations (Gjelle 1974). A N–S profile across Dunderlandsdalen just southwest of the present area reveals the fold pattern and relationships shown in Fig. 14. The interpretation described above implies that the rocks between the Dunderland group and the Kjerringfjell group belong to the Ørtfjell group. The westernmost marble horizon could thus be the same as that running from the east side of Jarfjell (Plate 1, M–28) across Storvoll and continuing further north. The latter has been mapped by Søvegjarto as a continuous horizon all the way to the Langvatn area, north of Mo i Rana. An interesting feature is the low metamorphic grade (B 1.3 of Winkler (1967)) of the uppermost Ørtfjell group rocks compared with the adjacent rocks of the Dunderland group (B 2.1–B 2.2). This feature is recorded in the area from Bredek southwards and could possibly be regarded as evidence of movement between the two groups. Further north the metamorphic grade of the rocks along this boundary has not been investigated. Søvegjarto (1972) report local discordances of late F_1 or younger age between the two groups in the Storforsheia area. A few observations thus appear to indicate that the Dunderland group may constitute a separate tectonic unit and has been affected by a late F_1 thrusting, similar to the Beiarn Nappe of Rutland & Nicholson (1965). To the present author the discontinuity and the lower metamorphic grade are rather the result of minor local sliding and thrusting between the two groups during the different deformation phases.

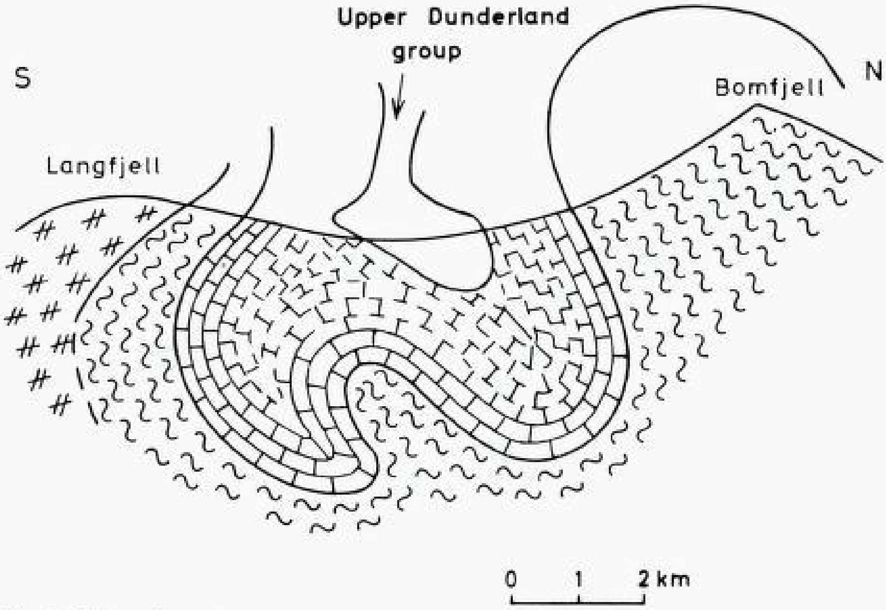

Fig. 14. The relationship between the different groups in Dunderlandsdalen as interpreted by the author, based on a profile constructed by Søvegjarto (1972); not drawn to scale.

The Rödingsfjäll Nappe ,which has quite a clear thrust front in the southern part of the area, becomes more and more vaguely defined northwards. It would seem as if the thrusting dies out and that there is a primary contact between the Kjerringfjell group and the underlying rocks. Such an interpretation, however, would imply an older age for the Tespfjell group relative to the Ørtfjell group. As the latter is supposed to rest on Caledonized basement, this group should be the older of the two. Thus the thrust zone is thought to exist beneath the Kjerringfjell group also in the north.

At Storbekken (Plate 1, O–13) there are exposures of ultramylonite of up to 10 m thickness over a distance of at least 500 m. Around the Tespfjell 1099 m trig.point (Plate 1, Q–9 there is a zone of 'augen gneiss' development. Augen of both microcline and plagioclase can be seen in the mica schist/gneiss of the formation immediately beneath where the thrust zone is supposed to occur.. On a microscopic scale evidence of thrusting is indicated by a greater degree of cataclasis along this zone than anywhere else in the area.

The Tespfjell group located beneath the thrust front of the Rödingsfjäll Nappe shows great lithological similarities to the Dunderland group, a fact which might suggest that the two groups are identical. They are tectonically separated from each other by the Rödingsfjäll thrust and by the intervening Ørtfjell group rocks belonging to the eastern limb of the Tespa syncline. The Tespfjell group rocks are squeezed together into a series of tight F_3 folds with vergence towards the east and with N–S trending axial-plane traces.

Another thrust zone separates the Tespfjell group from the Bjøllådal group.

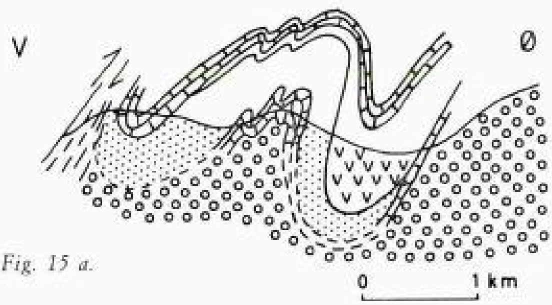

Fig. 15 a.

Fig. 15. Two alternative interpretations of the position of the Bjøllådal group. Generalized sections across Tespfjell–Bjøllådal about 6 km north of Bjøllånes. Symbols as in Fig. 2.

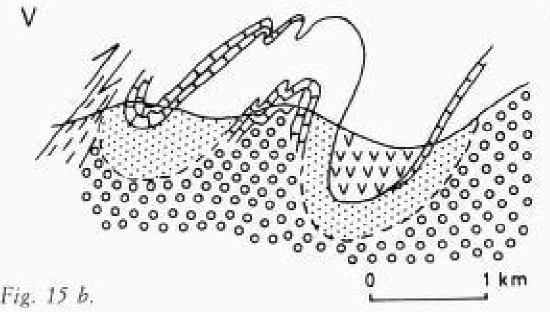

Fig. 15 b.

Because of heavy overburden in the critical area at Hjartåsen it is not quite clear as to which of the deformation phases it should be linked. It could well be due to a local splitting of the Rödingsfjäll thrust zone. The great similarities of the Tespfjell and Dunderland groups are in accordance with this view, as are the almost identical trends of the zones. Almost everywhere along the boundary between the two groups in the Bjøllådalen valley the formation is steep to vertical. This could be due to the compression which gave rise to the almost upright F_3 folds at Tespfjell and need not imply the presence of a root zone to the Bjøllådal group. From a lithological point of view the Bjøllådal group probably does not constitute a complementary synform to the easternmost antiform of Tespfjell (Fig. 15a). This would imply that the Bjøllådal group wedges out rapidly westwards and that the Tespfjell group likewise wedges out in the opposite direction. The lithologies of the two units seem to be too different to be explained as primary lateral facies variation. Besides, the Tespfjell group has a clearly recognizable internal stratigraphy while it seems impossible to establish a stratigraphy in the Bjøllådal group. This interpretation (Fig. 15a) would also imply that the Bjøllådal group is the younger of the two and with the Hjartås marble as the uppermost unit within this group instead of within the Tespfjell group.

Another interpretation is sketched in Fig. 15b, but also here the great lateral facies variations over relatively short distances make the interpretation appear very unlikely. Besides, the relationship between the Bjøllådal group and the Hjartås marble at Hjartåsen shows that the marble is lying above the Bjøllådal group. Because of the overburden it is possible that the map of this small area is incorrectly interpreted. An alternative interpretation is shown in Fig. 16;

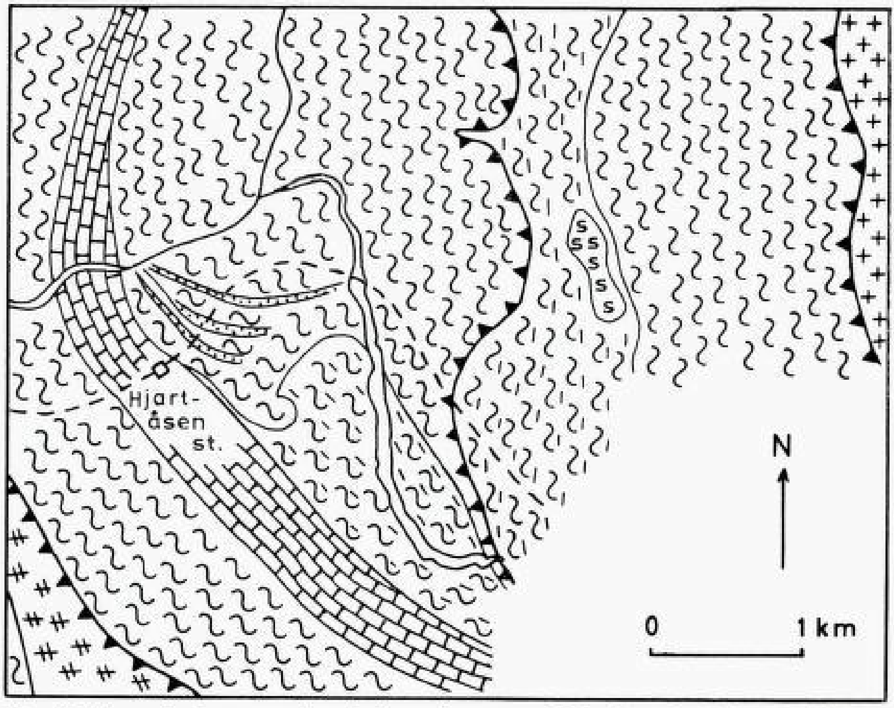

Fig. 16. Alternative interpretation of the geology around Hjartåsen. Symbols as in Plate 1.

this necessitates the acceptance of great variations in facies over short distances. In both interpretations we would have a teconically unbroken sequence of rocks between the Lønsdal basement window and the Rödingsfjäll thrust zone consisting of the Raudfjell, Tespfjell and Bjøllådal groups.

Another difficulty with these interpretations is the relatively abundant occurrence of basic igneous rocks in the Bjøllådal group while in the Raudfjell group none has been recorded so far within the mapped area.

It should be pointed out, however, that only a small area of the Raudfjell group has been investigated and, further, that the area is not too well exposed. Steenken (1957) in the Saltdal area north of the basement window and Marklund (1952) south of the window both describe igneous rocks in units which are probably correlatable with the Raudfjell group.

Regional correlations and considerations

SALTDAL–SULITJELMA

Table 9 shows an attempted tectonostratigraphic correlation with sequences in the Saltdal–Sulitjelma region north of the Lønsdal basal massif and the Västerbotten–Southern Norrbotten region in the south. Some comments are needed in connection with these proposed correlations. The Raudfjell group has a graphitic quartz–mica schist of less than 10 m thickness at the bottom which must be equivalent to Steenken's (1957) graphite schist formation. Both are

Table 9. Proposed tectonostratigraphic correlation with the Västerbotten–southern Norrbotten region and the Saltdal–Sulitjelma region

SARVAS (Marklund 1952)			AIVO-SARVAS (Kulling 1972)	BJØLLÅNES (Gjelle 1974)		SALTDAL (Steenken 1957)	SALTDAL (SULITJELMA (Nicholson 1973)
				Mica schists Quartzites and marbles	Ørtfjell group	Plagioclase - poor mica schists of the calciferous mica schist formation	Conglomerate Quartzite Marble Mica schist
			(The Rödingsfjäll nappe)	Orthogneisses and para-gneisses	Kjerring-fjell group	Biotite-rich microcline gneisses of the calciferous mica schist formation	Biotite-microcline gneis
		Vojtja conglomerate	The Storfjäll nappe Quartzites (Viris) Calciferous sediments (Løvfjäll) Slätdal limestone Vojtja quartzite congl.	Marbles Mica schists Quartzites	Tespfjell group	Part of the north-western part of the calcifereous mica schist formation	Fauske Marble
GILLIKS SERIES	Vuorgin Form.	Phyllite Conglomerate Limestone Calcareous arkoses	Tjanga limestone	Marbles Calcareous mica schists Amphibolites	Bjøllådal group	Amphibolite - staurolite gneiss formation	Group
	Gillika	volcanics	Gilliks Group				?
SARVA SERIES	Lospas Form.	Limestone Phyllite Quartzite	(Greywackes, schists, quartzites, conglomerates)	Marble		Calciferous mica schist formation (eastern part)	Sulitjelma schist sequence (Gasak) Furulund Group
	Tjakkik Form.	Phyllites Quartzites	Greenstones Quartzites	Various mica schists with thin quartzite layers	Raudfjell group		Sjönstå Group
MISKET SERIES	Jullega Form.	Limestone Schists	Pieske Group	Marble calciferous mica schist		(Marble at the bottom)	Pieske Marble
	Tjäula Form.	Tuff Limestone Greenstone Phyllite Quartzite	Metamorphic sediments and volcanics	Graphite schist with quartzite Basement		Graphite schist Granite-gneiss formation	Psammite graphite schist Granitic gneiss
	Klippo Form.	Schists greywackes Limestone (Pieske) Garnet mica schist	Limestone				
	Skertas Form.	Graphite schist Quartzite Basement	Autochthonous sediments Basement				

situated directly on basement rocks of the Lønsdal massif. Steenken also describes 'thinly layered, usually white quartzites' between the graphite schists and the calciferous mica schist formation which has a limestone horizon at the bottom. This is the same sequence as occurs east of Bjøllånes, but because of the small thickness of each rock-type the individual horizons have all been included in the Raudfjell group. In Table 9, however, the graphite schists have been separated from the group.

The 'calciferous mica schist formation' of Steenken covers a wide area and is subdivided by a downfolded unit, called the 'amphibolite–staurolite gneiss formation', with an intervening thrust-plane. The latter formation divides the former into a southern and southeastern part and a northwestern part. The southern/southeastern part must correspond to the main part of the Raudfjell group (excluding only the graphitic quartz-mica schist at the bottom) while the northwestern part of the formation in the present author's view corresponds to a higher tectonic level and is probably an entirely different rock unit.

The correlation of the Bjøllådal group with the amphibolite–staurolite gneiss formation seems to be on relatively safe ground. The most conspicuous common features of the two units are the occurrence of metaperidotites and the abundance of amphibolites.

Comparing the maps of Steenken (1957) and Nicholson (1973), both from the same area, makes it clear that Nicholson too regards the northwestern part of the calciferous mica schist formation as a separate unit different from the south-eastern part. In fact, he includes part of the formation bordering the north-western side of the amphibolite–staurolite gneiss formation with the latter, attributing these rocks to the Fauske Marble Group of Nicholson & Rutland (1969). Tectonically overlying the Fauske Marble Group is a biotite microcline gneiss which is equivalent to rocks belonging to the calciferous mica schist formation of Steenken. A marble horizon constituting the top of the Fauske Marble Group and situated within the calciferous mica schist formation would possibly be equivalent to the Hjartås marble of the Tespfjell group, and the biotite–microcline gneiss could then correspond to the Kjerringfjell group. More detailed mapping is necessary, however, before complete reliance can be placed on these correlations.

Nicholson's (1973) map shows that the rocks of the Sulitjelma region are overlain by the Fauske Marble Group and also by the amphibolite–staurolite gneiss formation of Steenken. It can be concluded from this that the Sulitjelma rocks including the Gasak Nappe of Kautsky (1953) must belong to a tectonostratigraphic level lower than the Rödingsfjäll Nappe, in fact lower than the Bjøllådal group. The Sulitjelma rocks as far down as the Furulund schist (Sjøgren 1900) have thus been more or less wedged out on the west side of the Lønsdal basal massif and correspond to a level beneath the Bjøllådal group (i.e. within or above the Raudfjell group). The phenomenon of rock units thinning and wedging out towards the west has been described by Nicholson & Rutland (1969) and Zachrisson (1969) from adjoining areas. From Nicholson's map the correlation of the Fauske Marble Group with the Bjøllådal and Tespfjell groups would seem to be quite reasonable, but some comments are necessary in this connection.

Because of the thrusting between the Bjøllådal and Tespfjell groups and the dissimilarity of their rock successions, it is difficult to accept that they could belong to one unit (i.e. equivalent to the Fauske Marble Group). Correlation of the Tespfjell group with the Fauske Marble Group lends support to the assumption that the former is equivalent to the Dunderland group, as the Fauske Marble contains iron ore of the Dunderland type (the Neverhaugen deposits, Vogt 1910). In addition, the Dunderland group and the Fauske Marble Group are dominated by carbonate rocks. It is, however, not impossible that the latter is directly continuous with the Dunderland group. If this really is the case, then it would also follow that the Rödingsfjäll Nappe has the same tectonostratigraphic position as the Gasak Nappe of Sulitjelma. However, providing the correlation of the amphibolite–staurolite gneiss formation with the Bjøllådal group is correct, then the Gasak Nappe must belong to a tectonic level lower than the Rödingsfjäll Nappe. Only further detailed mapping can clarify this problem.

VÄSTERBOTTEN – SOUTHERN NORRBOTTEN

Kulling (1972) has described three nappes in north-western Västerbotten, namely the Seve–Köli Nappe, the Storfjäll Nappe and the Rödingsfjäll Nappe, which cross the national border between the southernmost end of the Lønsdal basal massif and Lille Umevann about 40 km further south-west.

The Rödingsfjäll Nappe, the lower parts of which correspond to the Kjerringfjell group, is the uppermost nappe unit on the Swedish side of the border. Beneath it is the Storfjäll Nappe, the lower border of which according to Kulling (1972) is 'admittedly based on relatively little field evidence'. Kulling has drawn it between the Sarvas and the Gilliks Series of Marklund (1952) about 5 km south of the border between Norrbotten and Västerbotten, but the continuation towards the Norwegian border is not clear.

The basal thrust of the Seve–Köli Nappe must be found beneath the Raudfjell group. The stratigraphy described by Marklund (1952) from the Sarvas area south of the Lønsdal massif seems to be mostly missing in the Bjøllånes area (Table 9). The Skertas Formation of Marklund (1952), consisting of arkoses, quartzites and graphite schist is almost certainly equivalent to the rusty graphite schist and quartzite lying immediately above the basal granite.

The lowermost marble of the Raudfjell group is considered to be equivalent to the marble of the Jullega Formation of Marklund and to the marble of the Pieske Group of Kulling (Øines, pers. comm. 1974). If this interpretation is correct this would mean that the Klippo and Tjäula Formations are missing in the Bjøllånes area, having probably been cut out by the thrust plane above the Skertas Formation. As well as the notable metamorphic break mentioned earlier, the tectonic discordance reported by Marklund, Kulling and Steenken provides evidence of a thrust plane beneath the Raudfjell group.

The Tjakkik and Luspas Formations of the Sarvas Series (Marklund) should broadly correspond to lithologies of the Raudfjell group, while the Gilliks volcanics and the lower part of the Vuorgin Formation are possibly equivalent to the Bjøllådal group. No metaperidotites, however, are described from the Sarvas area. They are found on the Norwegian side of the border, but it is not yet clear to which tectonostratigraphic level they belong. If there is a tectonic break beneath the Bjøllådal group, as maintained by Steenken (1957), then the correlation of this group with the Gilliks Series becomes more uncertain.

According to Kulling (1972) the entire stratigraphy of Marklund (1952) belongs to the Seve–Köli complex; the same possibly holds for the Bjøllådal group while another possible counterpart of this group, the Mesket lava of Quensel (1922), belongs to the Storfjäll Nappe. The rocks north of Södra Storfjäll, which very much resemble the Bjøllådal group sequence, are ascribed to the Storfjäll Nappe by Kulling (1972) while Zachrisson (1969) regards them as belonging to the lower part of the Köli unit (the Tjopasi Group). In the upper part of the Seve and the lower part of the Köli, Zachrisson describes a strong concentration of ultrabasic rocks. It is tempting to correlate this zone with the Bjøllådal group sequence such that this group represents the top of the Seve complex and that the overlying Tespfjell group is an equivalent unit to the Storfjäll Nappe. On the other hand it is equally possible that the Tjopasi Group should be correlated with the Bjøllådal group, a correlation which does not interfere with recognition of the equivalence between the Storfjäll Nappe and the Tespfjell group.

To carry the correlations a bit further it is worth mentioning that Zachrisson (1969) correlates the lower part of the Tjopasi Group with the Rotik 'Series' and the Mesket 'Series' of Kulling (1933) which again are approximately equivalent to the Ro 'Series' and the Seima 'Series', respectively, of Kulling (1958). All this adds up to the rather uncertain conclusion that the Bjøllådal group is possibly of Lower or Middle Ordovician age.

THE COASTAL DISTRICTS OF NORDLAND: MO I RANA TO BODØ

The rock sequence above the basal massifs described by Hollingworth et al. (1960), Nicholson & Walton (1963), Rutland & Nicholson (1965) and Wells & Bradshaw (1970) from the Glomfjord area, the Meløy Group, is quite similar to that above the Lønsdal basal massif. It consists of psammitic to pelitic schists, hornblende schists, calcareous mica schists and marbles. From Holmsen's (1932) map it can be seen that ultramafic rocks also occur within the group. The sequence is described as parautochthonous (Hollingworth et al. 1960) and is quite similar to that of the Raudfjell and Bjøllådal groups. The Sokumfjell Marble Group belonging to the Beiarn Nappe (Rutland & Nicholson 1965) is a structurally higher unit than the next group in the Bjøllånes area, the Tespfjell group. As discussed earlier, the latter can probably be correlated with the Fauske Marble Group which again is correlated with the Saura and the Gildeskål Marbles (Rutland & Nicholson 1965), all of which are belonging to a middle tectonic unit beneath the Beiarn nappe.

The Hjartås Marble of the Tespfjell group is far more likely to be equivalent to the Fauske marbles than to the Pieske marbles, as suggested by Strand (1972) and Nicholson (1973). At least, the Pieske marble belongs to a lower tectonic level than the other two marble formations, but one cannot exclude the possibility of an identical age.

The Rödingsfjäll Nappe most probably belongs to a tectonic level between the Fauske Marble Group and the Beiarn Nappe, and the biotite–microcline gneiss of Nicholson (1973) is a likely unit for correlation with the Kjerringfjell group. Nicholson even suggests the possibility that this gneiss represents the lowermost unit in the east of the Beiarn Nappe. If this is so, then the Rödingsfjäll Nappe must be included in Nicholson's (1973) Fauske Marble Group somewhere between the rocks referred to as the amphibolite–staurolite gneiss formation of Steenken (1957) and the biotite–microcline gneiss of Nicholson (1973). The Beiarn Nappe might then correspond to the Helgeland Nappe, (Ramberg, in a lecture at Det Nordiske Geologiske Vintermøte i Åbo, 1966). As the description of these nappes seems to indicate that they are of different age, this correlation is not very likely. It is hoped that the mapping now in progress in the area between Rana and Salten west of the Lønsdal basal massif will eventually clarify these problems.

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Structural Succession in a Part of the outer Hardangerfjord Area, West Norway*

ARNE SOLLI, JOHAN NATERSTAD & ARILD ANDRESEN

Solli, A., Naterstad, J. & Andresen, A. 1978: Structural succession in a part of the outer Hardangerfjord area, West Norway. *Norges geol. Unders. 343*, 39–51.

Recent mapping has made possible a reinterpretation of the tectonostratigraphy of this area, situated at the eastern edge of the 'Faltungsgraben'. It is shown that certain rock units occurring over large areas, and formerly thought to be autochthonous, are made up of various allochthonous units. The possible relations of these to the succession of the Hardangervidda–Ryfylke area are discussed. Compared to the east, allochthonous crystalline gneisses seem to wedge out to the west. In this area, the highest thrust sheet, the volcanic-bearing Cambro-Silurian of the western facies appears as a new element, and its allochthonous character is discussed.

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Introduction

The area around the outer Hardangerfjord is a key region for many problems concerning the Caledonides of southwestern Norway. In this area, the relationship between the nappe system of Hardangervidda–Ryfylke (Naterstad et al. 1973) and the Central Trough — 'Faltungsgraben' of Goldschmidt (1912) — may be studied. The latter structure has been suggested by some as a possible root zone for the nappes (Smithson & Ramberg 1970; Smithson et al. 1974). Another point of interest is the transition from 'eastern' to 'western' facies Cambro–Silurian rocks (Strand 1972) which also occurs within the area. Recent field work has changed many of the previous ideas on the geology of this area, and it is intended here to present a summary of the new results.

The geology of the area has earlier been described by Reusch (1888, 1913), Rekstad (1907, 1908), Kolderup (1941), and more recently by Sørbye (1948, 1953, 1964). The geological map of Norway (Holtedahl & Dons 1960) presents the essence of published knowledge of the outer Hardangerfjord area up to now. On this map the following two main units are separated: (1) An autochthonous basement consisting of gneisses partly of certain Precambrian origin, partly of unknown origin but with structures of Caledonian age. The basement is covered by (2) a Cambro–Silurian supracrustal series, mainly pelites, but on the islands Halsnøy, Borgundøy and Fjelbergøy (Fig. 2) also metavolcanics. The contact between basement and cover has been variously interpreted as a tectonized depositional contact or as of a metamorphic gradational type (Kolderup 1941). No major thrust units have been depicted.

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* International Geological Correlation Programme
Norwegian Contribution No. 13 to Project Caledonide Orogen

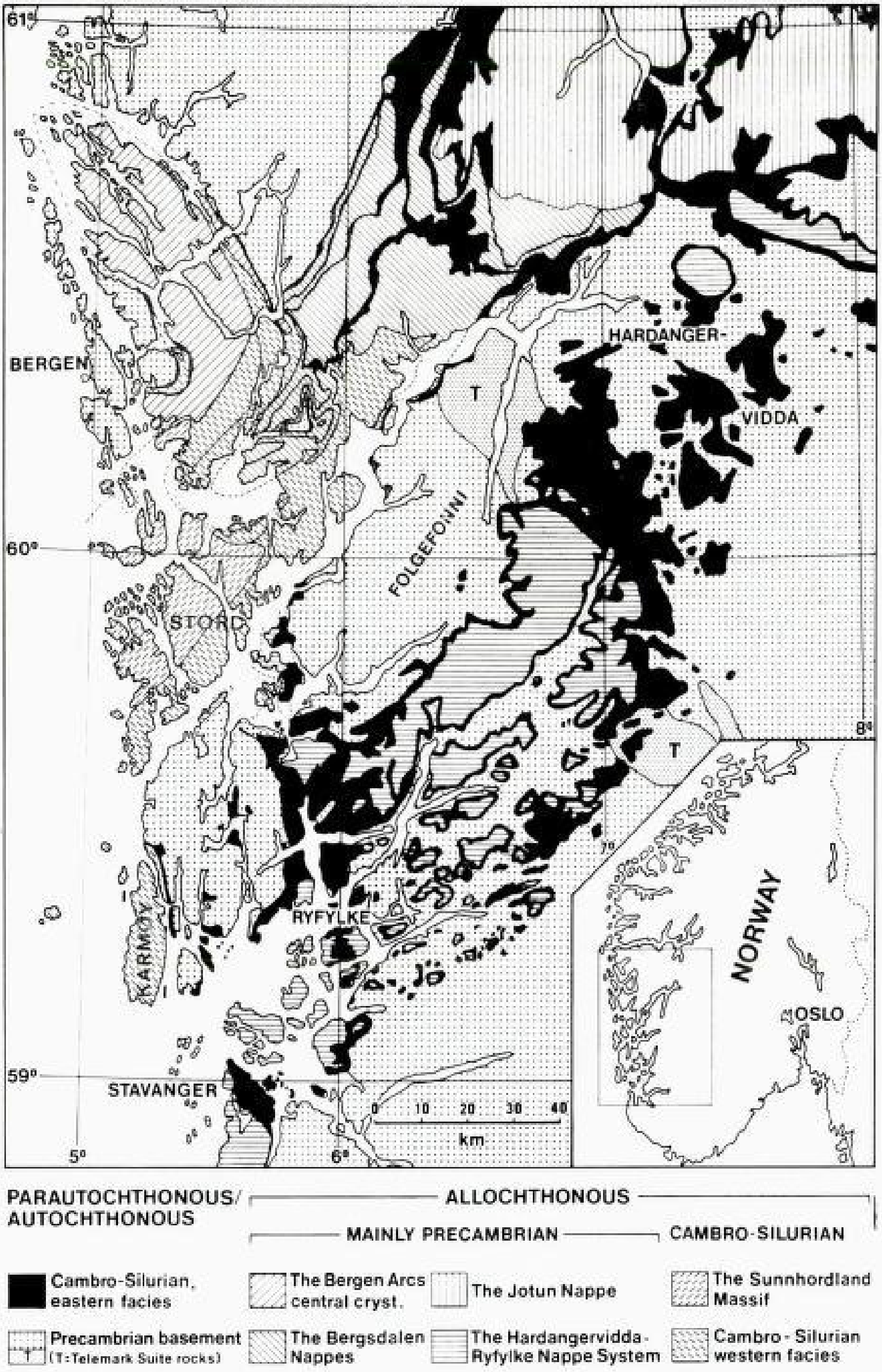

Fig. 1. The distribution of the main tectonostratigraphic units of SW Norway.

As a result of detailed studies in critical areas and reconnaissance mapping and reinterpretation of older data, a revised simplified geological map of the whole region is presented in Fig. 1. We will here deal only with the area covered by Fig. 2, where detailed studies have been undertaken. The purpose of this work is not to give a complete geological description of the area, but rather to present the new ideas on the geological development and also to point out the consequences of these interpretations and results for the region as a whole.

The main reinterpretations of the geology are as follows:

(i) Parts of what was formerly considered autochthonous Precambrian basement are, in fact, allochthonous nappes.
(ii) Large areas of metamorphic supracrustal rocks, previously incorporated within the Cambro–Silurian cover rocks, are shown to be part of the autochthonous Precambrian basement.
(iii) Only a minor part of the previously considered Cambro–Silurian cover rocks can be regarded as autochthonous; the main portion of the pelites is allochthonous and probably of Precambrian age.
(iv) The medium-grade metamorphism and igneous activity of the basement are of Precambrian age.
(v) The basement/cover contact, where not fault-bounded, is depositional. A relict but distinct metamorphic break exists at the boundary.
(vi) The volcanic-bearing Cambro–Ordovician sequence (western facies Cambro–Silurian) on the islands is allochthonous and forms the uppermost part of the nappe pile.
(vii) Late Palaeozoic and Mesozoic faulting is responsible for much of the irregular appearance of the geological boundaries.

The arguments and some of the data leading to these conclusions will now be presented together with a short description of the geology.

Precambrian basement

The basement lithologies have been grouped into three main units (see Fig. 2):

1. Metamorphic supracrustals of both sedimentary and volcanic origin; the Tittelsnes Group.
2. Gabbroic rocks which intrude the Tittelsnes Group. Only the largest of the many bodies is marked in Fig. 2.
3. Mainly granitoid orthogneisses and migmatites with varying age relations to the above-mentioned units.

(1) The metamorphic supracrustals of the basement seem to be most complete and best preserved on the Tittelsnes peninsula, and we have proposed the new term Tittelsnes Group as an informal name for these rocks. The Tittelsnes

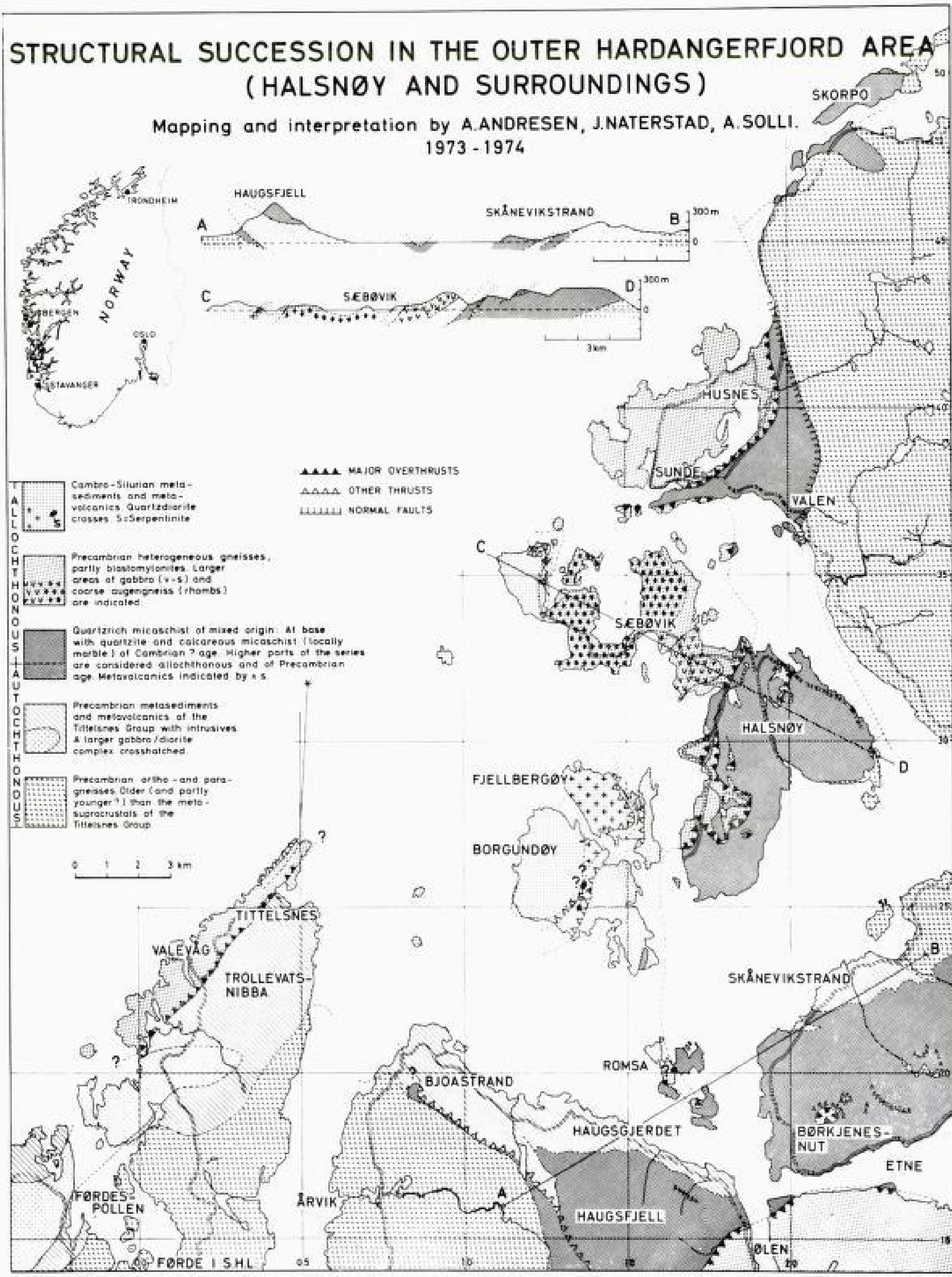

Fig. 2. Simplified geological map of the outer Hardangerfjord area.

Group consists mainly of metamorphic pelitic and semi-pelitic rocks, often with well-preserved primary sedimentary structures, chiefly preserved in the contact aureoles to the younger gabbros. There are also volcanic rocks of both acid and basic types, and some conspicuous zones of meta-agglomerates occur (Mortensen 1943; Sørbye 1948).

On existing geological maps much of the areas underlain by this Precambrian series has been designated as Cambro–Silurian metamorphic supracrustals, e.g. Tittelsnes, Bjoastrand (Kolderup 1941; Sørbye 1953; Holtedahl & Dons 1960). The Precambrian age of the series suggested in this paper is indicated by the fact that its rather complex structures are truncated by the sub-Cambrian peneplain and overlain by Cambro–Silurian basal deposits, nicely exposed at Bjoastrand and Skånevikstrand.

The occurrence of staurolite, sillimanite, cordierite and chloritoid in the pelitic parts of this group indicates that in Precambrian times amphibolite facies metamorphic conditions have been reached, a degree of metamorphism never attained in the phyllites of definite Cambro–Silurian age which overlie the Tittelsnes Group. The group is tentatively correlated with parts of the Telemark Suite of South-Central Norway. If this is the case, the sediments here in western Norway seem to be of a more pelitic character than those of the Central Talemark area. (See also Torske 1977).

(2) Only the largest of the gabbro/diorite bodies is shown on the map (Fig. 2), but quite a number of smaller bodies exist, especially in the supracrustals at Skånevikstrand (Mortensen 1943; Rekstad 1908). Textural and mineralogical variations in the bodies are frequent, but have not yet been studied in detail. The gabbros are intrusive into the Tittelsnes Group, and large xenoliths of the supracrustals appear inside the bodies. Extensive contact aureoles with so-called 'knotenskifer' (Rekstad 1908) or spotted slate with andulusite porphyroblasts are developed around the gabbros. Primary structures in the sediments are better preserved in these contact aureoles than in the surrounding areas. The bodies of gabbro and their contact aureoles seem to control the formation and distribution of migmatites of a later event (see below).

(3) Gneissic rocks of different types and with varying age relationships to the two former divisions make up the third main unit of the basement. The gneisses have different appearances in the various regions of Fig. 2. The areas east of Valen–Husnes and east of Skånevikstrand are dominated by a rather uniform granitoid orthogneiss which is intrusive into the Tittelsnes Group. The area east of Førdespollen and much of the area east of Årvik are mainly occupied by granitic migmatitic gneisses. Field relations indicate that the main migmatization phase post-dates the intrusion of the gabbros. Also the youngest granites and pegmatites of division 3 are intrusive into the gabbros.

There may, however, be parts of the gneisses which are older than the Tittelsnes Group. This may prove to be the case west of Bjoastrand where a quartz–dioritic gneiss appears to form the depositional base of the supracrustals.

Quartz-rich mica schist of mixed origin

Under this heading (see legend to the geological map, Fig. 2) is grouped most of the rocks that have been interpreted as Cambro–Silurian schists by earlier workers (e.g. Holtedahl & Dons 1960), but excluding areas of pelitic rocks around Bjoastrand and Tittelsnes which belong to the Tittelsnes Group. Our investigations indicate a subdivision of the two unit into: (a) a lower autochthonous sequence of Lower Palaeozoic age, and (b) an upper allochthonous sequence of possible Precambrian age. The great similarity in the fundamental lithology and a common late metamorphic and tectonic history of the two sequences makes a separation between them very difficult in the field. This has, however, been achieved locally, and the units will therefore be described separately, although we have not yet been able to distinguish between them over the whole region covered by our map (Fig. 2). Similar difficulties with the separation of the two sequences of mica schist have been noted earlier by Sigmond Kildal (1973) and Sigmond (1975) from the Suldal area to the southeast.

(a) LOWER AUTOCHTHONOUS SEQUENCE

This part of the sequence corresponds in our opinion to the lower part of what earlier has been named 'Fyllittavdelingen' (e.g. Rekstad 1907, Sørbye 1953) or the Phyllite formation — Cambro–Silurian of eastern facies (Strand 1972, pp. 31–32). Its base is well exposed at Bjoastrand, Skånevikstrand, Halsnøy and north of Husnes. The lowermost member is a medium-grained quartzite, usualy white, but sometimes with a bluish tint and a thickness which varies from zero to about 10 m. In most places only slices of the quartzite are found, due to post-depositional tectonic disturbances, but its basal depositional character is proven by its appearance in numerous non-tectonized localities. A thin marble horizon may be present above the quartzite, and this is followed by a calcareous mica schist, locally of considerable thickness.

This basal quartzite–marble–phyllite association linked to the discordance is found over wide areas in Hordaland and Rogaland. At Ritland in Rogaland (59°14'N, 06°25'E) a Middle Cambrian fauna occurs in an autochthonous dark shale above basal quartzite and breccia, and below an allochthonous mica schist sequence (Henningsmoen 1952, Sigmond 1975). Nearby, in Elfarvik, Nedstrand (59°25'N, 5°47'E) trace fossils have been found in the basal quartzite (Riis 1977). This evidence indicates that the contact represents the sub-Cambrian peneplain.

Intrusives have not been found in this lower mica schist sequence. Garnet and biotite indicate greenschist facies metamorphism (Solli 1976) and hence a lower metamorphic grade than in the sediments of the Precambrian basement. As garnet and biotite are never found in the basal deposits on Hardangervidda or in Ryfylke, an increase in (Caledonian) metamorphic grade towards the northwest is indicated. Indications of the same sort have been found by Riis (1977) in the Nedstrand area. Here a series of thrust sheets is found low in the nappe pile, all containing the basement/cover and the phyllite/mica schist sequence. The higher the position of a sheet in the nappe pile, the more northwesterly its derivation is thought to have been. These sheets show a distinct increase in metamorphic grade upwards.

(b) UPPER ALLOCHTHONOUS SEQUENCE

The upper and volumetrically more dominant part of the mica schist division is a greenish to greyish quartz-rich mica schist. It is very homogeneous and contains numerous characteristic 5–10 cm long distorted lenses of vein quartz. A few quartzite beds occur, but more conspicuous are 0.5–5 m-thick layers of a massive gneissic rock which are very persistent and can be followed for kilometres. It has a characteristic 'augen' structure, where each 'augen' (~ 0.5 cm across) is made up of a single plagioclase crystal. The mineralogy of the matrix is quartz, albite, chlorite, hornblende, clinozoisite, and minor amounts of calcite and sericite.

These rocks are almost identical to the meta-andesites described from Skorpeheii, Suldal, 30 km to the east (Sigmond Kildal 1973). These meta-andesites are also interbedded with mica schist, and they occur in a similar tectonostratigraphic posision as here. Based on their appearance in the field and the comparison mentioned, we tentatively interpret the gneissic layers as meta-andesites.

Rb/Sr whole rock dating of the meta-andesites at Skorpeheii has yielded an age of 1145 ± 98 m.y. (λ $1.39 \cdot 10^{-11}$) (Sigmond & Andresen 1976). An attempt at Rb/Sr whole rock dating of the metavolcanics at Ølen has failed to define an isochron, but the data clearly point towards a Precambrian age (A. Råheim, pers. comm. 1977).

The arguments for dividing the mica schist into autochthonous and allochthonous parts are as follows. At the base of the sequence there is an angular unconformity with a break in metamorphic grade, and in a nearby area Cambrian fossils are found above what appears to be the same unconformity. Higher up in the sequence are found several horizons of interbedded, possibly metavolcanic rocks of indicated Precambrian age. It seems therefore reasonable that the upper part is allochthonous. The main argument against this theory is that we have not been able to ascertain the presence of a single main thrust between the two sequences of mica schists. Locally, however, many thrust faults occur, and we therefore interpret the boundary between the sequences as represented by an imbricate zone where mica schists of Cambro–Ordovician and Precambrian age are tectonically mixed and overprinted by a common, early Caledonian, regional metamorphic event.

Although no obvious break in metamorphic grade has been found between the upper and lower mica schist sequences, some textural differences seem to exist. The upper part contains more vein quartz and also has a more coarse-grained texture. This conclusion is supported by recent detailed studies in the same mica schist complex at Nedstrand, Rogaland (Riis 1977).

The existence, and Precambrian age, of the metavolcanics should, however, be accepted with some caution. On Halsnøy (Solli 1976) and Nedstrand (Riis 1977) it can be demonstrated that gneisses form thin tectonic wedges or sheets in the mica schist and that the cataclastic products of these in the field show a striking similarity to metavolcanics. The larger part of these thin and persistent gneissic layers have, however, a field appearance as well as mineralogical and textural relations strongly suggesting a volcanic origin as tuffs or lavas. For this reason we favour a Precambrian age for the upper sequence.

Allochthonous Precambrian heterogeneous gneisses

Most of the rocks of this unit are banded orthogneisses which are easily distinguished from the orthogneisses of the basement by the presence of a more marked foliation in the former. A Precambrian age is suggested from correlation with other nappe areas (e.g. Heier et al. 1972, Andresen et al. 1974, Andresen & Heier 1975).

The gneisses represent very heterogeneous rock-types, but the following main lithologies have been recognized. Large parts of the unit are occupied by various types of foliated granitic gneisses, the most spectacular of which is a coarse-grained augen gneiss with porphyroblasts of microperthitic microcline. Intrusive into the augen gneiss are gabbroic/dioritic rocks. In intimate accociation with the gabbros are quartz–dioritic rocks which probably represent a late stage in the magmatic evolution of the gabbros.

Studies of the allochthonous gneisses show that they have undergone several stages of deformation. Fieldwork demonstrates that the gabbros were intruded into a foliated augen gneiss and that the gneisses have suffered at least one episode of foliation and tectonism after this intrusion. Generally, the gneisses now show a greenschist facies mineralogy with chlorite, albite, biotite, microcline and garnet. Locally, gneisses with relics of higher grade metamorphism (mesoperthite) are found. Some gabbroic bodies with primary magmatic minerals (clinopyroxene, labradorite) also occur (Solli 1976).

The lower boundary of the gneisses (major thrust on the map, Fig. 2) is not one single thrust surface, but a series of imbrications between gneisses and mica schists. This is indicated on the map in the profile section of Halsnøy, Fig. 2 C–D, and described in more detail by Solli (1976). The same phenomenon has also been reported by Sigmond Kildal (1973) from the Suldal area.

Most of what have been intepreted as allochthonous gneisses is shown on earlier maps as autochthonous basement, e.g. Tittelsnes, Halsnøy and Husnes.

Allochthonous metasediments and metavolcanics of supposed Cambro–Ordovician age

This is the uppermost tectonostratigraphic unit in the mapped area. Further west, a more complete section of these rocks can be seen. They have earlier been designated Cambro–Silurian rocks of western facies (Strand 1972). The reason for this is that there are some scattered fossil localities, e.g. on Karmøy (59°15′N, 5°15′E) (Broch et al. 1940), Stord (59°52′N, 5°23′E) (Færseth &

Ryan 1975, Ryan & Skevington 1976), and in the Os area (60°9'N, 5°30'E) (Kolderup & Kolderup 1940), indicating Upper Ordovician and Silurian ages (Ashgill & Llandovery). It would seem, however, that the rocks in the mapped area might belong to a lower part of the sequence and hence would have a pre-Ashgillian age (Solli 1976), but palaeontological evidence for this notion has yet to be found.

Pelitic schist, metagreywacke and greenschist are the major components of the series. A rapid alternation combined with a strong tectonic deformation often makes distinction between metasediments and metavolcanics impossible. In some of the schists are found polymictic conglomerates. One larger body of quartz–diorite (Fjelbergøy) and some smaller bodies of gabbro occur. On Borgundøy there are a few lenses of serpentinite. All rocks seem to have suffered a greenschist facies metamorphism.

The boundary of the unit to the allochthonous gneisses below is strongly tectonized, but even so it has a rather uniform appearance, not only in this area, but also along the entire northwestern side of the Hardangerfjord. This must mean that: (1) a thrust contact has been established against the gneisses below, without the stratigraphy of the sequence being too much disturbed; or (2) that the contact to the gneiss unit was originally a depositional one, subsequently disturbed. The authors favour the first alternative.

Mesozoic igneous and tectonic activity

A swarm of alkaline dykes has recently been described from the Sunnhordland area (Færseth et al. 1976). Of the approximately 80 dykes which have been recorded, 8–10 are located within the map area (Fig. 2). The dykes have a width ranging from 10 cm to 2 m. Both the major element chemistry and the high abundances of incompatible elements of these dykes are typical of alkali olivine basalts.

K–Ar dating on amphibole and whole-rock samples demonstrates a spread in age from 280 m.y. to 160 m.y. with a major activity about 220 m.y. B.P. (Triassic) (Færseth et al. 1970).

The dykes have a N–S to NNW–SSE strike and seem to be associated with a system of fractures and faults in the same direction. It can be demonstrated that some of the fractures have suffered more than one episode of brecciation. East of Husnes–Valen one of the largest faults is found with a westerly downthrow of about 500 m. Partly as an effect of this, the Cambrian peneplain on Halsnøy and Skånevikstrand reaches much further to the east than would be expected from its attitude at Tittelsnes and north of Husnes.

Concluding remarks

The main results of the tectonic reinterpretation of the different lithological units are summarized in the introduction (p. 41). We will here only discuss some further implications of the new results.

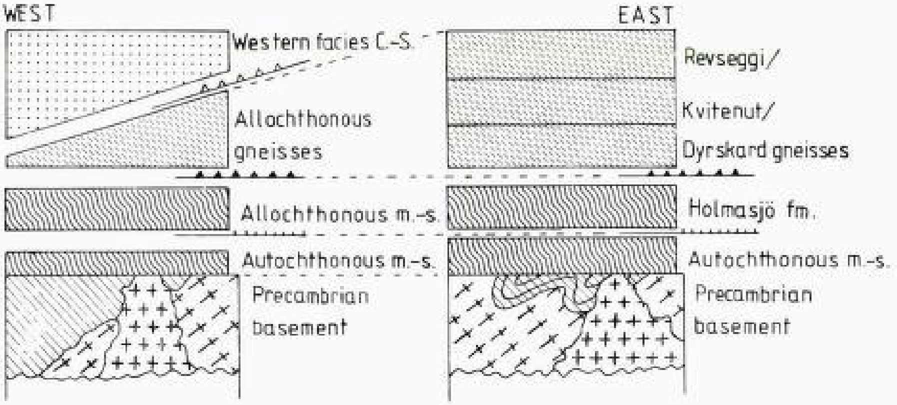

Fig. 3. A comparison between the tectonostratigraphy of the Hardangervidda–Ryfylke area (east) and the outer Hardangerfjord area (west).

It is the author's impression that the tectonostratigraphic succession in the area bears a great resemblance to that established in the Hardangervidda area to the east (Naterstad et al. 1973). This is illustrated in Fig. 3. In both areas the Precambrian basement is overlain by an autochthonous Cambro–Ordovician or Cambro–Silurian sequence, fossiliferous in the Hardangervidda area (Andresen 1974). In the latter area this sequence is succeeded by an allochthonous/parautochthonous sequence of mica schists; the Holmasjö Formation (Naterstad et al. 1973). It has not been possible to identify a similar tectonic unit in the outer Hardangerfjord area. However, the mica schist found just above the basal quartzite and marble is lithologically indistinguishable from the Holmasjö Formation.

The next unit of regional extent in the Røldal–Haukelisæter area is the Dyrskard Group. This unit is dominated by quartzites, rhyodacites and metabasalts (Andresen & Gabrielsen, in prep.) with some horizons of mica schists. The amount of mica schist seems to increase westwards and also contains layers of meta-andesites (Andresen & Gabrielsen, in press), the unit showing great similarities to parts of the upper allochthonous mica schist unit in the outer Hardangerfjord area. Following this, a correlation between the Dyrskard Group and the volcanic-bearing parts of the upper mica schist unit in the outer Hardangerfjord area may be suggested.

We also consider the Kvitenut Complex in the Røldal–Haukelisæter area (Naterstad et al. 1973) to represent the same tectonostratigraphic unit as the allochthonous Precambrian heterogeneous gneisses in the outer Hardangerfjord area.

The main difference between the areas seems to be that the gneissic Precambrian part of the eastern allochthon wedges out towards the Hardangerfjord, and in this area the next nappe unit, the Cambro–Ordovician metasupracrustals of western facies, appears as a new and major element on top. It has to be stressed that the suggested Cambro–Ordovician age of this series has never been proven. It is separated from the fossiliferous series on Stord (Færseth & Ryan 1975, Ryan & Skevington 1976), and from the Rb/Sr dated volcanics (455 ± 5 m.y.) on the same island by faulting (Priem & Torske 1973, Lippard 1976), and its grouping with the Cambro–Ordovician is still only based on 'long range' correlation made on specific lithological characters. This correlation is accepted with caution for the present by the authors. There is a great similarity between retrograde parts of the volcanic-bearing Tittelsnes Group and the volcanic-bearing series of supposed Cambro–Ordovician age, a fact that makes misinterpretations possible. It might be expected that the supracrustals of the Tittelsnes Group continue to the northwest beneath the rock sequence in the Faltungsgraben, and that during Caledonian nappe movements they are likely to have been moved southeastwards together with slices of their own substrate, these slices now being represented by the heterogeneous allochthonous gneisses.

The contact between the supposed Cambro–Ordovician series of western facies and the autochthonous/parautochthonous sequence capping the basement is always a thrust, almost everywhere with a sole og gneisses in between, e.g. on Halsnøy and Tittelsnes. This sole may have been: (1) short-transported slices of the local basement caught by the advancing allochthon; (2) the tectonized base of the sequence derived from somewhere to the north-west; or (3) more likely a part of the continental edge on to which the Cambro–Ordovician sequence was obducted during the early stages of its movements (Gale & Roberts 1974).

The point that the volcanic-bearing Cambro–Ordovician sequence is allochthonous in this region has not yet been recognized explicitly in the literature. Up to now, only brief remarks have been made, e.g. by Strand (1972, pp. 69–70) and Naterstad et al. (1973, Fig. 1 and p. 17).

The allochthonous nature of the Cambro–Ordovician succesion is also indicated by the common occurrence of widely diverse intrusive rocks of Caledonian age, from ultrabasic to granitic, that have never been found in the local basement. Some of the intrusive rocks, e.g. the stratabound serpentinites and the greenstones, are generally accepted as originating in tectonic situations very different from their present setting within a seemingly unbroken continent. If the suggested Cambro–Ordovician, pre-Ashgillian age is correct, this strongly volcanic sequence would be a partial time-equivalent to the nearby autochthonous Hardangervidda series (Andresen 1974a) which is almost devoid of volcanic elements, a situation which can best be explained by considering the western volcanic-bearing series as allochthonous.

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Tectonostratigraphic Succession and Development of the Finnmarkian Nappe Sequence, North Norway

K. B. ZWAAN & D. ROBERTS

Zwaan, K. B. & Roberts, D. 1978: Tectonostratigraphic succession and development of the Finnmarkian nappe sequence, North Norway. *Norges geol. Unders. 343*, 53–71.

Detailed investigations of the Finnmarkian nappe sequence within the 1:250 000 map-sheets 'Hammerfest', 'Nordreisa' and 'Honningsvåg' have revealed a complex construction of discrete nappes, sub-nappes and minor thrust slices. In the Kalak (Reisa) Nappe Complex the nappes are composed not only of the ubiquitous Vendian to Cambrian lithostratigraphy but also of proven (dated) or suspected, older, Precambrian, high-grade gneissic/amphibolitic units and slices of Raipas carbonates and volcanites. In places, thick sequences of gneisses and schists have been converted to blastomylonites and locally ultramylonites, mainly during the first two of four principal deformation episodes.

On a regional scale, major D_1 folds are present in northwesterly areas whereas further southeast a more homogeneous flattening deformation prevailed. D_2 fold structures, related to the regionally developed principal foliation, show a variable development in style and trend with fold axial rotations into a NW–SE trend related to high internal strains, noticeably towards the lower parts of the nappe units. These deformations were wholly Finnmarkian (late Cambrian – early Ordovician). Nappe translation, linked to D_2, diminished in magnitude towards the northeast. Later deformation episodes include imbrication structures on all scales which can be shown to relate to the thrusting of higher nappes containing Ordo-Silurian stratigraphies. These date to late Silurian time. The Silurian-emplaced nappes continue southwards into the well-documented nappe complexes of Nordland and Trøndelag. Slices of higher grade schists and gneisses in the Silurian nappes of the Tromsø region probably represent upthrust segments of the subjacent Finnmarkian-deformed sequence and Precambrian crystalline basement, thus producing an extremely complex succession of units of differing depositional age and initial metamorphism.

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Introduction

Modern interest in the Caledonian geology of northernmost Norway could rightly be said to have been stimulated by the 1960 International Geological Congress excursions (Føyn 1960). Since that time geological research in this region has progressed unabated (see, e.g., NGU no. 269). In the early 1970's Norges geologiske undersøkelse began systematic detailed geological mapping in western Finnmark and north Troms, commencing south of the Komagfjord tectonic window and progressing southwards towards the Lyngenfjord–Skibotndal district, the aim being to cover the 1:250 000 map-sheet 'Nordreisa'. At the same time gaps were filled in on the 1:250 000 map-sheet 'Hammerfest' as a step towards compilation and publication. A decade earlier, British university groups under the leadership of Sturt, Ramsay, Gayer and Hooper had commenced separate programmes of detailed tectonic and petrological studies

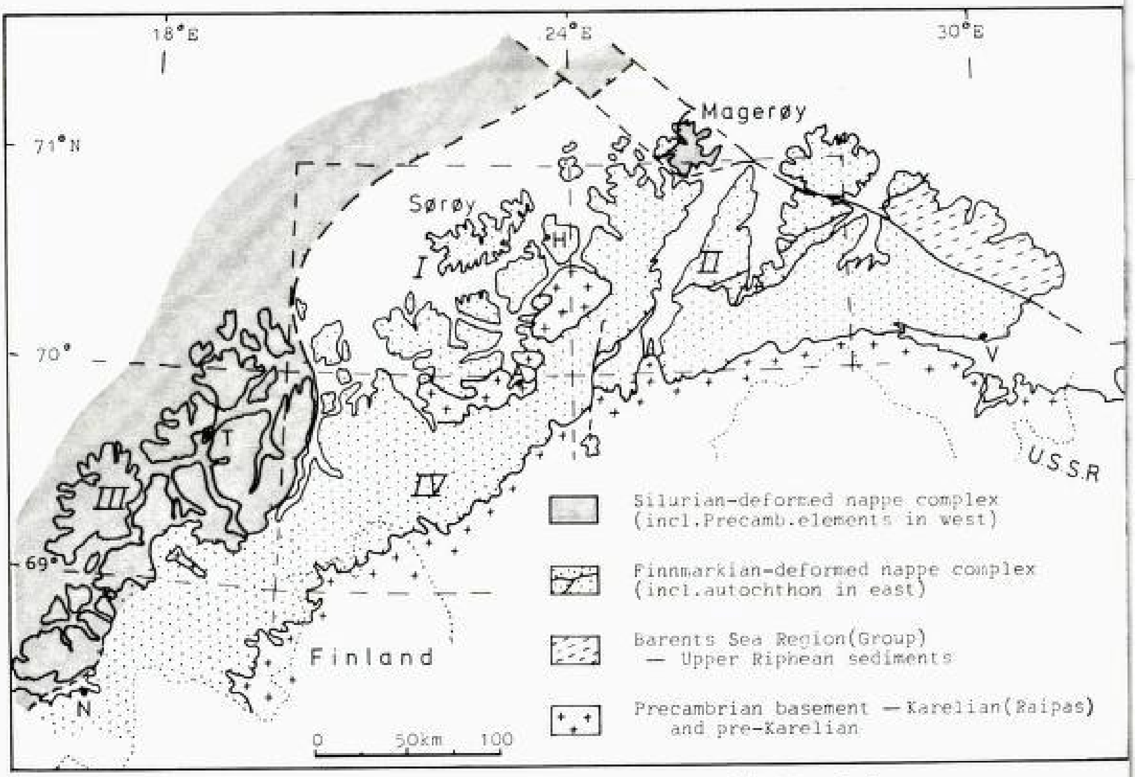


Fig. 1. Simplified outline map of northern Norway to show the principal division of the Caledonian allochthon, and the limits of the 1:250 000 map-sheets 'Hammerfest' (I), 'Honningsvåg' (II), 'Tromsø' (III) and 'Nordreisa' (IV). A – Alta; H – Hammerfest; N – Narvik; T – Tromsø; V – Vadsø. The Nordkyn peninsula, mentioned in the text, is situated in the north-east corner of map-sheet II.

within a wide region extending from Kvænangen through the Sørøy–Seiland district to Porsangerfjord. Much of this work formed a basis for the 'Hammerfest' map-sheet compilation (Roberts 1974).

With the 'Nordreisa' map-sheet now near completion (Zwaan 1976), new data available from the 'Hammerfest' sheet (Jansen 1976, Ramsay & Sturt 1977) and work on the 'Honningsvåg' sheet at an advanced stage, a synthesis of these mapping results was considered timely. The outline presented here, essentially a synopsis of a contribution to the XIII Nordiske Geologiske Vintermøte (Zwaan & Roberts 1978), is regional-tectonically orientated and is purposely brief. It should thus be regarded as complementary to other recent publications, cited in the text, to which the interested reader should turn for local or regional details. Further refinements of the general picture may be required as a result of more recent detailed mapping and of other work in progress (D. M. Ramsay, pers. comm. 1978).

Regional setting

The Caledonian allochthon in North Norway can be divided into two main units (Sturt et al. 1975, Sturt & Roberts 1978) (Fig. 1):

(1) A nappe sequence which was deformed and metamorphosed initially and principally in late Cambrian to early Ordovician time; this orogenic phase is now referred to as the 'Finnmarkian' (Ramsay & Sturt 1976, Roberts & Gale 1978).

(2) An overlying nappe sequence characterized by a Silurian age of emplacement; rocks in this complex of nappes vary in age from Precambrian to Silurian.

These allochthonous units were emplaced upon an autochthonous sedimentary succession of Upper Riphean to Tremadocian age in the far north-east and Vendian to Middle Cambrian age further south, and this in turn unconformably overlies two different Precambrian basement rock units; (a) the Karelian Raipas Suite; and (b) pre-Karelian gneisses. In the Alta district (Fig. 1) the Raipas is exposed in the tectonic windows of Alta–Kvænangen, Komagfjord (Reitan 1963), and Altenes (Roberts & Fareth 1974).

The region to be discussed in this paper stretches roughly from Laksefjord in the north-east to the Lyngenfjord–Balsfjord area in the south-west, and consists largely of the highest nappes belonging to the Finnmarkian sequence. These particular nappes have undergone a more or less common tectonometamorphic history, and constitute the now well-known *Kalak Nappe Complex* (Fig. 2). In North Troms the equivalent allochthonous pile is usually referred to as the *Reisa Nappe Complex.* Interposed between this nappe complex and the autochthon in north-eastern areas are two further nappes, the *Laksefjord Nappe* (Føyn 1960) and the *Gaissa Nappe* (Rosendahl 1945); an equivalent to the Gaissa in the area of the 'Nordreisa' map-sheet is the *Tierta Nappe* (Zwaan in Fareth et al. 1977). These sub-Kalak/Reisa nappes are regarded as parautochthonous to locally allochthonous in contrast to the comparatively far-transported Kalak/Reisa nappes.

Gaissa, Tierte and Laksefjord Nappes

Both the Gaissa and the Tierta Nappes comprise low-grade metamorphic foreland-facies sandstones and stromatolite-bearing dolomites of late Precambrian age. The Gaissa Nappe is of maximum allochthonous character in the Porsangerfjord area. Just south-west of there it is cut out by a proposed N–S-trending strike-slip fault (p. 65; Plate 1) to the west of which rocks of the same age and facies type are lying in autochthonous position in the Alta area. On the north side of the Alta–Kvænangen window the highest formation of the Bossekop Group (Føyn 1964) comprises a stromatolitic dolomite. West of Alta the highest units of the Raipas Suite together with rocks of the Bossekop and younger Borras Group were progressively deformed during the thrusting of the Reisa Nappe Complex. It is thus conceivable that the Tierta Nappe (a redefinition of Skjerlie & Tan's (1961) Jerta Nappe) represents slices of the Bossekop and Borras Group rocks transported south-eastwards from the Kvænangen area.

The Laksefjord Nappe (Føyn 1960, Laird 1972) is situated between the Gaissa Nappe and the Kalak Nappe Complex (Fig. 2, Plate 1). Meta-arkosic

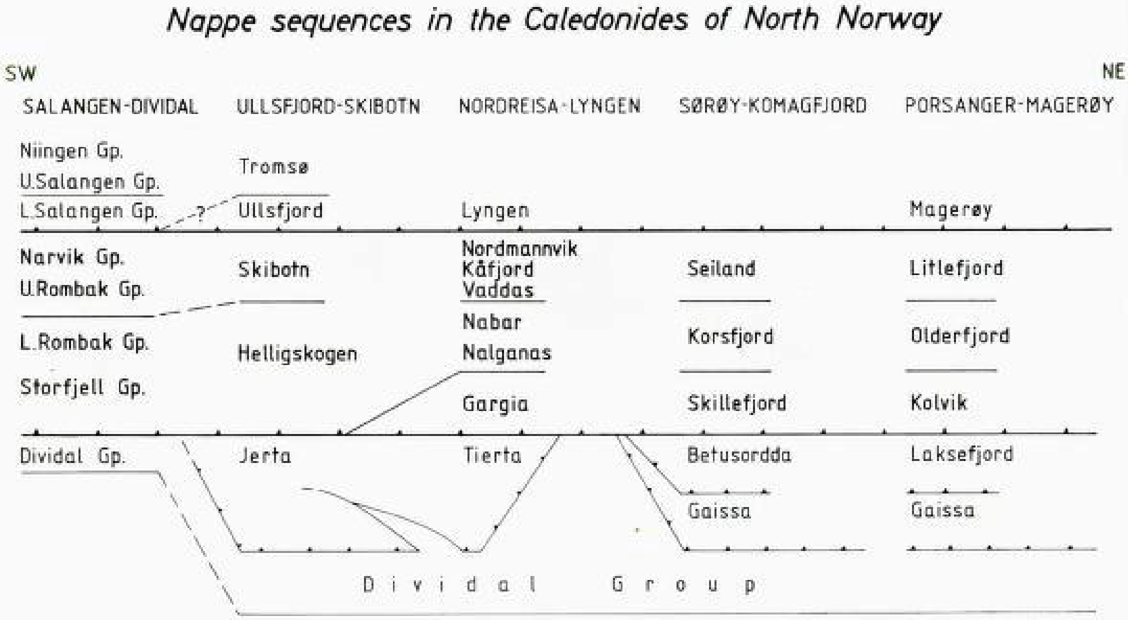


Fig. 2. Correlation of nappe sequences in the Caledonides of North Norway. The Kalak/Reisa Nappe Complex is ornamented. The principal references for the nappe stratigraphy in the various columns are as follows: – Salangen–Dividal (Gustavson 1972, 1974); Ullsfjord–Skibotn (Binns 1975); Nordreisa–Lyngen (Zwaan 1972, Zwaan et al. 1975); Sørøy–Komagfjord (Roberts 1974, Williams 1976); Porsanger–Magerøy (Føyn 1960, Ramsay & Sturt 1976, Rhodes & Gayer 1977).

lithologies in this nappe show marked similarities to psammites occurring in the lower parts of the Kalak/Reisa Nappe Complex; in some cases, conglomerate clast petrography can be very closely matched (J. J. Cramer, pers. comm. 1974).

Kalak/Reisa Nappe Complex

Subdivision of Føyn's (1960, 1967) Kalak Nappe was formally recognised in compilation of the 1:250 000 map-sheet 'Hammerfest' wherein the term Kalak Nappe Complex was introduced (Roberts 1974) as a cover name for three allochthonous units, the Skillefjord, Korsfjord and Seiland Nappes. A similar subdivision has later been reported from the adjacent 'Honningsvåg' and 'Nordreisa' map-sheets. These correlations are depicted in Fig. 2.

LATE PRECAMBRIAN–CAMBRIAN ELEMENTS

The greater part of the Kalak Nappe Complex consists of metasediments of assumed Vendian to Cambrian age. A well established stratigraphy from Sørøy (Ramsay & Sturt 1963, Roberts 1968a, Ramsay 1971), now recognised throughout the region, comprises a thick basal psammitic sequence followed by pelitic formations and then by a distinctive metalimestone–graphitic schist–quartzite succession. At the top is a monotonous unit of alternating thin-bedded metagraywacke and pelite, representing a flysch sequence (Roberts

1968b); towards the south, in the Kvænangen area, greenstones make an appearance at the base of, and locally within, this flysch unit (Padget 1955, Lindahl 1974). Archaeocyathids described from a limestone on Sørøy (Holland & Sturt 1970) point to a Lower to Middle Cambrian age for this formation. The oldest meta-arenaceous sediments in this continuous lithostratigraphical succession have always been considered as Vendian (Eocambrian); however, unlike in the autochthon and lower nappes of East Finnmark, Varangian glacigene diamictites have not been found in the Kalak and thus the maximum age of the sedimentary pile is unknown.

An important element within this nappe complex is that of a suite of plutonic rocks whose occurrence is centred in the well-known Seiland–Stjernøy Petrographic Province. There, igneous intrusion was broadly coeval with the multiphase Finnmarkian tectonothermal event with the earliest emplacements represented by a variety of layered gabbros and basic dykes. These were succeeded by diorites, gabbros and peridotites and by later alkaline complexes including carbonatites and nepheline syenites (Sturt & Ramsay 1965, Ramsay & Sturt 1970a, Robins 1972, Robins & Gardner 1975). In the Nordreisa area, several smaller sheet-like bodies of gabbro (Fig. 3; also Zwaan et al. 1975) are mostly situated along the basal thrust zones of the Vaddas and Kåfjord Nappes.

Fig. 3. Metagabbro sheet within Vendian meta-arkoses of the highest part of the Nabar Nappe. Photo (by P. Ryghaug) from Njallavarri, looking north. Map-sheet 1:50,000 'Kvænangsbotn' 1734 II (co-ord. 250 240): gb — gabbro; gn — gneiss; m-a — meta-arkoses.

Radiometric age determinations of Finnmark nappe rocks are numerous and show that the peak of Caledonian metamorphism dates to 535–530 m.y. B.P. in the west and ca. 515–505 m.y. B.P. in the east and in the autochthon. This would appear to indicate that the main phase of the Finnmarkian deformation and metamorphism was diachronous, migrating from west to east or southeast with time. In the Seiland province, in terms of deformation episodes the oldest intrusions were emplaced during D_1 at 548 m.y. ago while late-D_2 alkaline rocks date to ca. 500 m.y. B.P. Finnmarkian deformation was thus a protracted event spanning Upper Cambrian to Lower (or even Middle) Ordovician time.

PRECAMBRIAN ELEMENTS

At an early stage during systematic mapping in the Alta district (by K. B. Z.), some doubt was cast on the age and origin of certain rock units of complex lithology and structure which consist largely of gneisses. On the Geological Map of Norway these rocks, near Alta, were indicated as 'gneiss-granite'. Subsequently it was found that these gneisses were quite extensive further to the south-west within the lower nappe units of the Reisa Nappe Complex (Plate 1). In contrast to zones of gneissified and migmatized metasediments within the Sørøy stratigraphy, these gneisses were found to carry older, relict structures and show a higher grade metamorphism than in the surrounding rocks, and also to have tectonized mylonitic contacts with the latter. By comparing these gneisses with lenses of supposed basement granite rocks within the Caledonian allochthon further south (Kalsbeek & Olesen 1967), they were considered likely to represent tectonic slices of older Precambrian rocks (Zwaan & Ryghaug 1972).

At about the same time, Brueckner (1973) indicated the possibility that some of the gneissic rocks in the Øksfjord area could be as old as Svecofennian, but stressed that more studies were required. Recent investigations have, in fact, now revealed that the Precambrian element is a significant constituent of the Kalak Nappe Complex. Field studies on Kvaløy resulted in the discovery of an important unconformity separating greenschist facies psammites from subjacent, higher grade, granite-veined gneisses (Ramsay & Sturt 1977). Further south, at Korsfjord, gneisses similar to those on Kvaløy provided Pringle with a preliminary Rb–Sr whole-rock isochron of 2760 ± 150 m.y., while a granite dyke transecting this sequence yielded an age of 1469 ± 70 m.y. B.P. (reported in Ramsay & Sturt 1977). From our map picture (Plate 1) these Caledonized Precambrian crystallines would appear to continue southwards into the slices of gneisses originally deduced as Precambrian (Zwaan & Ryghaug 1972).

Over wide areas of the Nordreisa map-sheet, together with the slices of basement gneisses noted above, or in places separated from these, one finds yet another foreign element in the allochthon in the form of heterogeneous units of carbonate rocks, pelites, greenstone and local serpentinites (Plate 1). These are usually of lower metamorphic grade than the crystalline gneisses, although variations in their metamorphic state are apparent across the region. Interestingly, these variations closely reflect the metamorphic changes seen in the surrounding Vendian–Cambrian metasediments. Like the gneisses they show tectonic contacts with their host metasediments; where internal strains were high, greenstone, for example, shows stages of conversion into sheared amphibolite and ultimately, in blastomylonite zones, into talc schists.

Comparison of these allochthonous dolomite–greenstone–pelite units with similar lithologies in the Alta–Kvænangen window initially suggested their possible derivation from this source, i.e., they may represent Karelian Raipas rocks. Occurrences of stromatolites in similar dolomites in the allochthon NW of Talvik (Geukens & Moreau 1960, I. Bakke, pers. comm. 1975) also lend support to this theory. As mapping progressed southwards on the 'Nordreisa' sheet, compilation work was concluded on the adjacent 'Hammerfest' map-sheet. Similar carbonate–pelite–greenstone units and tectonic lenses in the Altafjord–Vargsund area on the latter map-sheet were then placed in the category of 'undifferentiated metamorphic allochthon of unknown age' (Roberts 1974). Subsequently, Jansen (1976) came to the conclusion that Raipas rocks were definitely incorporated in the allochthon in the Lerrisfjord–Komagfjord area, an opinion elaborated upon in an important contribution by Ramsay & Sturt (1977). Mapping by one of us (D.R.) south of Korsfjord has confirmed this story.

Caledonian deformation

The multiphase Caledonian deformation sequence within the Kalak or Reisa Nappe Complex can be divided into 5 or 6 fold episodes. Generally, structures relatable to only 3 or 4 of these episodes are recognised in any one small area, but attempts to trace these over long distances on bases of fold style, axial orientation, associated foliations, etc., frequently meet with difficulty. It is not the intention here to catalogue the properties of the deformation episodes in any detail, but rather to present some principal characteristics in so far as they relate to the megatectonic picture. Local details of deformation sequences and fold patterns may be found in Ramsay & Sturt (1963, 1973), Roberts (1968a), Hooper & Gronow (1969), Gayer & Roberts (1971), Ramsay (1971), Zwaan & Ryghaug (1972), Zwaan et al. (1975) and others (see papers and references in NGU no. 269 and Roberts 1974).

Structures of the first deformation episode, D_1, developed under comparatively low-grade metamorphic conditions. In view of the subsequent complex strain history and textural overprinting effected by amphibolite facies metamorphic events, it is not surprising that our knowledge of D_1 is less complete than that of later fold phases, taking the region as a whole. In the north-west, a schistosity axial planar to non-cylindrical D_1 folds has been preserved and this has been traced in association with large-scale isoclinal folds in western Sørøy (Ramsay & Sturt 1963, Ramsay 1971). These structures have been modified by a late-D_1 flattening event. Towards the south-east, however, on the mainland, and especially lower down in the nappe complex, both mesoscopic and macroscopic D_1 folds are extremely rare. It appears that the effects of D_1, in these areas, are largely those of a regionally homogeneous, strong flattening;

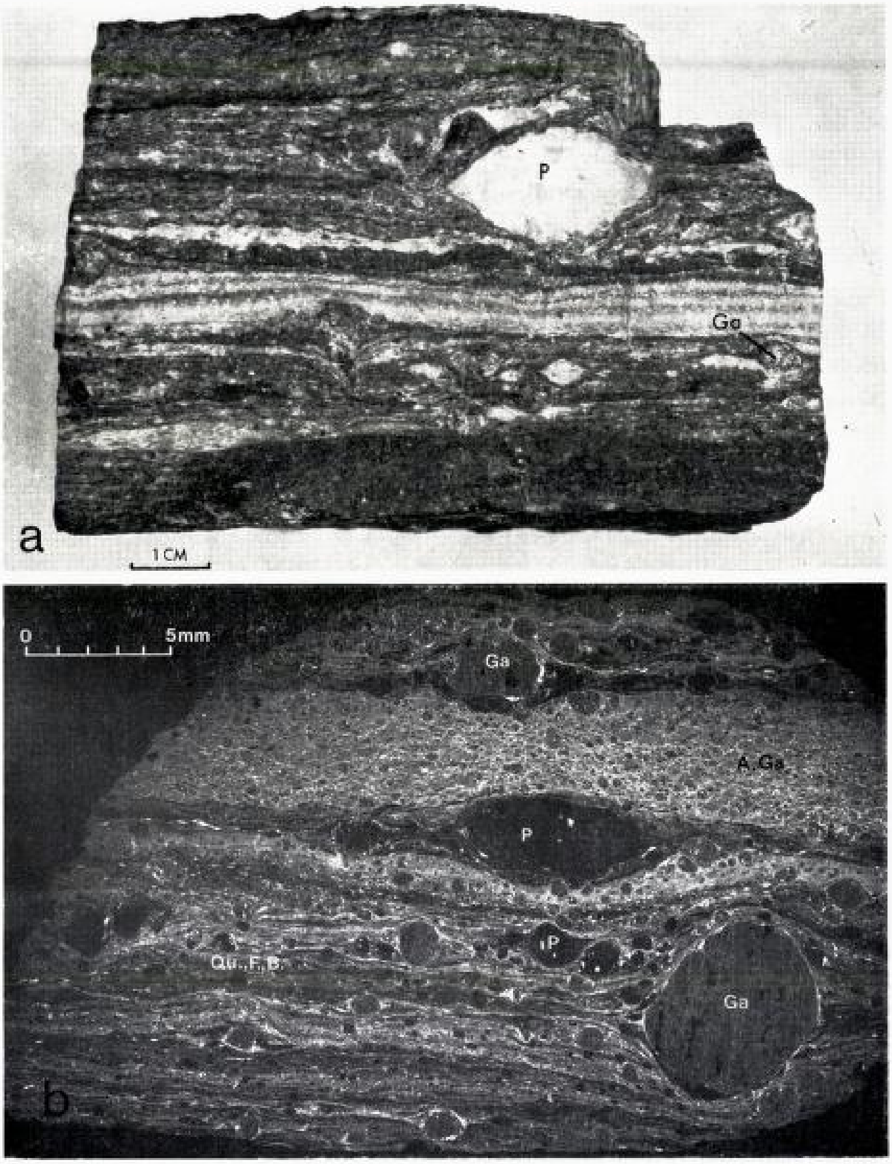


Fig. 4. (a) Blastomylonite from the basal thrust zone of the Vaddas Nappe, Specimen no. 634a. Map-sheet 'Kvænangsbotn' 1734 II (2640 3725). P – plagioclase; Ga – garnet.
(b) Photomicrograph of specimen no. 634a (Fig. 4a). Crossed nicols. P – plagioclase; Ga – garnet; A – amphibole; Qu, F, B – Quartz, feldspar, biotite.

boudinage structures on all scales are common, occasional intrafolial folds are present and sliding locally disrupts the stratigraphy. As a fold-producing deformation, D_1 was thus better developed in north-western areas towards the internal parts of the orogen.

Higher grade, amphibolite facies conditions characterize the complex second

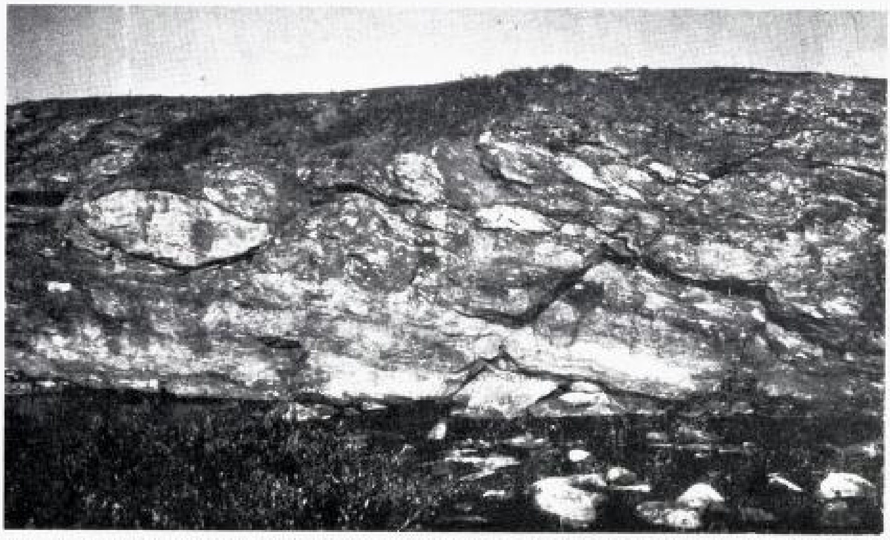


Fig. 5. Mega-blastomylonite in a thrust zone within the Nabar Nappe. The prominent lenticular bodies consist either of Precambrian gneisses (these occur in situ above the thrust zone) or of Vendian meta-arkose (which occurs below the thrust zone). From Signugäppi, map-sheet 'Mållesjåkka' 1733 I (264 966).

deformation episode, D_2, with syn-kinematic kyanite and sillimanite common in the highest nappes of the Finnmarkian allochthon. In the lower nappes, middle or even lower greenschist facies prevailed. Large- to small-scale, tight to isoclinal, asymmetrical D_2 folds with long upper limbs and areally restricted hinge zones are recognised over wide areas, particularly in the south and south-east, with a NW–SE stretching lineation well developed. The principal or regional schistosity, S_2, parallels the axial surfaces of these folds and is traceable as such from Laksefjord down to Skibotndal and beyond. As with the D_1 deformation a late-stage near-vertical gravitational flattening also attended the D_2 episode. On Sørøy, D_2 fold axes follow the large-scale D_1 arcuations (Ramsay 1971) with monoclinic structural symmetry prevailing in 'N–S' strike belts whereas an orthorhombic or triclinic symmetry typifies complementary 'E–W' strike belts (Ramsay & Sturt 1963, Roberts 1968a).

Systematic changes in D_2 axial trend of a different kind to those on Sørøy are documented from the Porsangerfjord–Laksefjord district (Gayer & Roberts 1971). There, dominant N–S folds show rotation within S_2 into NW–SE alignment in lower parts of the nappe, and a more NE–SW trend higher up. Towards the south-west and the 'Nordreisa' map-area, the NW–SE trend gradually becomes dominant throughout most of the nappe complex, paralleling the regional stretching lineation, while a more N–S trend is seen only in the highest parts of the Reisa allochthon. Rotation there led to the development of both structural and metamorphic discordances with the production of blastomylonites (Fig. 4) between the Kåfjord, Vaddas and Nabar Nappes. This regional prevalence of NW–SE 'transverse' structural elements and fold rotation from a 'primary' N–S or NNE–SSW trend is considered to relate to the high internal

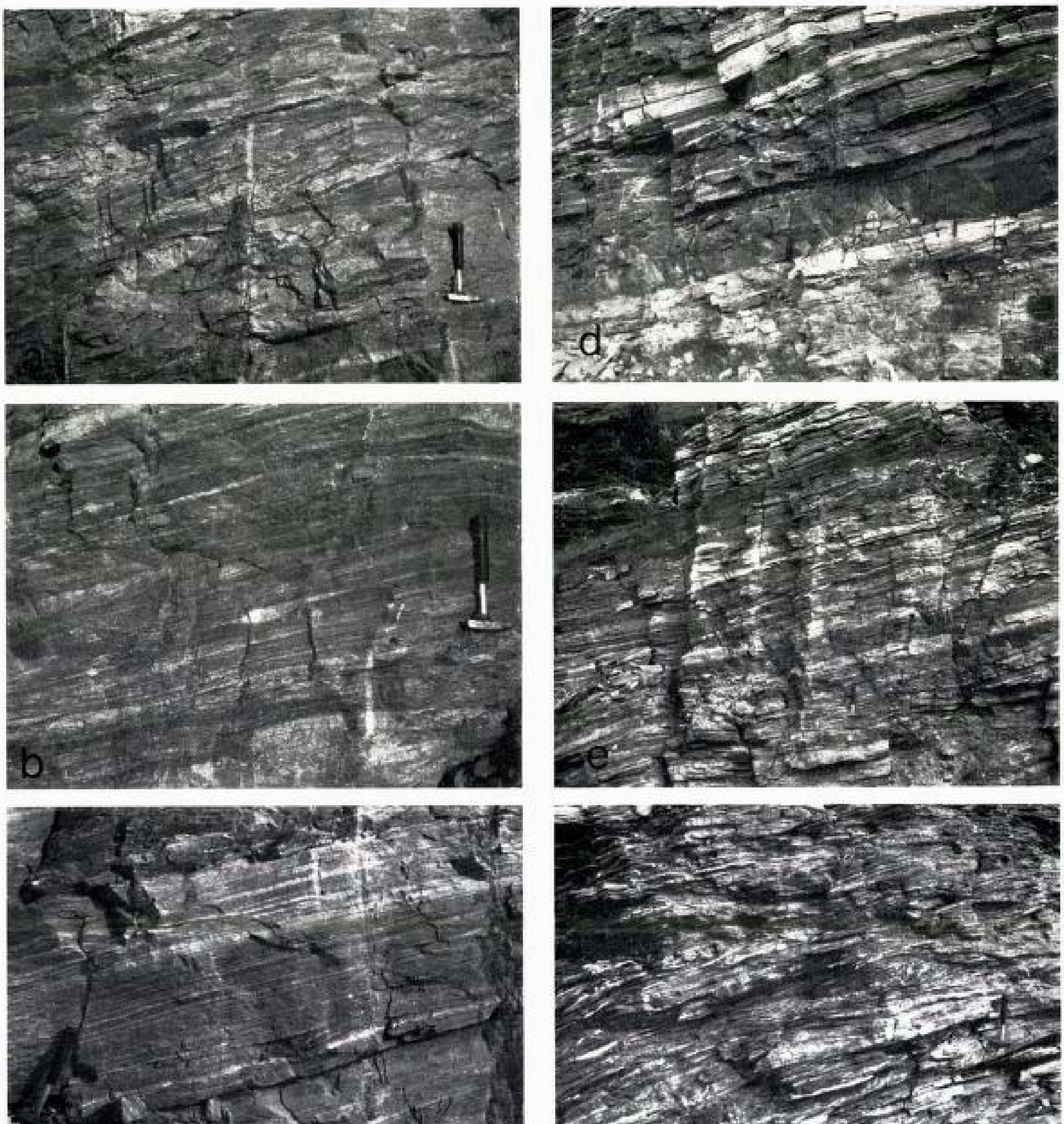


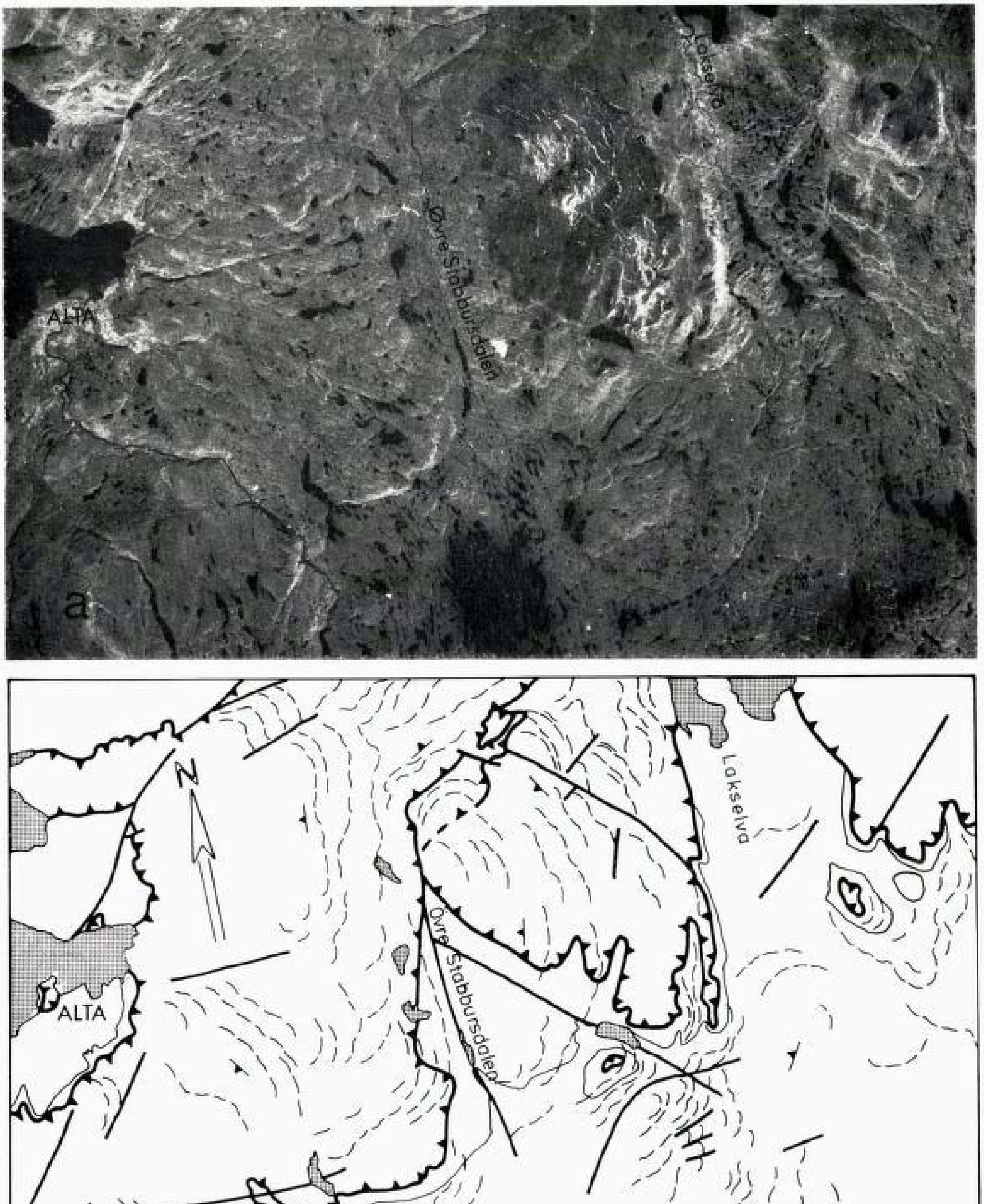
Fig. 6. Two examples of progressive deformation of gneissic units in the allochthon on the southwest side of the Komagfjord window. Photo series *a, b, c,* from the north side of Skillefjord, shows the gradual transformation of a medium-grained, grey gneiss with pegmatitic schlieren into a strongly flattened, thin-banded, fine-grained, locally porphyroclastic lithology resembling the 'pseudo-psammite' of Ramsay & Sturt (1977). Series *d, e, f,* from ca. 1 km south of Storekorsnes, shows a similar transformation of a Precambrian-dated, alternating amphibolitic and acidic gneiss sequence; photo *f* is from a position close to the the basal thrust surface of this particular tectonic unit.

strains which obtained during the D_2 period in the Kalak/Reisa Nappe Complex. An additional complicating factor may be that of irregularities in the subthrust surface (Price 1969, Rhodes & Gayer 1977). Moreover, vergence of transverse D_2 folds is consistently to the north-east. Towards north-eastern areas around Laksefjord and Nordkyn, D_2 deformation was clearly less intense with close to tight N–S folds dominating and with a pervasive NW–SE lineation largely restricted to zones adjacent to major thrusts. In the Nordreisa area, high strains in the rotated lower parts of the nappe complex produced a blastomylonitic S_2 schistosity, whereas a more equigranular texture is dominant in the N–S-lineated higher parts of the nappe pile with a penetrative axial planar schistosity limited to fold hinge zones.

The principal structural and metamorphic discordances within the Finnmarkian allochthon including the main thrusting of the Kalak Nappe Complex relate to the latest stages of D_2. During D_2 and also in some cases possibly earlier, in D_1, slices of crystalline basement with or without Raipas supracrustals were incorporated in the deforming Vendian–Cambrian cover (Fig. 5), acquiring strongly mylonitized, often blastomylonitic contacts in the process. Protracted straining locally produced thin-banded, fine-grained, porphyroclastic gneisses out of coarse-grained crystallines (Fig. 6) with recrystallization fabrics sometime masking the tectonic banding (cf. Ramsay & Sturt 1977).

Younger deformation structures within the Kalak/Reisa and subjacent nappes are of less ductile character. Minor tectonic phases including incipient crenulations and local folding associated with the main thrust zones are not considered here. The third principal fold episode, termed D_3 in this synthesis, is represented by open, upright to moderately flat folds generally with a variably developed crenulation cleavage and little or no neocrystallization. Dislocations related to southeastward movement and overturning are common. Displacements along lineaments recorded on stereoscopic Landsat (ERTS) satellite imagery in the area between Porsangerfjord and Alta (Fig. 7) are probably related to this phase. These appear to parallel the D_3 megastructures measured in the field and traced on aerial photographs, although detailed mapping has yet to be carried out in this area. Landsat-linears (Aarnisalo 1977) in the overriding Kalak Nappe Complex suggest both a thrusting over and a deflection around the Gaissa Nappe unit. It may also be noted that the Precambrian basement is strongly Caledonized in this area.

Abundant megaimbrication structures have been mapped out in the highest parts of the Reisa Nappe Complex. These imbrications and minor thrusts show a marked parallelism with the basal thrust to what we term the *Lyngen Nappe* (Fig. 2, Plate 1). This nappe we consider to represent the lowest unit in the post-Finnmarkian, Silurian-emplaced allochthon. It would therefore seem that the D_3 phase in the Reisa Nappe Complex relates to the thrusting of the Lyngen Nappe in Silurian time. Another feature associated with this thrusting is a gradual westward thinning of the entire Kalak/Reisa Nappe Complex towards the Lyngen thrust. Towards the base of the Reisa Nappe Complex and in the subjacent parautochthonous units a prominent imbrication structure on all


Lakselva
Øvre Stabbursdalen
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scales is related to this D_3 phase. Elsewhere, renewed movement along earlier-established, middle greenschist facies, mylonitic thrust zones, including the basal Kalak and lower thrusts, yielded low-T, retrograde, cataclastic fabrics (Sturt et al. 1975). This translation, which from radiometric studies was terminated before the end of the Silurian, brought the nappe sequence into its present position. Geological evidence thus supports the concept (Sturt et al. 1975) that the emplacement of the Kalak/Reisa Nappe Complex was essentially a two-stage process, initially late Cambrian to earliest Ordovician and later, Silurian.

Structures which post-date D_3 and the final mise-en-place of the nappes include local monoclinal folds, crenulations, kink bands, large-wavelength gentle warps, and fractures of one kind or another. Some of these are almost certainly Silurian, some may be Devonian (though we have no confirmation of this), while part of the faulting and jointing is conceivably post-Caledonian (Roberts 1971).

Nappe geometry and correlations

Recognition of Precambrian elements incorporated in the lower parts of the Kalak/Reisa allochthon bears witness to the existence of a more complex nappe geometry and deformation pattern than hitherto envisaged for this segment of the Caledonides. The picture which has emerged reveals a nappe pile comprising extensive, thin, tectonic units of Vendian–Cambrian lithologies (but only Vendian in the lowest units) locally floored by crystalline Baltic basement gneisses (Ramsay & Sturt 1977), and here and there with Raipas rocks as an additional constituent. The higher nappes, starting with the Vaddas Nappe, have the character of subhorizontal to gently inclined thrust slices. These are only locally floored by Precambrian segments and have basic to ultrabasic intrusions along their basal thrust zones. The highest Finnmarkian nappe, the *Nordmannvik Nappe* (Fig. 2), includes partly exotic rock elements such as dolomites and sagvandites (Schreyer et al. 1972, Ohnmacht 1974, Binns 1975) whose origin is not yet understood.

In the depression between the thrust front to the south-east and the Alta–Kvænangen and Komagfjord windows, magnetic data denote that the Caledonian allochthon is relatively thin (< 1 km; Åm 1975). Here, the Gaissa and Laksefjord Nappes are restricted, by a N–S-trending probable strike-slip fault, to the area east of Stabbursdalen where they lie in maximum allochthonous position. A major lineament recorded on satellite photos (Fig. 7) passing through

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Fig. 7 (a) Satellite photo NASA Landsat (ERTS) E–1006–O9481–7 of the region between Porsangerfjord and Altafjord.

(b) Photogeological interpretation of the satellite photo. The dashed lines are 'linears' depicting major D_3 structures of various types (elongate fold hinge zones, imbrications, etc.). Faults shown with thick continuous lines. The thrust boundaries to the Kalak/Reisa and Gaissa Nappes are indicated by the usual triangular-ticked lines. Autochthonous Dividal Group also indicated (thin continuous line).

upper Stabbursdalen possibly indicates a southern extension of this fault. West of this, rocks of the same facies as the Gaissa are autochthonous in the Alta area. Further south-west in the Nordreisa district, these rocks are progressively involved in thrusting (p. 55). In Finnmark there are indications that the Finnmarkian nappes are of diminishing allochthonous character towards the northeast, along nappe strike; the Gaissa rocks, for example, at best local-allochthonous, pass east-northeastwards into an autochthonous sequence; and in the Kalak, internal bulk strains diminish markedly towards Nordkyn with basal thrusting giving way to a gradually more brittle faulting on N.W. Varangerhalvøya (Levell & Roberts 1977). Thrust translations of the Finnmarkian nappes can therefore be visualized as being about vertical 'poles of rotation' situated in NE Finnmark or beyond. The thrusts are thus essentially hinge-thrusts with maximum relative movement in the southwest of the region considered here (Plate 1). There, D_2 strains were appreciably greater with the important late-D_2 stretching providing an increment of translation following the primary progressive simple shear and initial nappe construction. The foreland facies rocks form two separate parautochthonous nappes, the Gaissa Nappe in the north-east and the Tierta Nappe in the south-west. These nappes are separated by an area between Porsanger and Alta where equivalent rocks are occurring in autochthonous position. The lensoid, mega-boudin geometry of some smaller sub-nappes and tectonic slices also highlights the significance of flattening in the deformation history of this region.

In considering the correlation of nappe units from district to district within the extensive Finnmark–Troms region, the Kalak Nappe Complex provides a natural starting point by virtue of its continuity; in Troms, as noted earlier, its correlative is the Reisa Nappe Complex. On a smaller scale separate nappes are distinguishable and, from our mapping, traceable over wide areas, but the very nature of the nappe configuration and the expected effects of this geometry require that caution be employed in equating minor units over large areas. Nevertheless, with continuity the key-word, we feel secure in correlating from the 'Hammerfest' to the 'Nordreisa' map-sheets and then following the principal units towards both the north-east and south-west. A schematic, simplified presentation of this correlation is shown in Fig. 2.

Taking the tripartite sub-division of the Kalak Nappe Complex (Roberts 1974) as a base, the Korsfjord and Skillefjord Nappes can be traced without difficulty south-westwards into the Nabar/Nalganas and Gargia Nappes, respectively (Zwaan 1972, 1977, Zwaan et al. 1975). On the 'Hammerfest' map-sheet the gneisses which compose the Nalganas were (at the time of publication) not distinguished as a separate tectonic unit, but Jansen's (1976, pers. comm. 1977) work in the Lerrisfjord–Komagfjord area has disclosed the presence of 4 separate nappes, including gneisses correlative with the Nalganas, which further subdivide the Korsfjord and Skillefjord Nappes. Samples of gneisses from the Korsfjord Nappe at Korsfjord have provided the Precambrian Rb–Sr ages noted on p. 58.

Further north-east, in the Porsangerfjord district, Rhodes & Gayer (1977,

Fig. 1) have indicated the presence of three separate nappes within the Kalak (Fig. 2). We believe that the picture there may be somewhat more complicated, with slivers of Nalganas-equivalent along their Kolvik/Olderfjord Nappe boundary (Plate 1). Moreover, work by Ø. Jansen on Kvaløy (pers. comm. 1977) has disclosed the presence of important Precambrian crystalline elements and these are now believed to continue into the Litlefjord Nappe of Rhodes & Gayer (1977), (B. A. Sturt, pers. comm. 1977).

In the Nordreisa district, three separate nappes are recognised above the Nabar Nappe (Fig. 2). These comprise lithologies and stratigraphies which compare favourably with those in the Seiland Nappe further north-east. Moving south and south-west on the Nordreisa map-sheet, Binns (1975) has divided the Reisa Nappe Complex into two tectonic units, the Helligskogen and Skibotn Nappes (Fig. 2), although our mapping (by K.B.Z.) has revealed a more complex picture. In this part of the area the Gargia Nappe appears to wedge out. Further to the south-west, on the 1:250 000 map-sheet 'Narvik' (Gustavson 1974), description of the sequence there (Gustavson 1972) has led us to the correlation depicted in Fig. 2.

Of the nappes beneath the Kalak/Reisa Nappe Complex, the Gaissa appears to be of greatest areal extent. An equivalent but separate nappe further south-west is the Jerta or Tierta Nappe (Fig. 2, Plate 1). Between the Gaissa and the Kalak in the north-east is the Laksefjord Nappe (Plate 1); this wedges out towards Porsangerfjord but then re-appears briefly, as the Betusordda Nappe of Williams (1976), south-west of Porsangerfjord. Williams et al. (1976) have indicated a separate nappe unit between the Laksefjord and the Kalak Nappes — their Labbarnjunne Nappe — but Rhodes & Gayer (1977) include this as part of the Laksefjord Nappe.

Higher nappe units

In Finnmark the highest of the Caledonian nappes, the Magerøy Nappe of Ramsay & Sturt (1976), contains polyphasally deformed metasediments carrying an Upper Ordovician–Lower Silurian fauna (Reitan 1960, Føyn 1967, Ramsay & Sturt 1970b) and is considered to have been emplaced in late Silurian time. A migmatized Finnmarkian sequence forms the basement to this Silurian klippe in western Magerøy (Plate 1).

Rock sequences of a not dissimilar lithofacies to those in the Magerøy Nappe reappear to the south-west in Troms, in the Lyngen district (Randall 1971, Munday 1974). These have been considered by Roberts & Gale (1978) to provide an important link between the Magerøy Nappe and the Silurian-deformed nappe succession of Nordland and Trøndelag (Figs. 1 & 8), and an Ordo–Silurian age for low-grade metasediments south of Balsfjord has, in fact, now been confirmed by fossil finds (Olaussen 1976). This particular sedimentary succession together with the Lyngen gabbro constitutes our Lyngen Nappe, a unit which is broadly equivalent to the so-called Middle Nappe of Landmark (1973) or Ullsfjord Nappe of Binns (1975) (Fig. 2). Further west, Landmark

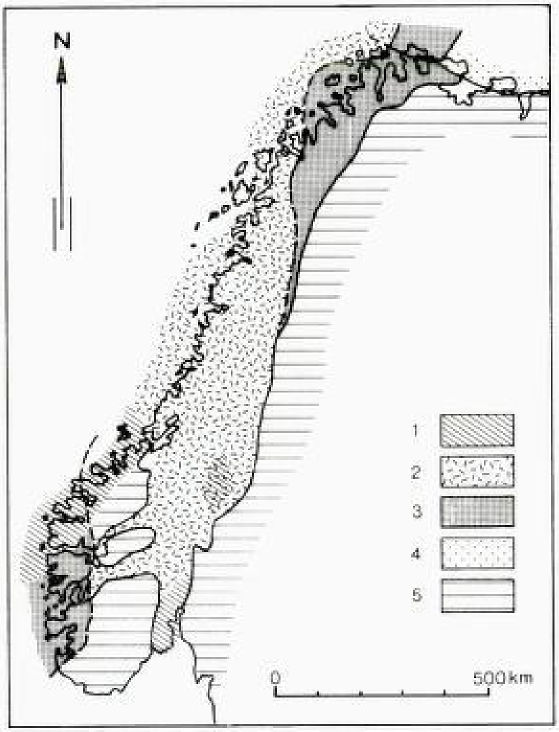

Fig. 8. Generalized representation of zonal distribution of timing of the principal tectonometamorphic episodes within the Scandinavian Caledonides, to show the situation to the south of the Finnmark/Troms region (from Roberts & Gale 1978). For the sake of clarity, older elements incorporated in the Silurian-deformed zone have been ignored. In West Norway the important Cambro-Ordovician event has been highlighted at the expense of the ubiquitous Silurian phase.
1. Devonian deformation. 2. Silurian deformation. 3. Late Cambrian – early Ordovician deformation ('Finnmarkian' in the north). 4. Baikalian deformation. 5. Precambrian deformations.

(1973) distinguished an Upper Nappe, later termed the Tromsø Nappe by Binns (1975), which contains a heterogeneous fairly high-grade sequence of lithologies. Suggested correlations with units in the Narvik region (Gustavson 1972, 1974) are shown in Fig. 2.

Detailed mapping within the confines of the 1:250 000 map-sheet 'Tromsø' is still in its early stages, but from the wealth of data which has emerged from 'Nordreisa' and 'Hammerfest' and by comparison with the situation in Nordland (cf. Nicholson & Rutland 1969) we would expect to eventually recognise an equally complex sequence of nappes, sub-nappes and tectonic slices of a variety of rock-types of dissimilar age, metamorphic constitution and strain history also in these Silurian-deformed western areas. In this way, some of the higher grade Finnmarkian schists and gneisses which represent the immediate basement to the Lyngen Nappe and correlatives may be incorporated as slices and nappes in the Silurian allochthon (Zwaan & Roberts 1978) and older, Precambrian elements may also have found their way into the nappe pile during nappe translation. The extent to which Precambrian crystallines are incorporated would have depended partly on the palæotopographical and geological set-up prior to Ordo–Silurian deposition, but from geochronological studies it is now known (W. Griffin, pers. comm. 1976) that Precambrian elements are far more extensive within the Silurian-translated allochthon in Nordland than hitherto realised.

Recent data from the East Greenland Caledonides has also indicated that

Lower Palæozoic sequences there are less extensive than previously assumed, with tectonic units of Precambrian rocks of regional importance in the westward-transported allochthon (Higgins 1976, Henriksen & Higgins 1977). This parallel situation has been discussed in an orogenic context by Roberts & Gale (1978). It may also be noted, in conclusion, that the effects of Caledonian (Silurian) deformation have been found to be minimal in the Lofoten–Vesterålen area (W. Griffin, pers. comm. 1976, Tull 1977), a finding which places constraints on models for the megatectonic evolution of this segment of the Scandinavian Caledonides.

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Lithostratigraphy of the Late Precambrian Løkvikfjell Group on Varanger Peninsula, East Finnmark, North Norway

S. SIEDLECKI & B. K. LEVELL

Siedlecki, S. & Levell, B. K. 1978: Lithostratigraphy of the Late Precambrian Løkvikfjell Group on Varanger Peninsula, East Finnmark, North Norway. *Norges geol. Unders. 343*, 73–85.

The basal contact of the Løkvikfjell Formation of the former Raggo Group on Varanger Peninsula is an unconformity rather than a thrust as had been previously supposed. A new stratigraphy is formally proposed for this formation which is here upgraded to group status. This stratigraphy is based on new mapping and sedimentological work and allows a stratigraphic framework for the Løkvikfjell Group to be established for the northern part of Varanger Peninsula.

The unconformity is an angular one which implies a previously unrecognised deformation phase in the underlying Barents Sea Group rocks. It also helps to establish the age relations of the Løkvikfjell Group and bears on correlation problems.

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Introduction

Siedlecka & Siedlecki (1967) recognised that Varanger Peninsula is divided by a major fault (the Trollfjord–Komagelv fault) into two stratigraphically distinct geological regions. The northern (Barents Sea) region was thought to be underlain by a c. 9 km-thick succession (the Barents Sea Group, comprising in ascending order the Kongsfjord, Båsnæring, Båtsfjord and Tyvjofjell Formations) which was in turn overlain by the 9 km-thick Raggo Group. The contact between the two groups was interpreted as a thrust, although the actual contact was never observed in this stage of the investigations.

Work by Laird (1972a) and Teisseyre (1972) conformed with Siedlecka & Siedlecki's (1967) view that the Raggo Group was a continuous sequence from the sandstone dominated, cross-bedded, Løkvikfjell Formation at the base into the flysch-like Berlevåg Formation above. Laird also confirmed Siedlecka & Siedlecki's subdivision of the Løkvikfjell Formation into two members: the Sandfjord Member below and the Kjølnes Member above.

From regional mapping, Levell & Roberts (1977) showed that the Berlevåg Formation is thrust over the Løkvikfjell Formation, is of higher metamorphic grade than the latter and constitutes part of the Kalak Nappe Complex. Furthermore, the Kjølnes Member as described by Laird (1972a) was shown to have been partially measured upside-down. The term Raggo Group therefore became invalid.

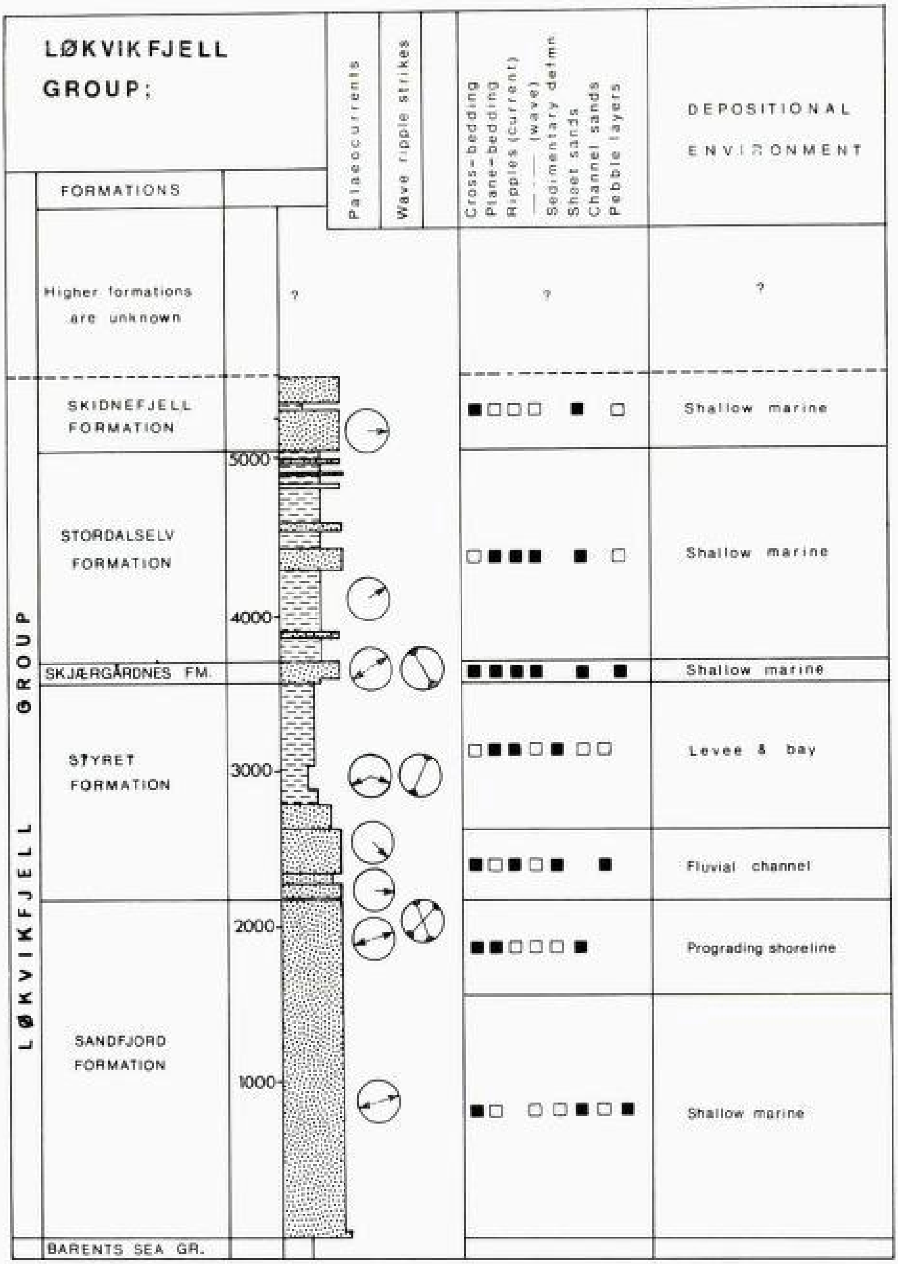

Fig. 1. Stratigraphic and sedimentological summary of the Løkvikfjell Group based on measurements of the type section (Sandfjord – lower Stordalselva Formations) and on estimated sections from the higher formations outcropping down-plunge in the core of the Kjølnes syncline. Solid squares indicate features that are common in the given formation, open squares those that are rare. Dotted arrows indicate the subordinate palaeocurrent directions. Lithologies: dots – sandstone and conglomerate; dashes – shale and siltstone.

The Løkvikfjell Formation in the type area near Berlevåg (Plate 1) has previously been carefully distinguished from similar rocks elsewhere on Varanger Peninsula because no correlation has been established on grounds other than general similarity (Siedlecka & Siedlecki 1972). These rocks were referred to as possible Løkvikfjell Formation correlatives.

The purpose of the first part of this paper is to establish the correlation of all the outcrops of Løkvikfjell Formation and to reinterpret the sharp basal contact as an unconformity. In the second part the Løkvikfjell Formation is renamed the Løkvikfjell Group, and rigorously defined for the first time. It is subdivided into five formations, the Sandfjord, Styret, Skjærgårdnes, Stordalselva og Skidnefjell Formations (Fig. 1).

Løkvikfjell Group outcrops

Various outcrops of the old Løkvikfjell Formation and specifically of the old Sandfjord Member correlatives were roughly shown on Siedlecka & Siedlecki's (1967) map and are indicated with modifications in Plate 1. The main problem of correlation between these outcrops is that lithostratigraphic boundaries are scarce outside the Berlevåg area, where the group is folded into a southwest-plunging syncline, the Kjølnes syncline (Levell & Roberts 1977). Elsewhere, the folding of the Løkvikfjell Group is open or gentle, and facies are constant over large thicknesses (up to 2 km). Consequently, of the five formations erected in this paper, only two have been found to outcrop outside the type area, and one of these (the Styret Formation at Hamningberg) occurs at only one other locality. As a result, only the Hamningberg outlier can be correlated with the type section on the basis of lithostratigraphic *boundaries* (Fig. 2).

Sedimentological work by one of us (B. K. L.) allows *facies* correlation of an unconformity at the base of the group and allows some precision in this correlation.

The Sandfjord Formation in all of the outcrops can be correlated on the basis of lithofacies. The lithologies are predominantly monotonous, thick-bedded, coarse-grained sandstones. These are notably feldspathic (5–25%) and pink or orange in colour. This colour is due to late diagenetic haematite or hydrated iron oxides, which have apparently been produced from the weathering of iron-rich clay minerals (mostly illites). Feldspar types are mostly microclines and perthite, but untwinned K-feldspar, microcline–microperthite and plagioclase (albite) also occur. Rock fragments are scarce but fragments of sheared quartzites, sandstone or metasandstone, quartz–mica rocks and granophyre can be found. Pebbles are predominantly siliceous; vein quartz and sheared quartzites dominate, with red sandstone, jasper and a few quartz–tourmaline rocks also occurring. Most heavy minerals are of stable type and include zircon, rutile, green tourmaline, ilmenite, leucoxene, garnet, epidote, zoisite, clinozoisite and sphene.

The sandstones are well sorted with very well rounded grains. The beds are notably parallel-sided as seen in several cliff exposures. Occasionally the bedding is defined by very thin pebble layers sometimes only a single grain diameter thick (about 5 cm); these layers are apparently derived by reworking from underlying pebble-rich beds. The principal structure is trough cross-bed-

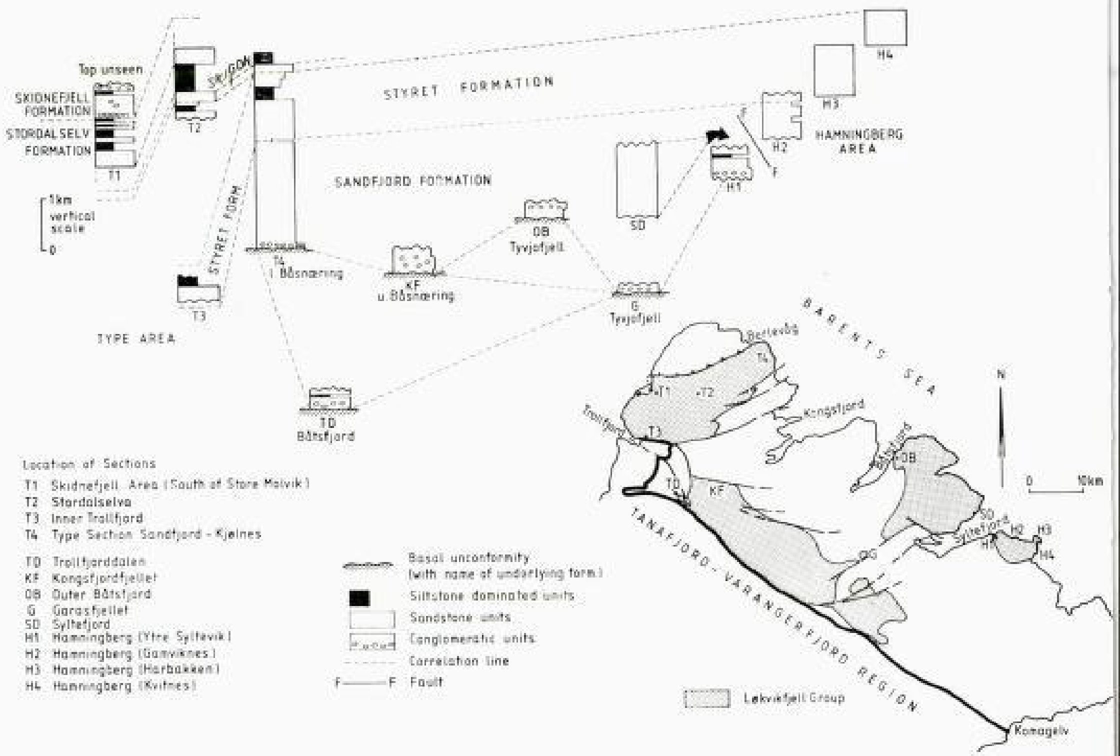

Fig. 2. Fence diagram showing the locations of measured (K2–4, KF, H1–4) and estimated (T1, TD, OB, G, SD) sections through the Løkvikfjell Group. Lithostratigraphical correlations are indicated by the dotted lines.

ding with subordinate tabular sets of planar or convex-upward cross-bedding, and rare wave ripples. Palaeocurrents from all outliers are uniformly towards the east or northeast which suggests that any tectonic rotation between the outcrops is small. There is generally more variability in palaeocurrents (with reversed sets fairly common) in the lower 400 m of the Sandfjord Formation.

In summary, the similar petrography and palaeocurrent pattern and the consistent appearance of the facies over the neighbouring outliers are regarded as sufficient grounds for suggesting that they all expose the same stratigraphic units. The details of the suggested correlations are shown in Fig. 2. The possible Løkvikfjell Formation correlatives are therefore all part of the new Sandfjord Formation.

The basal unconformity

In most localities the base of the Løkvikfjell Group is not exposed. However, in several places, notably Outer Båtsfjord, Trollfjorddalen and Inner Sandfjord it is possible to see the contact.

In Outer Båtsfjord (OB, Fig. 2), the contact is a sharply defined, planar surface (Figs. 3 and 4) between underlying, red and grey sandstones of the

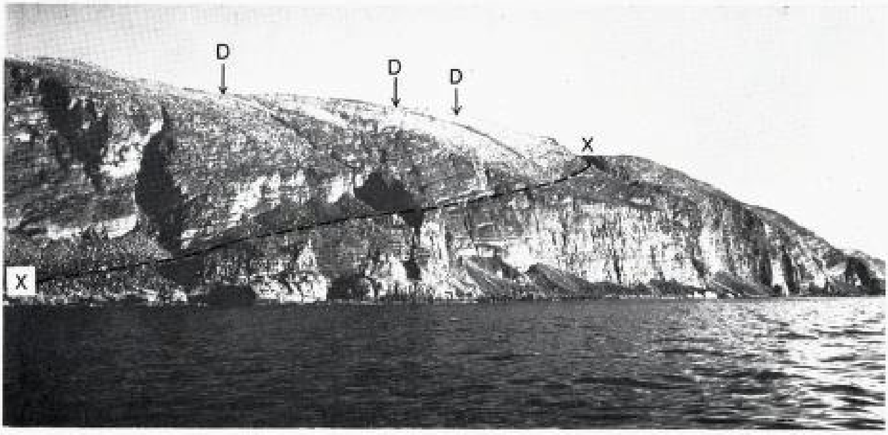

Fig. 3. The contact between the Tyvjofjell Formation (Upper Barents Sea Group) and the Løkvikfjell Group ,eastern coast of Båtsfjord. This contact (x-x) is cut by dolerite dykes (D) dated by Beckinsale et al. (1975) at 651 ± 19 ma. B.P. Photo: S. Siedlecki.

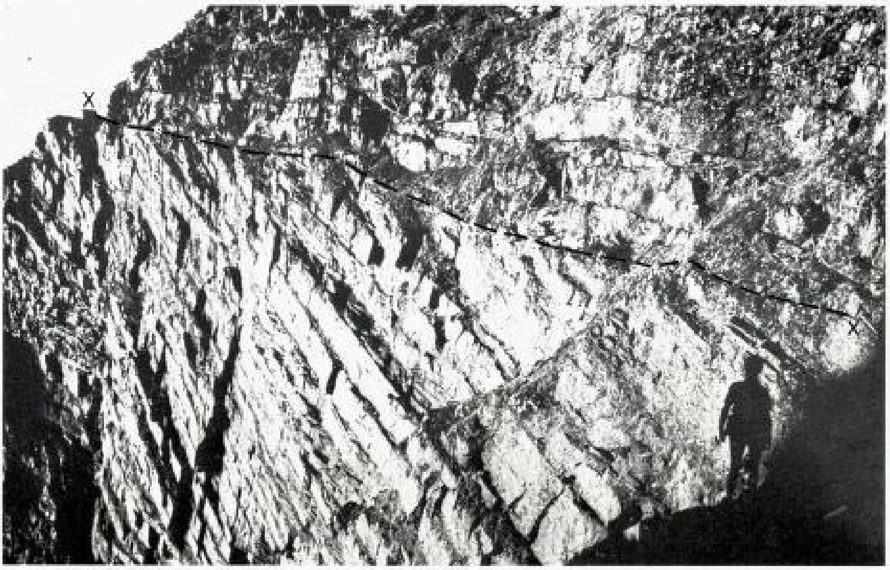

Fig. 4. Closer view of the sharp planar contact (Fig. 3), interpreted as an unconformity (x-x), between the underlying Tyvjofjell Formation dipping south-east and nearly flat-lying Løkvikfjell Group above. The figure (shadow) is approximately 2 m tall. Photo: S. Siedlecki.

Tyvjofjell formation (uppermost Barents Sea Group) and the pink, coarse, pebbly, feldspathic sandstones of the Sandfjord Formation. Pebbles near the contact, and the sandstone fabric, are unsheared, and there is no evidence of small-scale deformation in either unit. The contact is a simple angular junction. The Tyvjofjell Formation dips gently (20°SE) and the Sandfjord Formation even more gently (5°N). The contact can be observed for at least 2 km along the coast. The lack of evidence of tectonic disturbance along the contact suggests that it is an unconformity rather than a thrust.

Other exposures are less striking. In Trollfjorddalen (Fig. 2 – ID) at two localities, the Sandfjord Formation can be seen to rest abruptly, and without significant deformation, on the Båtsfjord Formation sandstones. In the Sandfjord area (T4, Fig. 2) the contact can be observed continuously for several hundred metres in inland exposures. It has been later folded along NE–SW axes, with the anticlines frequently being faulted out on the same trend. Stretched pebbles are found in the cores of the synclines. The contact, against the lower Båsnæring Formation, (middle Barents Sea Group) is sharp. The lowest unit of the Sandfjord Formation here is a 20 m-thick conglomeratic (cobble grade) horizon, and this can be traced along the contact without thickness variation for several kilometres. This contact may be either an unconformity or a bedding-parallel fault.

Generally, facies relations are not constant along the unconformity and there is no well defined conglomerate, although the lower 400 m of the Sandfjord Formation is usually pebble-rich. Also, the sharpness of the basal surface and the relative scarcity of clasts which can be directly matched with the underlying rocks are notable. Vein quartz is the dominant clast type, though a variable proportion of red or grey sandstone clasts similar in lithology to those of the Tyvjofjell and Båtsfjord Formations does occur (Fig. 5). The lack of channelling, the good sorting (both texturally and mineralogically) and the facies types in the Sandfjord Formation suggest that the unconformity is shallow marine in origin, rather than fluvial or subaerial. In no locality has weathering of the underlying rocks or any significant relief been found along the contact.

Significance of the unconformity

The unconformity implies that the Løkvikfjell Group is younger than the Barents Sea Group, for which a preliminary Rb/Sr whole rock isochron date on Kongsfjord Formation rocks gives an age of about 828 ± 60 m.y. B.P. (A. Råheim, pers. comm. 1977). Moreover, K/Ar dates (from the Båtsfjord dyke swarm; Beckinsale et al. 1975) suggest that the Løkvikfjell Group is older than 640 m.y. This brackets the Løkvikfjell Group within the late Precambrian age that was originally assigned to it (Siedlecka & Siedlecki 1967).

The attitude of lithologies above and below the unconformity surface suggests some tilting of the Barents Sea Group prior to Løkvikfjell Group deposition (Plate 1). This deformation may have been a simple south-eastward tilting resulting in the Løkvikfjell Group resting on progressively older formations westwards, hence it oversteps from Tyvjofjell to Båtsfjord to (?) Båsnæring Formation in this direction. The outcrops with definite unconformable contacts are too few to substantiate this conclusively.

Previously it was argued that the principal fold-producing deformation of the Barents Sea Region was single phase and of Caledonian age (Roberts 1972). Subsequently Beckinsale et al. (1975) postulated a Precambrian deformation phase based on K/Ar ages of dolerite dykes which cut the supposedly thrust contact of the Løkvikfjell Group on the Barents Sea Group in outer Båtsfjord. However, as this contact is now thought to be unconformable, there is no reason

Fig. 5. Hand specimen from across the unconformity (x-x) of Løkvikfjell Group on Båtsfjord Formation some 11 km from the head of Trollfjord, in Trollfjorddalen. Rounded pebbles of sandstone in the conglomerate closely resemble the underlying lithologies. Thin-sections taken across the actual contact show no evidence of any deformation. Scale in mililmetres. Photo: I. Aamo.

for accepting these dates as 'post-tectonic'. The angular unconformity does however imply some tilting of the Barents Sea Group prior to Løkvikfjell Group deposition, so a Precambrian deformation phase must have occurred.

The later folding of the Løkvikfjell Group and its basal unconformity is open or gentle in the east of the area. In the west, however, both the Løkvikfjell and Barents Sea Groups are folded into tight anticlines and synclines over a distance of several kilometres. Any evidence of gentle Precambrian tilting, is here destroyed by subsequent folding. The age of this later folding may be similar to that in the Kalak Nappe Complex (and the Berlevåg Formation) and hence be Caledonian.

Dyke dating of the syn-folding Kongsfjord dyke swarm has unfortunately been inconclusive (R. Beckinsale, pers. comm. 1976). The occurrence of a distinctive black siltstone in the Lower Sandfjord Formation in both the Hamningberg and the Trollfjorddalen areas suggests that these outcrops may possibly have been nearer each other than they are now. Within the Sandfjord Formation there is a general fining, and an increase in the proportion of siltstone to the east. The Trollfjorddalen outcrop would fit this facies pattern better if it were located south of Hamningberg along the main Trollfjord–Komagelv fault. This would be in line with the suggestions of Roberts (1972) and Johnson et al. (1978) that there had been dextral movement along this fault zone.

Numerous possible correlations have been proposed for the Løkvikfjell Group with sequences in East Greenland, Svalbard and further west in Finnmark (Laird 1972a and b, Siedlecka & Siedlecki 1972). In the light of the recognition of the unconformable relationship with the Barents Sea Group, these ideas will need reassessment.

The Løkvikfjell Group: Lithostratigraphy

Following the work of Levell & Roberts (1977) the term Raggo Group is invalid and it is therefore proposed that the name Løkvikfjell Formation be upgraded to Løkvikfjell Group to allow the units into which it is divided (one of which is two kilometres thick) to be called formations. The stratigraphy of the group is given in Fig. 1.

Name of the group

Løkvikfjell is a hill to the west of Sandfjord some 10 km southeast of Berlevåg.

Type area

The type area is the northwestern outcrop of the Løkvikfjell Group, which extends from Sandfjord to Berlevåg on the Barents Sea coast, and from Store Molvik to Trollfjord on Tanafjord. Type profiles for all five formations are to be found in this area, which is the only one in which the three higher formations are exposed.

Thickness

The group is at least 5.6 km thick (Fig. 1).

Boundaries

The base of the group is taken at the unconformity, discussed above, on the underlying Barents Sea Group. The top is unknown.

SANDFJORD FORMATION

Name of the Formation

Sandfjord is a sandy bay some 9 km southeast of Berlevåg. The formation includes only the lower 2 km of Laird's (1972a) Sandfjord Member.

Type Profile

The only known continuous and possibly complete section through the formation is that on the west side of Sandfjord, along the coast and cliff to the west side of the bay Storsteinbukten. This is taken as the type profile (Fig. 1), see also Johnson et al. 1978).

Thickness

This formation is the most extensive of the Løkvikfjell Group with an inferred minimum areal extent of about 300 km^2. It is 2 kilometres thick.

Lithology

This is described on page 76. A largely shallow marine origin is proposed by Levell (thesis, in prep.).

Boundaries

The lower boundary is taken at the plane of unconformity on the Barents Sea Group which forms the base of the Løkvikfjell Group as discussed above. The upper boundary with the overlying Styret Formation is transitional and occurs as a coarsening-upward sequence of plane-laminated, fine- to medium-grained fawn sandstones. This lithofacies can be found both in the type section and in profiles at Hamningberg. The precise boundary is best taken at the base of the first, coarse-grained, thick-bedded sandstone above this sequence.

STYRET FORMATION

Name of the Formation

Styret is a point on the coast midway between Kjølnes and Sandfjord.

Type profile

The type section is that on the coast between Storsteinbukten and Styrelven.

Thickness

Approximately 1.5 km at the type profile. The maximum thickness of 1.6 km occurs at Hamningberg where the top of the formation is unseen. These two sections are some 60 km apart.

Lithology

Thick-bedded, green or grey sandstone interbedded with thick units (up to 20 m) of dark siltstone form the main lithologies. The sandstone to siltstone ratio is very variable, in the type section the lower half is dominantly sandstone (70%), and the upper half dominantly siltstone with medium-bedded sandstone. At Hamningberg where the formation is thicker, the lower half is mostly (70%) sandstone and the upper half is almost completely (95%) sandstone.

Characteristically, the sandstones are lenticular and have erosional bases which down cut as much as 9 m. In laterally extensive exposures several channel sequences can be mapped; the sandstone bodies filling these are up to 700 m wide and 10–20 m thick. The sandstones are, as a rule, slightly more feldspathic than those of the Sandfjord Formation, but are still sub-arkosic with mixed quartz/calcite cements. Pebbles occur but are generally less than 5 cm in diameter. They include vein quartz, red sandstone and feldspar, and are generally less abundant than in the Sandfjord Formation. Sedimentary structures in the sandstones are principally through cross-bedding, with ripple cross-lamination, wave ripples and plane-lamination characterising the silt units. Soft sediment deformation is abundant in the form of type B pillars (Lowe 1975) up to 3 m high and over-steepened cross bedding. Palaeocurrents are dominantly towards the southeast, though the variance is large. A largely fluvial origin is suggested for the formation by Levell (in prep).

Boundaries

The lower boundary of the formation is placed at the base of the first, coarse, green-grey, thick-bedded sandstone above the thin-bedded, plane-laminated lithofacies at the top of the Sandfjord Formation. The upper part of the formation is a siltstone-dominated, thin-bedded facies and is transitional over about 300 m with a slightly more sandy, silty and sandy streak facies (de Raaf et al. 1965) above. The best mapping boundary is probably the last occurrence of the silty and sandy streak facies beneath the thick, planar-based sheets of cross-bedded sand belonging to the overlying Skjærgårdnes Formation. The boundary in the type area between the silt-dominated lithologies in the upper half of the formation and the sand-dominated lithologies in the lower half is a good mapping boundary and was used by Laird (1972a) as the boundary between his Kjølnes and Sandfjord Members. It enables the formation to be divided (in the type area only) into two informal members: an upper siltstone member and a lower sandstone member. A predominantly fluvial environment of deposition is proposed by Levell (in prep.).

SKJÆRGÅRDNES FORMATION

Name of the formation

Skjærgårdnes is a point on the coast near Berlevåg some 2 km southeast of the lighthouse at Kjølnes.

Type profile

The best exposed section through the formation is that along the coast around the point at Skjærgårdnes.

Thickness

The formation is 210 m thick and maintains this thickness throughout its outcrop.

Lithology

Within the type area the formation shows a remarkably constant facies pattern, and is characterised by medium- to thick-bedded, coarse-grained, sandstone unts interbedded with siltstones and mudstones. The sandstones are tabular in geometry and can be traced up to 300 m along strike. Internally they are cross-bedded with occassional tabular herringbone sets, and abundant wave ripple cross-lamination. Synaeresis cracks are common. The tops of sandstone units frequently have concentrations of small pebbles and granules, sometimer only a single grains thick, composed chiefly of quartz. Petrographically the sandstones are moderately sorted sub-arkoses. Palaeocurrents from the abundant cross-bedding are predominantly towards the northeast, with wave ripple strikes almost exactly orthogonal to this. A shallow marine origin is proposed by Levell (in prep.).

Boundaries

The lower boundary is taken as the first occurrence of planar-based sandstones above the silty and sandy streak facies of the upper part of the Styret Formation. The upper boundary is transitional into the Stordalselva Formation over about 20 m, but can be taken as the top of the last sandstone unit which is greater than 1 m thick. Generally, the proportion of sandstone to siltstone decreases rapidly at the top of the formation.

Lithologies younger than the Skjærgårdnes Formation have been found only in coastal exposures in the core of the Kjølnes syncline where they are affected by tight, mesoscopic folding and cut by a spaced cleavage (Levell & Roberts 1977). This tectonic deformation hinders the establisment of a precise stratigraphy. It is probably advisable at our present state of knowledge to regard all the units occurring between the easily recognisable Skjærgårdnes and Skidnefjell Formations as constituting a single major unit (the Stordalselva Formation).

STORDALSELVA FORMATION

Name of the formation

Stordalselva is a river entering the sea at Berlevåg and which breaches the Kjølnes syncline some 10–12 km southwest of Berlevåg. The valley Stordalen contains the best exposures of the greater part of the formation.

Type profile

No continuous section was measured for the formation but sections were estimated from the Stordalen valley and from the area immediately north of outer Trollfjorden, on the southeast limb of the Kjølnes syncline. Little detailed work has been done on this unit.

Thickness

The total thickness is estimated as 1.2 km.

Lithologies

The formation consists of several, 20–200 m-thick sandstone units interbedded with 100–500 m-thick, medium-bedded, mixed sandstone and siltstone units. The sandstone members form good, traceable mapping horizons which allow some of the mesoscopic and macroscopic folding in the axial region of the syncline to be determined. They consist of coarse, white, pebble-bearing, sandstones. The beds have a tabular geometry and contain tabular, decimetre-scale sets of cross-bedding, with palaeocurrents to the northeast. Occasional sandstone units within this facies are granular and resemble those of the Skjærgårdnes Formation.

The heterolithic units are dominated by wave ripple cross-laminated or plane-laminated, medium-grained sandstones and siltstones, with synaeresis cracks. Beds are generally less than a metre thick and tabular. The vertical variation in facies is much greater than that in the underlying formation. A shallow marine origin is proposed by Levell (in prep.).

Boundaries

The lower boundary is taken at the last metre-thick sandstone at the top of thick-bedded sandstones assigned to the Skjærgårdnes Formation. The upper boundary is taken as the base of the first, thick, pebble-bearing, coarse sandstone of the Skidnefjell Formation. This latter boundary is generally marked by the geomorphological change from the frost-scattered blockfields of Skidnefjell Formation sandstones, to the grassed slopes of the mixed lithologies beneath. It is an easily mappable contact although actual exposures are scarce.

SKIDNEFJELL FORMATION

Name of the formation

Skidnefjell is a flat-topped, blockfield-covered hill north of Trollfjord.

Thickness

The top of the formation is unknown, and the thickness is estimated as greater enn 800 m.

Type profile

The best exposed section, although difficult of access, is the coastal section from outermost Trollfjord to Fugleviken.

Lithology

The formation bears a remarkable similarity to the Sandfjord Formation and consists of monotonous, white, creamy white or buff, medium- to thick-bedded, coarse sandstones, locally feldspathic, and occasional thin layers of granule conglomerate, with abundant small pebbles of white and pink vein quartz and quartzite, and sometimes of red sandstone. These may occur as only one pebble thick lags on bedding planes. A basal conglomerate on the south side of Skidnefjell is 40–45 cm thick and consists of pebbles mostly of quartz or quartzite up to 4 cm across in a sandy matrix but also fragments of the subjacent siltstone (D. Roberts, pers. comm. 1977).

Cross-bedding is the predominant structure in the sandstones, generally in decimetre-thick trough sets but also in planar sets up to 2 m thick. Wave ripples are the only other recorded primary structure in the sandstones. Two siltstone units (each less than 50 m thick) characterised by occur within the formation and can be used as convenient mapping horizons, although folding and sliding have resulted in local repetition of the sequence.

Boundaries

The lower boundary of the formation is transitional over 20 m with a thin coarsening-upward sequence from the mixed lithologies below; however, the first occurrence of pebble-rich beds is abrupt and forms an easily mappable horizon. The top of the formation, and thus of the group, is nowhere exposed.

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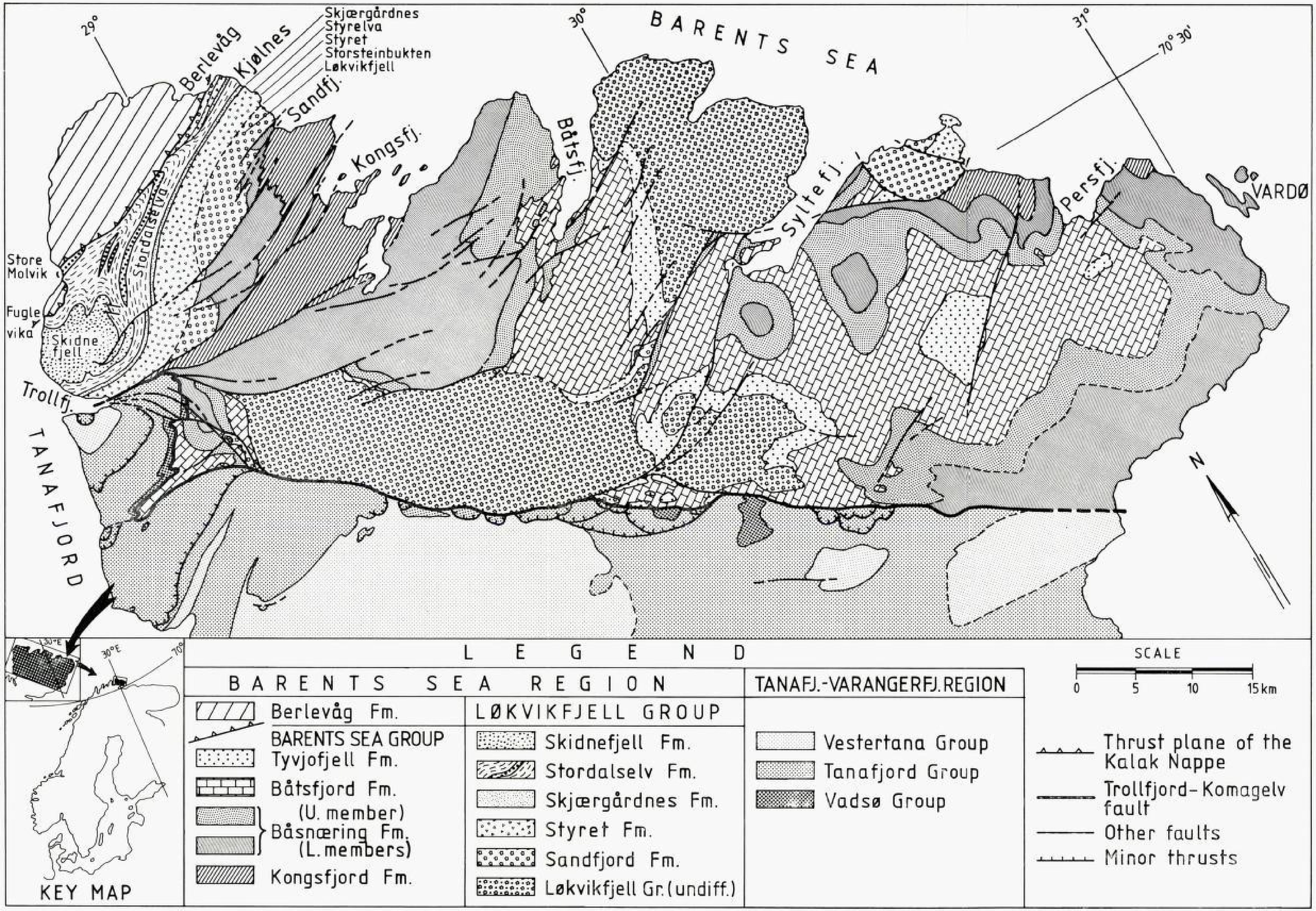
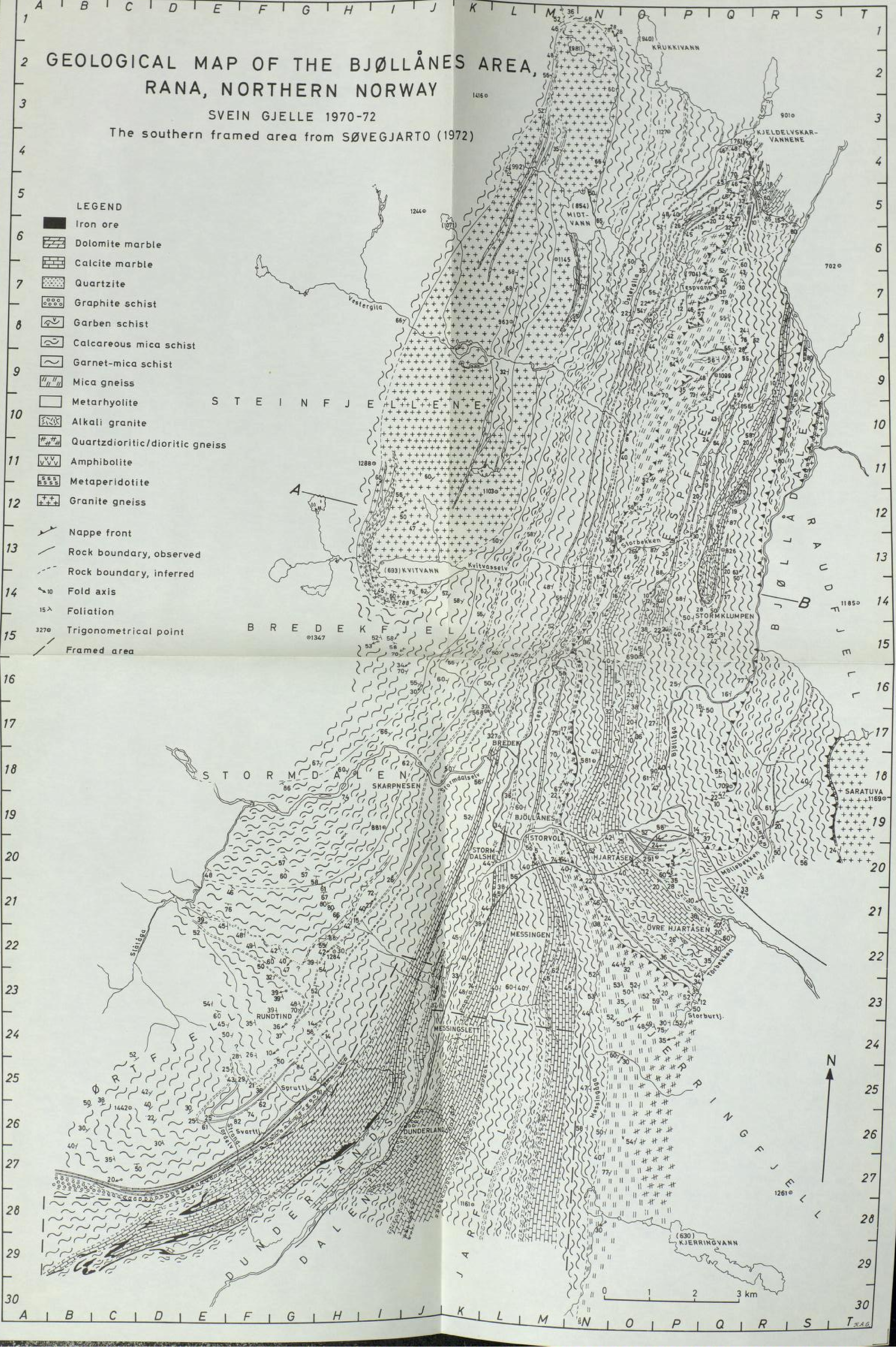


Plate 1. Geological map of the Barents Sea Region, based largely on the mapping of S. Siedlecki, with contributions by A. Siedlecka, B. K. Levell and D. Roberts. Areas of undifferentiated Løkvikfjell Group have not been mapped in detail but are probably composed mainly of Sandfjord Formation. (Fig. 3).

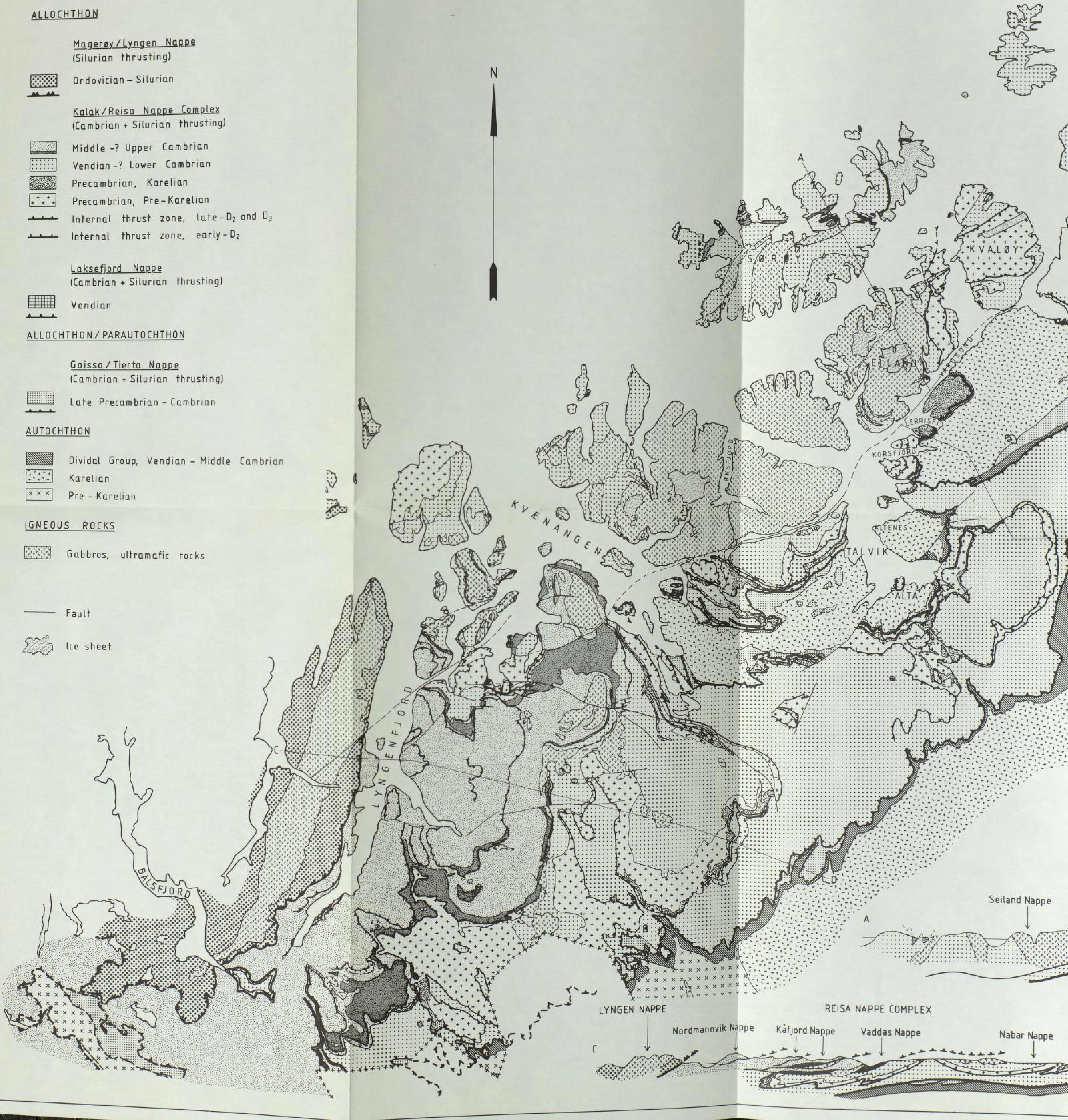
GEOLOGICAL MAP OF THE BJØLLÅNES AREA, RANA, NORTHERN NORWAY

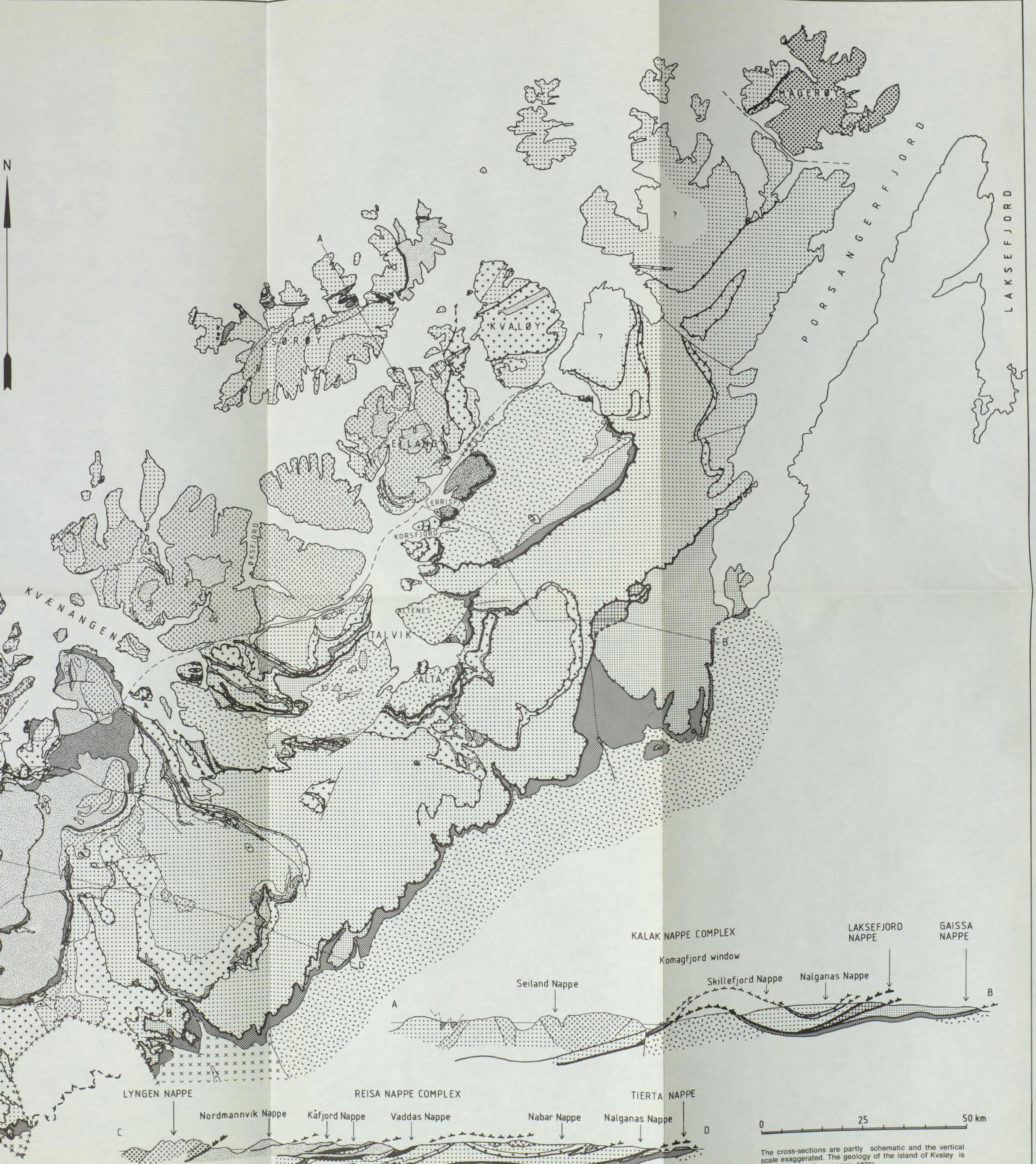
SVEIN GJELLE 1970-72

The southern framed area from SØVEGJARTO (1972)



TECTONOSTRATIGRAPHIC MAP, WEST FINNMARK - NORTH TROMS





The cross-sections are partly schematic and the vertical scale exaggerated. The geology of the island of Kvaløy is after Ø. Jansen (pers.comm. 1976).

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