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

K. B. ZWAAN & D. ROBERTS

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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

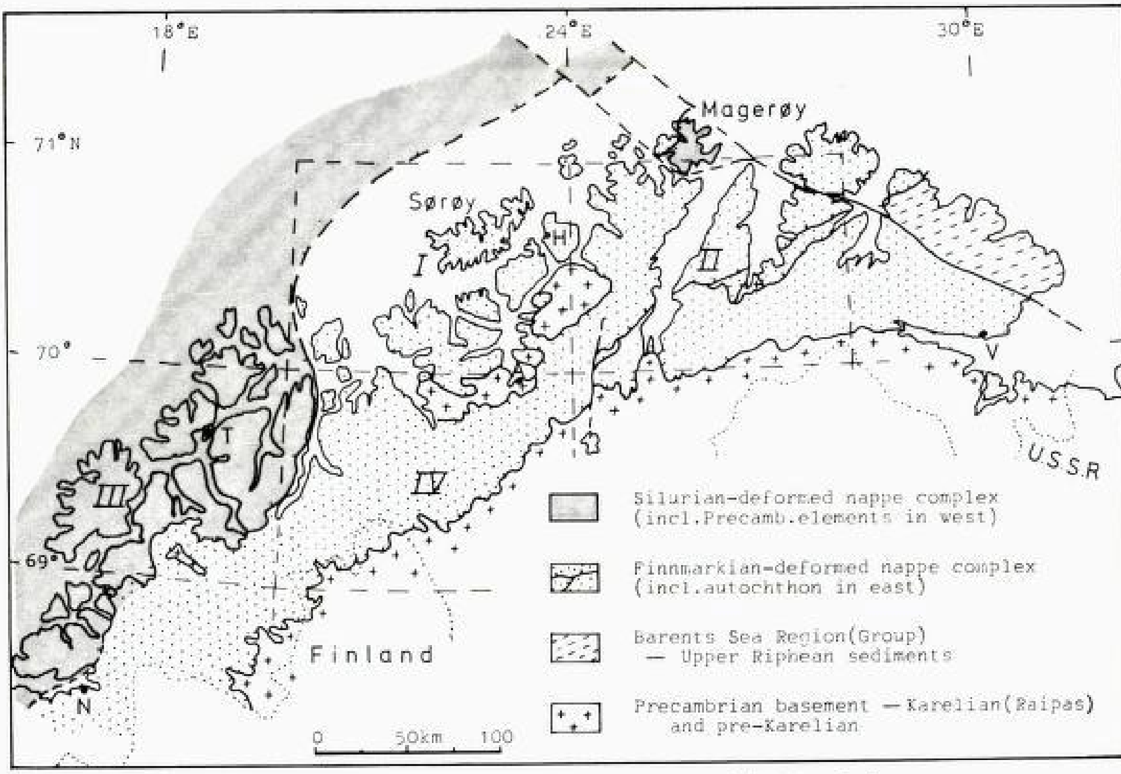


Fig. 1. Simplified outline map of northern Norway to show the principal division of the Caledonian allochthon, and the limits of the 1:250 000 map-sheets 'Hammerfest' (I), 'Honningsvåg' (II), 'Tromsø' (III) and 'Nordreisa' (IV). A – Alta; H – Hammerfest; N – Narvik; T – Tromsø; V – Vadsø. The Nordkyn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

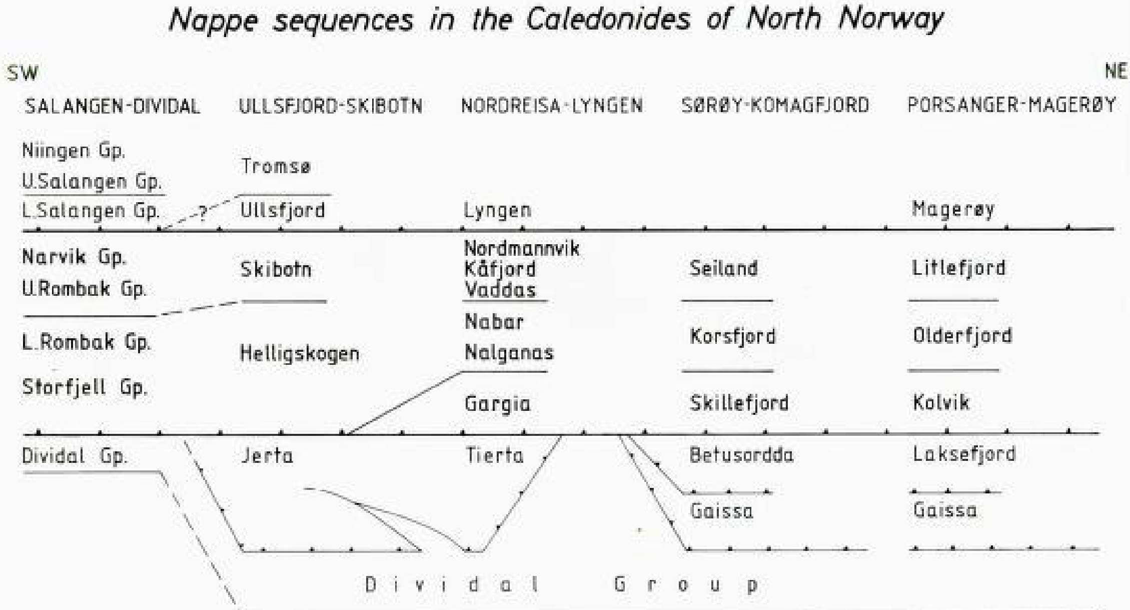


Fig. 2. Correlation of nappe sequences in the Caledonides of North Norway. The Kalak/Reisa Nappe Complex is ornamented. The principal references for the nappe stratigraphy in the various columns are as follows: – Salangen–Dividal (Gustavson 1972, 1974); Ullsfjord–Skibotn (Binns 1975); Nordreisa–Lyngen (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;

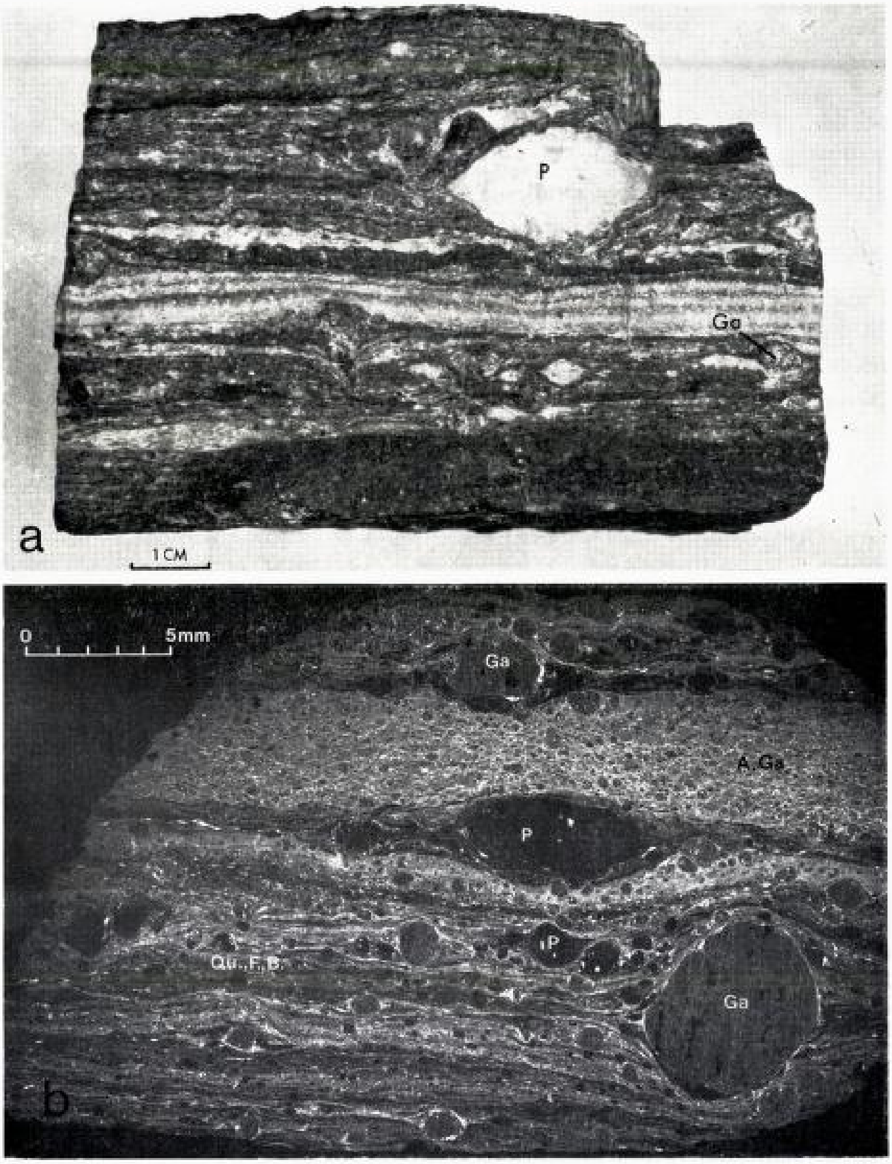


Fig. 4. (a) Blastomylonite from the basal thrust zone of the Vaddas Nappe, Specimen no. 634a. Map-sheet 'Kvænangsbotn' 1734 II (2640 3725). P – plagioclase; Ga – garnet.
(b) Photomicrograph of specimen no. 634a (Fig. 4a). Crossed nicols. P – plagioclase; Ga – garnet; A – amphibole; Qu, F, B – Quartz,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

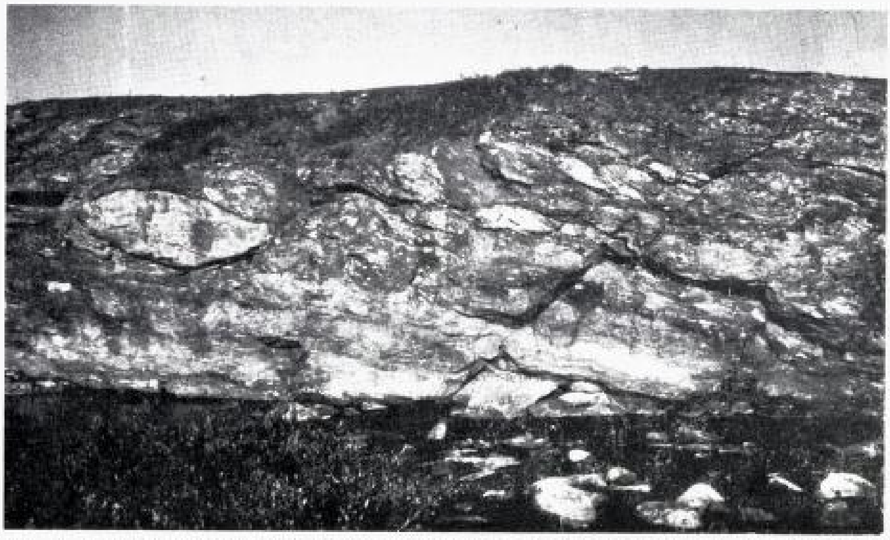


Fig. 5. Mega-blastomylonite in a thrust zone within the Nabar Nappe. The prominent lenticular bodies consist either of Precambrian gneisses (these occur in situ above the thrust zone) or of Vendian meta-arkose (which occurs below the thrust zone). From Signugåppi, map-sheet 'Mållesjåkka' 1733 I (264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

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

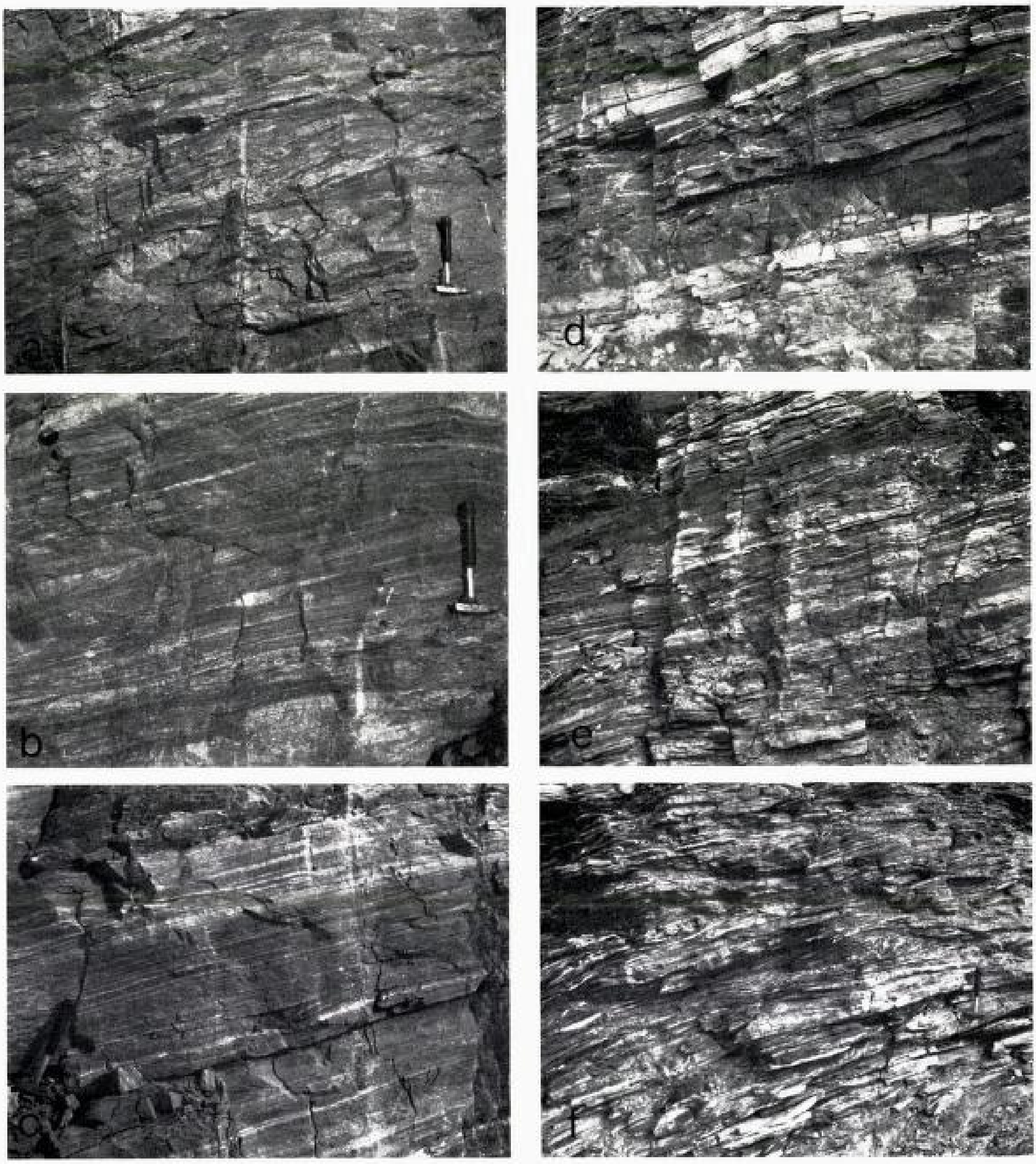


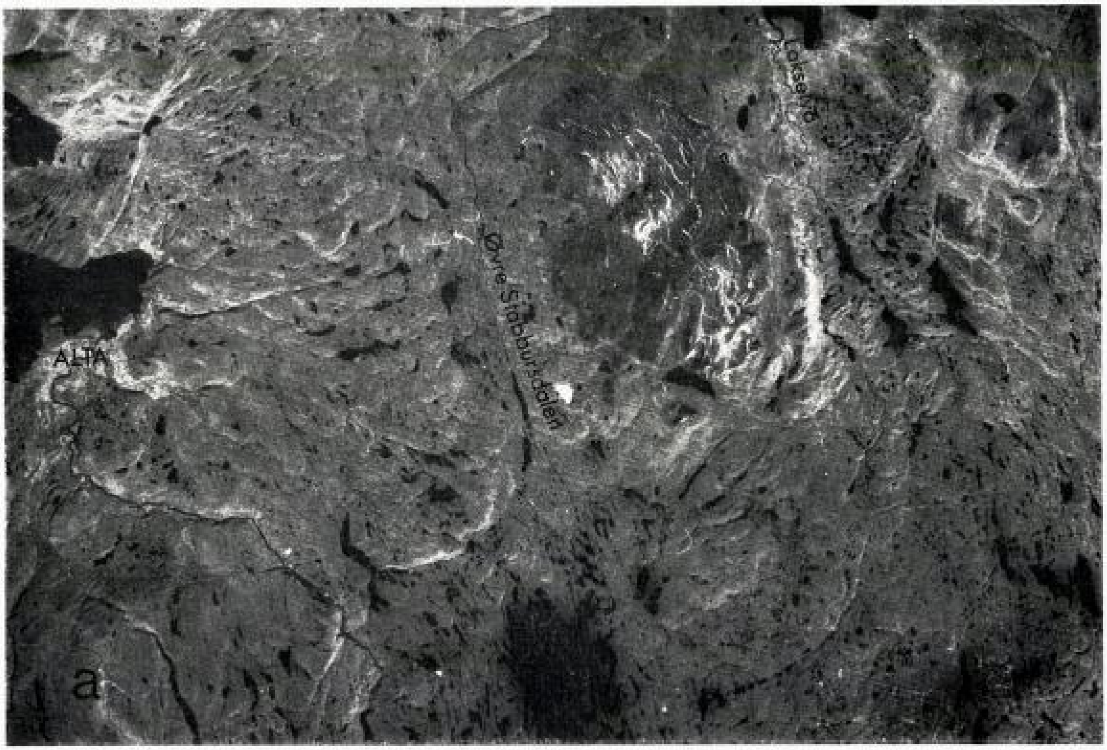
Fig. 6. Two examples of progressive deformation of gneissic units in the allochthon on the southwest side of the Komagfjord window. Photo series *a*, *b*, *c*, from the north side of Skillefjord, shows the gradual transformation of a medium-grained, grey gneiss with pegmatitic schlieren into a strongly 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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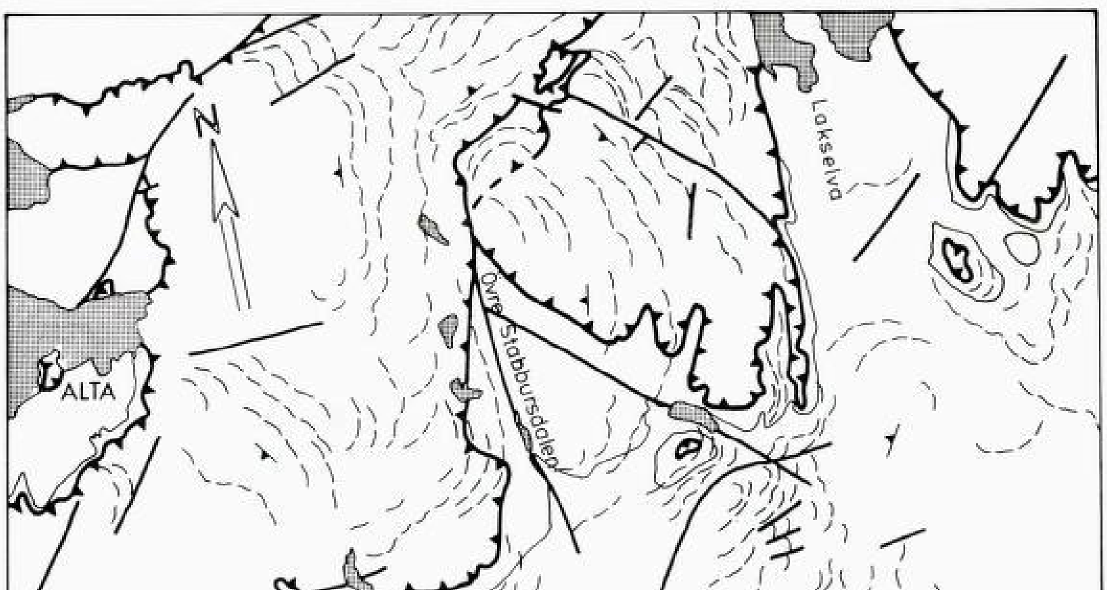
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scales is related to this D_3 phase. Elsewhere, renewed movement along earlier-established, middle greenschist facies, mylonitic thrust zones, including the basal Kalak and lower thrusts, yielded low-T, retrograde, cataclastic fabrics (Sturt et al. 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

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

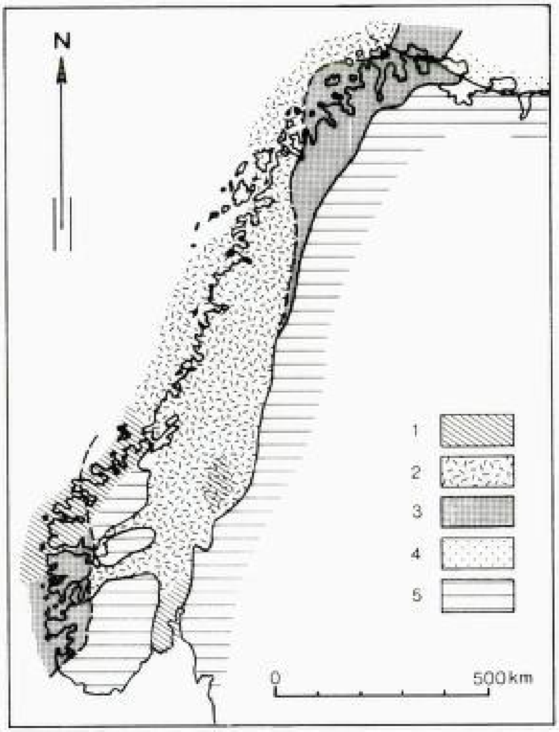

Fig. 8. Generalized representation of zonal distribution of timing of the principal tectonometamorphic episodes within the Scandinavian Caledonides, to show the situation to the south of the Finnmark/Troms region (from Roberts & Gale 1978). For the sake of clarity, older elements incorporated in the 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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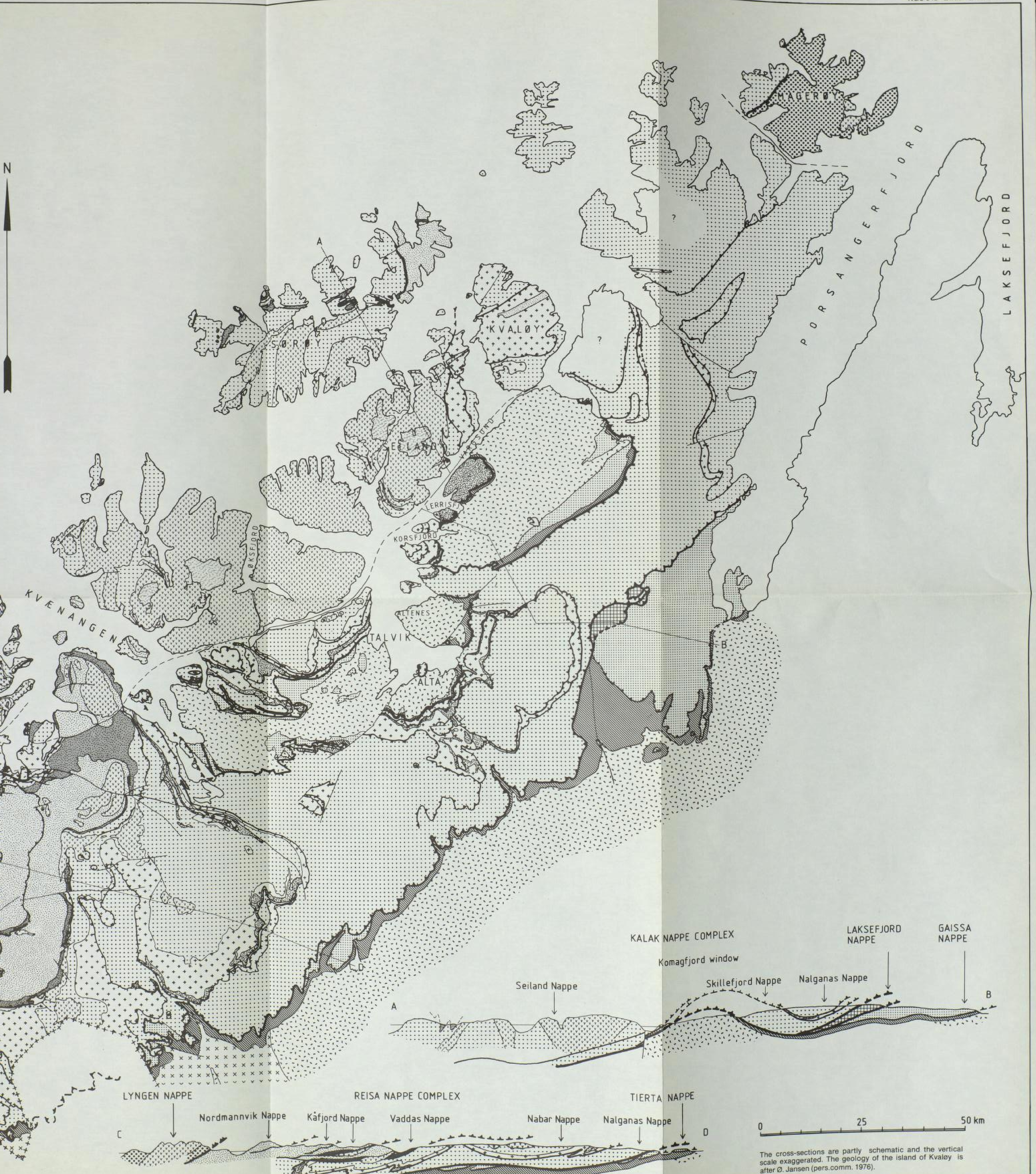

The cross-sections are partly schematic and the vertical scale exaggerated. The geology of the island of Kvaløy is after Ø. Jansen (pers.comm. 1976).

TECTONOSTRATIGRAPHIC MAP, WEST FINNMARK - NORTH TROMS