The Caledonian Fold Belt in Finnmark: a Synopsis

DAVID ROBERTS

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The Caledonian allochthon in Finnmark embraces 4 major nappes or nappe complexes named, from bottom to top, the Gaissa, Laksefjord, Kalak and Magerøy. Of these the 3 lower nappe complexes acquired their internal deformation structures and largely ductile basal mylonite fabrics (ultracataclasite in the case of the Gaissa) during the late Cambrian - early Ordovician *Finnmarkian* orogenic phase. The Magerøy Nappe, on the other hand, was internally deformed and thrust to its present position during the late Silurian to earliest Devonian *Scandian* orogenesis. Evidence of Scandian heating and final translation of the subjacent Kalak Nappe Complex is found in radiometric data and in diaphthoretic cataclasites overprinting ductile mylonites.

The Finnmarkian nappes are composed of both late Riphean to earliest Ordovician (lower Tremadoc) sedimentary sequences and tectonically incorporated sheets of Archaean gneissic rocks and Proterozoic volcanosedimentary assemblages of Baltoscandian affinity. Within the higher nappes, lower parts of the sedimentary 'cover' successions are found to lie unconformably upon the Precambrian rocks in several areas. In the autochthon and parautochthon the sedimentary sequences ranges in age from late Riphean to late Cambrian and includes the Varangian tillites. The metasedimentary succession in the Magerøy Nappe is of definite early Silurian age, and possibly in part late Ordovician. Syntectonic plutonic complexes occur in both the Finnmarkian- and the Scandian-deformed nappes.

As shown by geochronological evidence, Finnmarkian deformation and metamorphism began in the orogenic interior, far to the west, in the middle to late Cambrian, at which time rocks now in the upper Kalak were metamorphosed in highest amphibolite facies. This orogenic deformation migrated diachronously southeastwards, occurring at gradually shallower crustal levels and in lower metamorphic grades, and ultimately affected the rocks in the lowest nappes and parautochthon in post-early Tremadoc time. Thrusting is largely post-metamorphic and this, too, developed successively, in piggy-back fashion, in the principal direction of southeastward translation. Lower nappes in particular show internal imbricate zones and duplex structures, and the parautochthon is considered to be floored by a blind thrust. Tectonic windows of Proterozoic rocks in west Finnmark are probably parautochthonous to allochthonous, rather than autochthonous as traditionally believed. Scandian deformation and metamorphism in the Magerøy Nappe varied from greenschist to upper amphibolite facies. These rocks were then translated east-southeastwards along a thrust zone which locally attained sillimanite grade.

Faulting is an important component of Caledonian deformation and includes the NW-SE, dextral strike-slip, Trollfjord-Komagelv Fault Zone, a paleotransform structure in late Precambrian to Cambrian time, but which also shows evidence of late Caledonian and younger movements. Many faults elsewhere in Finnmark are polyphase structures with rejuvenations in late Palaeozoic, Mesozoic and Cenozoic time, some in connection with the opening of the Norwegian Sea.

David Roberts, Norges geologiske undersøkelse, Postboks 3006, N-7001 Trondheim, Norway.

Introduction

The county of Finnmark is dominated geologically by rocks of the Caledonian fold belt. Extending for some 370 km from the Andsnes Peninsula, Kvænangen, in the west to Varanger Peninsula in the east, the nappes of the metamorphic allochthon overlie a generally thin autochthonous sedimentary sequence deposited upon a peneplaned surface of deeply eroded Proterozoic and Archaean crystalline rocks. Towards the east, in the Varangerfjord region, the autochthonous (or parautochthonous) sediments are considerably thicker and are juxtaposed, across a major NW-SE-trending fault, against a sedimentary package, the Barents Sea Group, which appears to represent a tectonic incursion of rocks foreign to the Baltoscandian foreland milieu encountered elsewhere in Finnmark. These relationships are described a little more fully later in this account.

Our present knowledge of stratigraphy and tectonostratigraphy of the Finnmark Caledonides stems largely from the work of Reading (1965), Føyn (1967, 1969) and Sturt et al. (1975). Several synoptic or review articles followed during the 1970's, each reflecting the existing state-of-the-art (Gayer 1971, Gayer & J. Roberts 1974, Ramsay 1971, Siedlecka & Siedlecki 1972, Sturt et al. 1975, 1978, Williams et al. 1976, Sturt & Roberts 1978, Zwaan & Roberts 1978). In more recent time regional syntheses, stressing different themes, have been given by Føyn (1985) and Ramsay et al. (1985a) and a review of basin development on Varanger Peninsula by Siedlecka (1984).

The present contribution is concerned with highlighting aspects of recent mapping and research, and assessing how these results affect current models of Caledonide evolution of this part of the mountain belt. As a preliminary to this exercise it is, however, necessary to outline the main features of the tectonostratigraphy and of the lithostratigraphic successions occurring throughout the region.

Tectonostratigraphy

In terms of the now fairly well known major tectonostratigraphic divisions of the Scandinavian Caledonide orogen, the nappes of Finnmark belong for the most part to the Lower and Middle Allochthons (Fig. 1), with the Upper Allochthon represented only on Magerøy. Characteristic features of these allochthons are described elsewhere (Roberts & Gee 1985). Briefly, the Lower Allochthon (and subjacent Parautochthon and Autochthon) in northern Norway is dominated by Late Precambrian to Tremadoc sedimentary rocks, while the Middle Allochthon consists of both Precambrian crystalline rocks and Late Precambrian to Cambrian sediments of Baltoscandian miogeocline origin. Sediments of the Upper Allochthon are in general younger, Ordovician to Lower Silurian, and are considered to derive from shelf to eugeoclinal environments originally located further to the west.

Four principal nappes or nappe complexes are recognised in the Caledonides of Finnmark (Fig. 2):

Magerøy Nappe - Upper Allochthon
Kalak Nappe Complex - } Middle
Laksefjord Nappe Complex } Allochthon
Gaissa Nappe (Complex) - Lower Allochthon

The two highest units, the Magerøy Nappe and Kalak Nappe Complex, are floored by thick zones of mylonite to ultramylonite. The sole thrust to the Laksefjord Nappe Complex is also mylonitic, though less thick, while the Gaissa sole thrust carries only a 3-5 cm-thick band of ultracataclasite. In general, the prominent stretching lineations within and above the thrust zones denote a southeast to east-southeast translation of the nappe rocks.

Regarding the time of nappe detachment and final translation, the picture is complicated by the polyphase nature of the orogenic development of the Scandinavian Caledonian mountain chain (Roberts & Sturt 1980, Gee & Roberts 1983). This applies to Finnmark just as much as areas further south. To summarize, however, the three lower nappe complexes are considered to have acquired their largely ductile, basal mylonite fabrics during the latest Cambrian - early Ordovician *Finnmarkian* orogenic phase, with thrust translation migrating diachronously from hinterland to foreland (Sturt & Roberts 1978). Emplacement of the Magerøy Nappe, on the other hand, occurred during the latest Silurian - earliest Devonian *Scandian* orogenesis (Ramsay & Sturt 1976, Andersen 1981, Andersen et al. 1982) following internal deformation and initial imbrication. An important question relates to the extent to which the highest Finnmarkian nappe were reheated and deformed during Scandian time. Some details concerning the timing of deformation are presented on p. . All Rb-Sr isochron dates quoted have been recalculated using the ^{87}Rb decay constant of 1.42 x 10^{-11}/yr (Steiger & Jäger 1977).

Stratigraphies

With the exception of the rocks of the Magerøy Nappe and of the Barents Sea Region (p.), lithostratigraphies in the autochthon, parautochthon and Finnmarkian-deformed allochthons show many similarities in general lithofacies and can readily be assigned to the foreland or miogeoclinal environments which existed along the margin of the Baltoscandian Shield in Late Proterozoic to earliest Palaeozoic time. Many detailed descriptions have been given of the stratigraphical sequences occurring within each tectonostratigraphic unit or in specific areas (e.g. Reading 1965, Roberts 1968, Banks et al. 1971, 1974, Siedlecka & Siedlecki 1971, Laird 1972, Gayer & J. Roberts 1973,

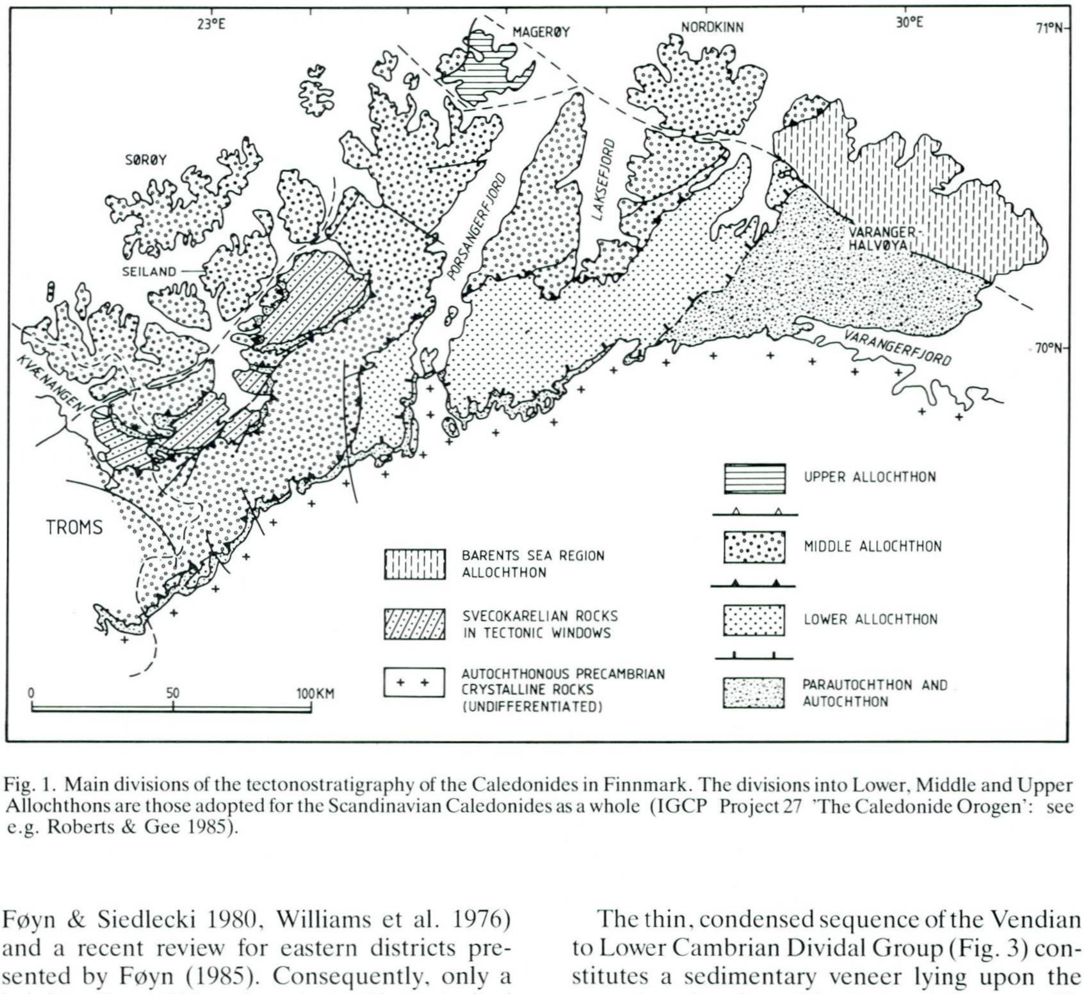

Fig. 1. Main divisions of the tectonostratigraphy of the Caledonides in Finnmark. The divisions into Lower, Middle and Upper Allochthons are those adopted for the Scandinavian Caledonides as a whole (IGCP Project 27 'The Caledonide Orogen': see e.g. Roberts & Gee 1985).

Føyn & Siedlecki 1980, Williams et al. 1976) and a recent review for eastern districts presented by Føyn (1985). Consequently, only a brief outline will be given here. The principal group-rank subdivisions are shown in Fig. 3.

Autochthon-parautochthon. This basal sequence is exposed most extensively in the Varangerfjord district, south of the Trollfjord-Komagelv Fault Zone (Fig. 1). Rocks of various formations lie with primary, unconformable contact upon the Archaean to Early Proterozoic Baltoscandian crystalline basement, and the stratigraphic sequence (Vadsø, Tanafjord and Vestertana Groups) carries several minor or moderately important unconformities. The succession, which includes the Varangian tillites, ranges from Late Riphean to Late Vendian or earliest Cambrian age, the upper limit here depending on the precise location of the basal thrust to the Gaissa Nappe. In the western part of southern Varanger Peninsula the strata are strongly folded (Siedlecki 1980) and are here regarded as parautochthonous (p.).

The thin, condensed sequence of the Vendian to Lower Cambrian Dividal Group (Fig. 3) constitutes a sedimentary veneer lying upon the peneplaned surface of the Precambrian crystallines; this can be traced over considerable distances across Finnmark and southwards into the county of Troms (Føyn 1967, 1984). In SW Finnmark and Troms the upper parts of the Dividal are locally deformed in thin thrust slices immediately beneath the nappes (Skjerlie & Tan 1961). Around the tectonic windows of Svecokarelian Raipas Supergroup rocks in western Finnmark (Fig. 1), Dividal Group correlatives are more strongly deformed with the development of an incipient slaty cleavage (Zwaan & Gautier 1980, Pharaoh et al. 1983).

Gaissa Nappe. The lithostratigraphy of the western part of the Gaissa Nappe has been subject to conflicting interpretations (cf. J. Roberts 1974, D.M. Williams 1976) within what was then termed the Porsangerfjord Group. Detailed mapping across Laksefjordvidda into the

TECTONOSTRATIGRAPHIC UNIT		STRATIGRAPHIC AGE & MAIN LITHOLOGIES	PALAEONTOLOGICAL EVIDENCE	DEFORMATION, METAMORPHISM AND IGNEOUS ACTIVITY	RADIOMETRIC AGE DETERMINATIONS
SKARSVÅG NAPPE		Age unknown. Gnt-mica schists, quartzites, migmatites.	None	Polyphase deformation (more complex than in Magerøy Nappe) Upper amph. facies metamorphism.	None
MAGERØY NAPPE		Early Silurian (?and Late Ordovician) Greywackes, shales, phyllites, schists, limestones, conglomerates.	Llandovery fauna – Monograptids, corals, brachiopods, crinoids, Trace fossils.	Polyphase def. and met. history. Lower greenschist to upper amph.facies. Mafic/ultramafic complex and granitic bodies.	411Ma, Rb-Sr isochron, Finnvik granite, age of intrusion.
KALAK NAPPE COMPLEX	Metasedimentary cover	Assumed Late Riphean or Vendian to Cambrian. Arkosic psammites in lower parts, schists, limestones, with metagreywackes on top. Local conglomerate above unconformity.	Doubtful archaeocyathids in limestone. Trace fossils in psammites.	Complex, polyphase def. & met. history. From greenschist to upper amph. facies, with migmatites. Mafic, ultramafic, granitic & alkaline rocks (Seiland Province). Dolerite dykes common locally.	540-490Ma, Rb-Sr isochron ages on synorogenic plutons. 500-488Ma, K-Ar on nephelines in dykes. 428-392Ma, K-Ar on micas. Scandian met. 410Ma, Rb-Sr isochron on migmatites (reset age in Scandian)
	Precambrian elements	Precambrian. Two different types of basement:- (1) Proterozoic Raipas Supergroup sediments and volcanic rocks. (2) Proterozoic to Archaean paragneiss and orthogneiss complexes.	Stromatolites in dolomites. None	Polyphase Precambrian def. & met. (amph. to granulite facies). Polyphase Caledonian reworking (greenschist to amph. facies). Precamb. granites, gabbros, dolerites. Caledonian – as in cover sequence.	c. 3000-2700Ma, Rb-Sr isochron ages, gneisses and acidic dykes. c. 1530–1440Ma, Rb-Sr isochron ages, tonalite sheet, pegmatite.
LAKSEFJORD NAPPE COMPLEX	Cover	Assumed Vendian to Cambrian. Metasandstones, schists, phyllites, basal conglomerates.	None	Two phases of folding, greenschist facies metamorphism. Listric thrusting common. Dolerite dykes locally.	493Ma, Rb-Sr isochron, phyllites; age of met. 485Ma ^{40}Ar-^{39}Ar, micas in cleavage; cooling age.
	Basement	Proterozaoic. Dolomitic lmst., metabasalt, tuff, gneissgranite, granodiorite, gabbro.	Algal mats in dolomite.	Polyphase Precambrian deformation. Caledonian reworking and thrusting. Doloerite dykes locally	None
GAISSA NAPPE COMPLEX		Vendian to Tremadoc. Quartzitic sandstones, shales, mudstones, phyllites, tillites, dolomites.	Cambrian to Tremadoc trilobites, brachiopods & graptolites. Vendian acritarchs. Stromatolites in dolomites.	One main fold phase with ax. pl. cleavage. Anchizone met. Listric thrust faults, duplex structures. Basic dykes rare.	482Ma, ^{40}Ar-^{39}Ar, micas in cleavage; cooling age.
PARAUTOCHTHON AND AUTOCHTHON (cover)		Late Riphean to Cambrian. Quartzitic sandstones, shales, mudstones, tillites. Several unconformities within the lithostratigraphic succession.	Cambrian macrofauna. Trace fossils. Late Riphean to Vendian acritarchs.	One main fold phase with ax. pl. cleavage. Lower anchizone met. Listric faults in parautochthon. Diagenetic fabrics in autochthon.	504Ma, Rb-Sr, isochron, age of clevage. 654Ma, Rb-Sr, isochron, age of deposition of inter-tillite shales. 807Ma, Rb-Sr, age of deposition of lower Vadsø Group.
AUTOCHTHON (basement)		Proterozoic (Svecokarelian) and Archaean crystalline basement			2800–1700Ma, Rb-Sr.

Fig. 2. Main features of the Caledonian nappe sequence and autochthon of Finnmark: revised and updated after Sturt & Roberts (1978). The Rb-Sr and K/Ar data are from sources sited in the main text. ^{40}Ar/^{39}Ar dates are from Dr. R.D. Dallmeyer (pers. comm. 1985). The broken horizontal lines denote major unconformities. All other boundaries are tectonic.

Porsangerfjord district by Føyn & Siedlecki (1980), Roberts (1983a) and Rice & Harrington (1983) have shown, however, that several formations of the Tanafjord Group can be traced into this district, thus rendering the term Porsangerfjord Group superfluous. Three of these formations can even be recognised further west in the Alta area, as the Bossekop Group (Fig. 3). There, it is significant that the Bossekop sediments lie *unconformably* above Karelian Proterozoic rocks (Zwaan & Gautier 1980).

In the northeastern part of the Gaissa Nappe, rocks of the Vestertana and Digermul Groups follow stratigraphically above the Tanafjord Group. The full sequence in the Gaissa thus ranges from Vendian (Vidal 1981) to Tremadoc (Reading 1965, Nikolaisen & Henningsmoen 1985). Earlier, it had been considered that displacement along the Gaissa sole thrust diminished to zero towards Andabaktoaive (Føyn 1937) such that the Gaissa Nappe gradually merged into the autochthon. Arguments have recently been presented (Chapman et al. 1985, Townsend et al. in press) that the Gaissa thrust in all probability extends northeastwards across the Tana estuary, and is eventually truncated by the polyphase Trollfjord-Komagelv Fault (Plate 1).

Laksefjord Nappe Complex. As no fossils have yet been recovered from the Laksefjord Group metasediments of this nappe, the age of the succession is unknown (Føyn 1985). Basal conglomerates have been interpreted as either glacigenic (Laird 1972) or alluvial fan deposits (Chapman 1980, Føyn et al. 1983). Based on general lithological character and comparison with other sequences, a Vendian (? or latest Riphean) to early Cambrian age for this group would appear to be the most likely possibility. In one area an unconformable contact has been found between basal clastic sediments and subjacent Proterozoic granitic and basic volcanic rocks (Føyn et al. 1983).

Kalak Nappe Complex. A thick sequence of metasedimentary rocks dominated by meta-arkosic psammites (Klubben Group) but also including younger schists, metalimestones and turbiditic metagreywackes characterizes the

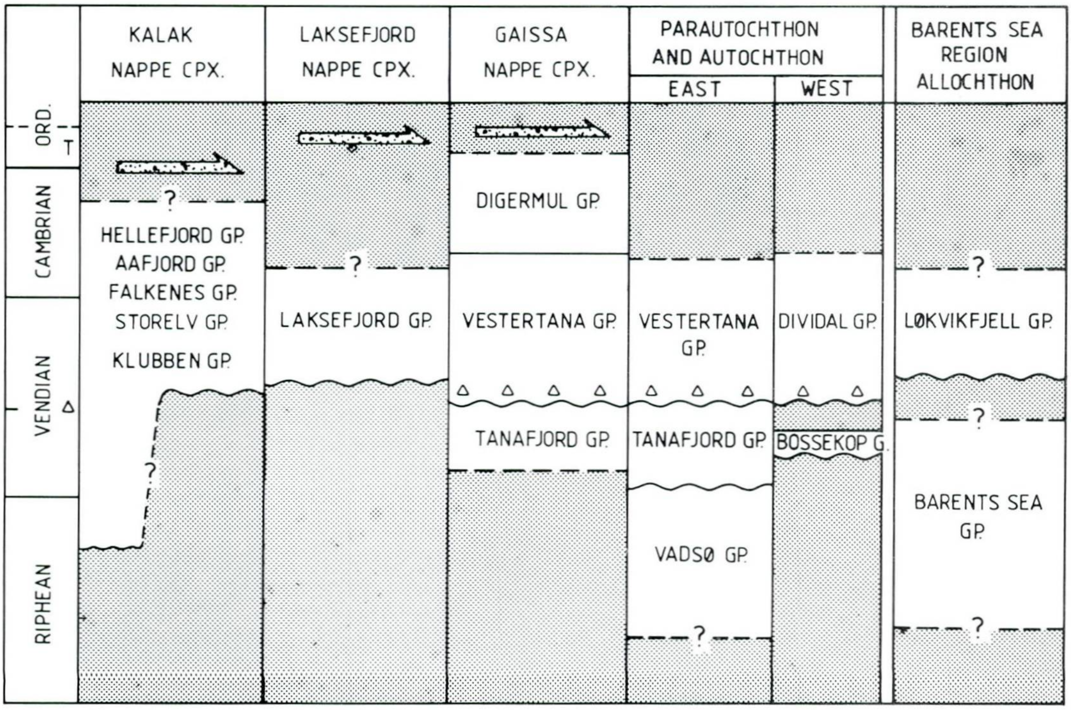

Fig. 3. The principal lithostratigraphical subdivisions (groups) within the Finnmarkian nappe complexes, parautochthon, autochthon and Barents Sea Region allochthon. The diagram shows the age-ranges of the various units, but is not intended to indicate thicknesses. Unconformities indicated by wavy lines: triangles – Varangian tillites: arrows above sequences in nappe columns indicate the approximate time of main thrusting: T at base of Ordovician = Tremadoc.

composite Kalak allochthon. As in the case of the rocks of the Laksefjord Nappe Complex, the age of the succession is uncertain but assumed late Riphean or Vendian to Cambrian. No major conglomerate or tillite horizons have yet been found in the succession. Doubt has recently been raised (Debrenne 1984) about the authenticity of 'fossils' described as archaeocyathids (Holland & Sturt 1970), reportedly of Middle Cambrian age, leaving the precise age of the upper part of the sequence an open question. However, Finnmarkian deformation of the succession provides a minimum age.

An important component of the Kalak Nappe Complex is that of tectonic units of Precambrian basement rocks, both Proterozoic supracrustal sequences and Archaean crystalline complexes (Sturt et al. 1978, Zwaan & Roberts 1978, Ramsay et al. 1985a, b). In one area, dykes of granodiorite cutting tonalitic gneisses have yielded a Rb-Sr whole-rock isochron age of ca. 3000 Ma B.P. (Sturt & Austrheim, this volume). Significantly, sediments of the Klubben Group have been found to lie unconformably upon these older Precambrian rocks at four separate localitites (Ramsay & Sturt 1977, Ramsay et al. 1979, Sturt et al. 1981). This couplet of basement and cover occurs at different tectonic levels within the Kalak Nappe Complex.

Another important element in the Kalak is the polyphase, synorogenic, magmatic complex represented by the 'Seiland Igneous Province' (e.g. Robins & Gardner 1975). These plutonic rocks range from ultramafites and gabbros to nepheline syenites, carbonatites and shonkinites and were intruded into the deforming sedimentary cover at several stages during the Finnmarkian orogeny. A further component in the Kalak sediments is that of metadolerite dykes. These vary in relative age from pre-tectonic to syn- or even post-tectonic, with respect to the Finnmarkian deformation.

Allochthon of the Barents Sea Region. The area northeast of the Trollfjord-Komagelv Fault, termed the Barents Sea Region (Siedlecka & Siedlecki 1967), consists of three main rock units: the Barents Sea Group, Løkvikfjell Group and Berlevåg Formation. The last-mentioned unit occurs only in the extreme northwest and is regarded as part of the Kalak Nappe Complex (Levell & Roberts 1977).

The Barents Sea Group is a ca. 9 km-thick regressive sequence comprising 4 formations, from a submarine fan accumulation at the base (Kongsfjord Formation) through deltaic and shallow-water coastal sediments (Båsnæring and Båtsfjord Formations) into a fluvial unit (Tyvjofjell Formation) at the top (Siedlecka & Siedlecki 1967, 1972, Siedlecka 1972, 1975, 1984, Siedlecka & Edwards 1980, Pickering 1981). Based on acritarch assemblages the group is of late Riphean to early Vendian age (Vidal & Siedlecka 1983). The Løkvikfjell Group (5 formations), which lies unconformably upon the Barents Sea Group (Siedlecki & Levell 1978), is a 5.6 km-thick sequence of shallow-marine to fluvial sediments. No time-diagnostic microfauna has yet been recovered from this group; however, based on a K/Ar whole-rock age of 640 Ma (Beckinsale et al. 1975) for a dolerite dyke which cuts rocks of the lowest formation, and the fact that the youngest microfaunally dated sediments in the subjacent Barents Sea Group are of early Vendian age, then a Vendian age seems likely (Vidal & Siedlecka 1983).

The Barents Sea Group sediments show marked differences in lithofacies, thickness and interpreted depositional environments as compared with the time-equivalent Vadsø and Tanafjord Group rocks south of the Trollfjord-Komagelv Fault (Siedlecka 1975, 1984). In addition, they are locally cut by swarms of dolerite dykes in some areas. Lithostratigraphically the Barents Sea Group has much in common with comparably aged sequences in East Greenland (Siedlecki 1975) and on the Ribachiy Peninsula of USSR (Siedlecka 1975), and Kjøde et al. (1978) have suggested an original close geographic association between this group and the Eleonore Bay Group rocks of East Greenland. In this regard, structural data have suggested that the Trollfjord-Komagelv Fault has functioned as a dextral strike-slip megafracture (Harland & Gayer 1972, Roberts 1972, Johnson et al. 1978) for a part of its early history, with more than 500 km of lateral displacement along what was then a paleotransform fault in a developing Iapetus Ocean in Late Precambrian to Cambrian time (Kjøde et al. 1978).

Recent work on the geochemistry of stream sediments, weathering products and local moraine material from localities on Varanger Peninsula has revealed major disparities in element anomaly patterns (Ottesen et al., this volume) on either side of the T-K Fault. In particular, there are marked enrichments in the heavy mineral fractions of stream sediments and local till in elements such as Pb, Mo, Zr, Nb, Sn, Th, Ta and Va northeast of the fault. As the analysed material is considered to be derived largely from the local bedrock, this lends further support to the notion that the rocks of the Barents Sea Region are quite different from those southwest of the T-K Fault and constitute a foreign element (or exotic terrane: Roberts 1983b) tectonically juxtaposed along the margin of the Baltoscandian Shield.

Magerøy Nappe. The metasedimentary succession composing the bulk of the Magerøy Nappe contains fossils of early Silurian (Llandovery) age. The 5.5 km-thick sequence, of 2 groups and 5 formations (Andersen 1981, 1984), consists of turbiditic to shelf-type sediments and may extend down into the late Ordovician. Plutonic rocks occurring within the nappe are of two main types, mafic/ultramafic and granitic, both of which are syntectonic with respect to the Scandian orogenic event.

In one area on Magerøy a klippe of migmatized schists and quartzites lies tectonically above the Magerøy Nappe; this unit is called the Skarsvåg Nappe (K. Kjærsrud, pers.comm. 1979, Andersen 1981). The Skarsvåg klippe may represent a structural unit of Kalak metasediments tectonically emplaced above the Magerøy Nappe during Scandian deformation.

Structural geology and regional metamorphism

Over the last twenty years, considerable research effort has been directed toward determining the structural and metamorphic evolution of the Finnmark Caledonides. In this regard, geochronological studies in selected areas have been invaluable in providing constraints on the timing of tectonothermal events, especially within nappe units where biostratigraphical control is lacking.

In this contribution, no attempt will be made to describe or synthesize the polyphasal structural and associated metamorphic histories of individual areas or nappes. Such an exercise has been carried out at various stages by e.g. Gayer & J. Roberts (1971), Sturt et al. (1975), Zwaan & Roberts (1978) and Ramsay et al. (1985a), based on innumerable articles and university theses. Here, only the main features of the fold deformation and metamorphic parageneses are outlined, and emphasis is instead placed on the results of recent mapping and research which have a bearing on the overall structural history and nappe geometries.

Fold deformation

Taking the Kalak, Laksefjord and Gaissa Nappes as a whole, i.e. excluding the Magerøy Nappe, there is a general decrease in intensity and complexity of structural deformation from northwest to southeast, moving down the tectonostratigraphy towards the foreland. This pattern can be taken further, into the parautochthon, where folds are open to gentle and eventually die out into the autochthonous sedimentary sequence in the Varangerfjord area (Roberts 1972, Siedlecki 1980). Allied regional trends are those of diminishing ductility of deformation and of generally progressively lower grades of metamorphism from northwest (amphibolite facies) to southeast (sub-greenschist facies). How much of this deformation and metamorphism is Finnmarkian and how much is Scandian, especially in the high-grade multiply folded sequences, is still an open question.

Within the Kalak Nappe Complex the Caledonian deformation is truly multiphase, some 5 or 6 fold episodes having been distinguished across the district as a whole; of these, perhaps only 3 episodes can be regarded as regionally significant (Zwaan & Roberts 1978, Ramsay et al. 1985a, Gayer et al. 1985). The oldest folds, D1, occur mainly in the highest part of the Kalak allochthon, especially on Sørøy. These developed under greenschist facies conditions and are commonly isoclinal. These structures are rare or lacking in eastern areas and in the lower nappes.

The second principal deformation phase, D2, occurred under generally higher grades of regional metamorphism and it is these fold structures and associated regional schistosity and stretching lineations that can be followed widely, both within the Kalak and from nappe to nappe. Fold style varies considerably across the region, commonly near to isoclinal in the higher nappes where a late-D2 flattening has tightened the fold structures and contributed to the rotation of fold axes (the folds originally developed by simple shear) into the penetrative NW-SE to WNW-ESE stretching lineation. Such rotation and extreme stretching is most prominent lower down in individual nappes in mylonite zones and in other high-strain zones. Towards the base of the middle unit of the Laksefjord Nappe Complex, stretched pebbles in conglomerates denote the imposition of high flattening strains (Chapman et al. 1979, Roberts & Sturt 1980). Within the Kalak Nappe Complex a generally less intense deformation can be recognised in northern areas, towards Nordkinnhalvøya. In this district, folds carrying the regional schistosity are comparatively upright, close to tight structures (Roberts & Andersen 1985). On the contrary, in the extreme southwest and into Troms county, the NW-SE D2 lineation is pervasive and folds are isoclinal, in marked contrast to the N-S grain of the overlying Scandian nappes (Zwaan 1985).

Synmetamorphic folds in the Laksefjord Nappe Complex are generally SE-verging tight structures modified by a late flattening strain. In high-strain zones fold axes are rotated into parallelism with the prominent extension lineation (Williams 1978). This lineation is generally oriented NW-SE but varies between NNW-SSE and WNW-ESE. In the Gaissa Nappe and parautochthon the schistosity-associated folds are open to close structures of mainly N-S to NE-SW axial trend and ESE vergence (Williams 1979) but swinging to ENE-WSW in the Varangerfjord district. Three different types or groups of folds have been described by Townsend et al. (in press) from this nappe, based on their time-relationship to internal thrust-faults.

In the allochthon of the Barents Sea Region, synmetamorphic folds are open to close structures resulting from SE-directed shortening (Roberts 1972), with a general decrease of strain towards the southeast. Metamorphic parageneses are in lower greenschist facies. Taking the Barents Sea Region rocks as a whole, deformation and metamorphism is more advanced in these sequences than in the Vadsø and Tanafjord Group rocks on the southern side of the T-K Fault, which suggests (Roberts 1972) that there was a component of right-lateral displacement along the fault in late- or post-Finnmarkian time. This was in addition to the major right-lateral movement in Late Precambrian- Cambrian time (Kjøde et al. 1978).

Folds which deform the regional schistosity in the Kalak and lower nappes are common in many areas, particularly those of the D3 phase which Zwaan & Roberts (1978) considered were associated with the Scandian orogenic episode. In the Kalak Nappe Complex on Porsangerhalvøya, structures belonging to 5 fold phases have been described by Gayer et al. (1985). These authors regard all these deformations as Finnmarkian. However, some may be Scandian or younger.

Nappe geometries

Although it has long been known that the Caledonides of northern Norway consist of comparatively thin thrust-sheets, and thus belong to the category of 'thin-skinned' fold belts, the internal construction and overall geometries of the individual nappes have received little attention until fairly recently. The initial tripartite subdivision of the Finnmarkian allochthon, for example, has been found to be far too simple, and insufficient to cover the complexity of the thrust deformation as revealed by detailed mapping and structural studies. Thus, 'nappes' such as the Kalak and the Laksefjord have been promoted to the status of 'nappe complexes'.

In the case of the *Kalak Nappe Complex*, a major advance in our understanding of the construction and geometry of this part of the thrust-belt was the discovery of basement/cover couplets and the intervening unconformity, by Ramsay & Sturt (1977). While an initial subdivision of the Kalak Nappe Complex had been made earlier (Roberts 1974), and Precambrian crystalline rocks already recognised as components in the allochthon (Zwaan & Ryghaug 1972, Jansen 1976), the significance of the unconformable cover on pre-Caledonian crystallines led to a careful evaluation of older maps and encouraged detailed investigations (some assisted by geochronology) in areas known to carry thick units of gneissic rocks. As a result, an increasing complexity has been found for the Kalak. Some 9 or 10 separate nappes have now been distinguished (e.g. Ramsay et al. 1981, 1985a,b, Gayer et al. 1985) between Porsangerhalvøya and Nordreisa (Plate 1), each consisting of various combinations of the three main units, crystalline gneissic rocks, Svecokarelian supracrustals and the Klubben to Hellefjord Group rocks as cover sediments. In the eastern Porsangerhalvøya district alone, Gayer et al. (1985) have divided eight nappes into 25 separate thrust-sheets. It should also be noted that a broad two-fold grouping of the Kalak nappes into 'distal' and 'proximal' – for far-travelled and less far-travelled nappes, respectively – has been introduced by Ramsay et al. (1985a).

An interesting and important feature of the 'basement' elements within the Kalak Nappe

Complex is that they are still recognisable as Baltoscandian continental assemblages, Svecokarelian (Raipas-type) or Archaean, even in the highest thrust-sheets. As a minimum total translation of more than 400 km appears to be indicated for these higher nappes (Ramsay et al. 1985a), this points to the cratonic nature of an originally extremely wide miogeoclinal depositional basin, or basins.

In comparison with the Kalak, the *Laksefjord Nappe Complex* (Chapman 1980) appears to display a somewhat simpler internal construction and is divided into the Lower, Middle and Upper Laksefjord Nappes by major listric thrusts. The Upper and Middle units consist largely of Laksefjord Group metasediments, although a small area of granitic and metavolcanic rocks occurs unconformably below the sediments near the base of the Middle Nappe. By contrast, the Lower Nappe constitutes a sheet or horse of granitic and dolomitic rocks which were accreted on to the base of the Middle Nappe during the progressive translation of the higher, sediment-dominated units of the Laksefjord Nappe Complex (Chapman et al. 1985; also in Føyn et al. 1983).

The important work of G.D. Williams (1976) and Chapman (1980) in the Laksefjord Nappes has shown that listric normal (extensional) faults are common within the Middle Nappe and that these pre-date the listric thrusting. Both the normal faults and the reverse, thrust-faults post-date the ubiquitous synmetamorphic folds, and the basal thrust surface to the Middle Nappe also truncates the high-strain zone with associated deformed conglomerates (p.) (Chapman et al. 1979). Restoration of cross-sections drawn across the Laksefjord Nappes has indicated a net shortening of zero, i.e. the restored and present-day cross-sections are of similar length. This is because the total extension ascribed to the low-angle normal faulting was fortuitously equal to the component of shortening which resulted from the earlier, synmetamorphic folding (Chapman et al. 1984).

Overall, the picture which has emerged from the Laksefjord district favours a ramp-flat geometry for the thrusts, with thrusts cutting up-section in their footwalls as they ascend ramps. Both the roof thrust (Kalak thrust) and sole thrust to the Laksefjord Nappe Complex show these features. With the successive, cratonward collapse of footwall ramps, duplex structures were developed; such a designation can be applied to the Middle and Upper Laksefjord Nappes.

D.M. Williams (1976b) described a possible equivalent of the Laksefjord Nappe in a small area west of Lakselv; this he called the Betusordda Nappe. Based on new mapping in this general area by K.B. Zwaan & D. Roberts (unpubl. results, 1983), Williams' interpretation is open to question. Rocks of probable Laksefjord Group type do occur, a little further to the southwest (Plate 1), with a basal thrust that appears to climb an oblique ramp behind the Gaissa Nappe. The western limit of these assumed Laksefjord Group rocks is a c. N-S fault contact against Kalak Nappe lithologies along Upper Stabbursdalen (cf. Zwaan & Roberts 1978).

Earlier structural work within the *Gaissa Nappe* concentrated on the common synmetamorphic folding and fold/cleavage relationships (e.g. Gayer & J. Roberts 1971, J. Roberts 1974, D.M. Williams 1976a, 1979). Internal thrusting was then regarded as subordinate. Reconnaissance mapping in 1979-81 in the inner Porsangerfjord district by the present writer showed that certain formations of the Tanafjord Group were repeated along layer-parallel thrusts. Moreover, bedding-plane thrusts were observed to cut obliquely up-section and resume their bed-parallel course at a higher stratigraphic level; this is the typical 'staircase' trajectory of ramp-and-flat thrusting. Structural studies in the Porsanger (Dolomite) Formation beneath the Kalak thrust by Dr. R.A. Gayer and co-workers revealed a comparable tectonic picture (Chapman et al. 1985). Detailed mapping east of Porsangerfjord, in 1983, on two 1:50,000 map-sheets (Rice & Harrington 1983, Roberts 1983a), assisted by structural profiling by Mr. C. Townsend, showed that the Gaissa Nappe is intensely imbricated by internal listric thrusts.

The mapping and structural analysis of this large segment of the Gaissa Nappe has allowed a division into four main structural zones or units (Roberts et al. 1984, Townsend et al. in press). From structural top to bottom these are: Børselv duplex, Munkavarri imbricate zone, Vuonjalrassa thrust sheet and Guiverassa duplex zone. Full details are given in the paper by Townsend et alia. Based on the construction and partial restoration of a balanced cross-section across this area, more or less parallel to the ESE thrusting direction, the total estimated displacement of the metasediments of the trailing (western) edge of the Munkavarri imbricate zone is at least 104 km. This indicates a derivation from the vicinity of the islands of Seiland and Stjernøy. However, as this does not take into account the shortening in rocks of the Gaissa exposed west of Porsangerfjord, which we know to show comparable thrust tectonics (D. Roberts, unpubl. results 1983), a cumulative displacement of more than 150 km is likely. This would put the area of provenance of these westernmost Gaissa Nappe rocks just southwest of Sørøy (Townsend et al. in press).

The complexity of thrust deformation revealed by the recent studies within the Gaissa is thus equal to, if not greater than that in the overlying Laksefjord Nappe Complex. In recognition of this, the term *Gaissa Nappe Complex* would be a more appropriate designation. This maintains the tradition of allochthon terminology in the Norwegian Caledonides, retaining the term 'nappe', even though 'thrust-sheet' would perhaps be a preferred term in the external zones of other, comparable, thin-skinned orogenic belts.

Acceptance of the intensity of thrust tectonics and subdivision of the Gaissa allochthon has consequences for the eastward extension of its sole thrust and the geographical limitation of the nappe complex. As noted earlier (p.), Føyn (1967) terminated the Gaissa thrust at Andabaktoaive, invoking a component of anticlockwise rotation for the nappe about a hinge point near this locality. This view is hardly acceptable now, and both Chapman et al. (1984) and Townsend et al. (in press) have presented arguments for extending the sole thrust northeastwards, as a flat across poorly exposed ground, and eventually linking with the easternmost thrust-fault northeast of Leirpollen (see Siedlecki 1980). This thrust is then truncated by the Trollfjord-Komagelv Fault. Immediately southeast of this extended Gaissa thrust, in the parautochthon, folds are open, upright structures, but these rapidly die out southeastwards; the folds are also cut by extensional faults. The folds in this district clearly relate to a component of shortening, and this can be most readily compensated for by inferring the subsurface occurrence of a layer-parallel detachment, or blind thrust (Chapman et al. 1985). Whether or not this inferred detachment actually cuts the present-day surface along part of its trajectory must await future structural study.

The *tectonic windows of Raipas rocks* in the region from Repparfjord to Alta and Kvænangen have traditionally been considered as part of the autochthon, positioned beneath the décollement surface of the Caledonian nappes but exposed in NE-SW-trending Caledonian culminations (e.g. Pharaoh et al. 1977, Zwaan & Roberts 1978). Åm (1975) presented aeromagnetic data and interpreted these as showing a gradual swing of anomaly trend from Finnmarksvidda beneath the Kalak Nappe Complex and into the window areas. The Dividal-equivalent cover sediments which occur unconformably above the Raipas around these windows are, however, quite strongly deformed and cleaved, in lowest greenschist facies, and thus differ from Dividal Group sediments further southeast below the Gaissa sole thrust.

The new structural data from the Laksefjord and Gaissa Nappe Complexes necessitate a reconsideration of the status of these window rocks. Discussion of the problem has been given by Chapman et al. (1985) and Townsend et al. (in press) who favour an allochthonous (or parautochthonous) solution, and see these Raipas rocks as part of a basement horse either accreted on to the base of the Kalak or forming a separate tectonic slice. Rhodes (1976) had earlier suggested a 15 km translation for the rocks of the Komagfjord window. Support for a parautochthonous interpretation has now come from a refinement and reassessment of the aeromagnetic data but the final results of this study are not yet available (Olesen et al. in prep.).

The structure of the *Magerøy Nappe* has been described in some detail by Andersen (1981). Overthrust east-southeastwards along a thick, amphibolite facies mylonite zone (Ramsay & Sturt 1976), this Scandian-emplaced nappe is far more significant for the Caledonian structural history of Finnmark than its restricted areal extent would indicate. The main synmetamorphic fold structure of the nappe is a mushroom-like NE-SW polycline with opposite vergence on either side of the fold axial zone (Andersen 1981). The small klippe of the *Skarsvåg Nappe* (p.) is interesting in that it carries a metamorphic fabric which predates the earliest structures recognised in the metasediments of the Magerøy Nappe. This pre-Scandian foliation may well be Finnmarkian, and if so the Skarsvåg would represent an imbricate slice of the Finnmarkian 'basement' to the Magerøy allochthon (thrust above the latter) in much the same way as e.g. the Tromsø Nappe in Troms has been incorporated into the Scandian allochthon (Zwaan & Roberts 1978).

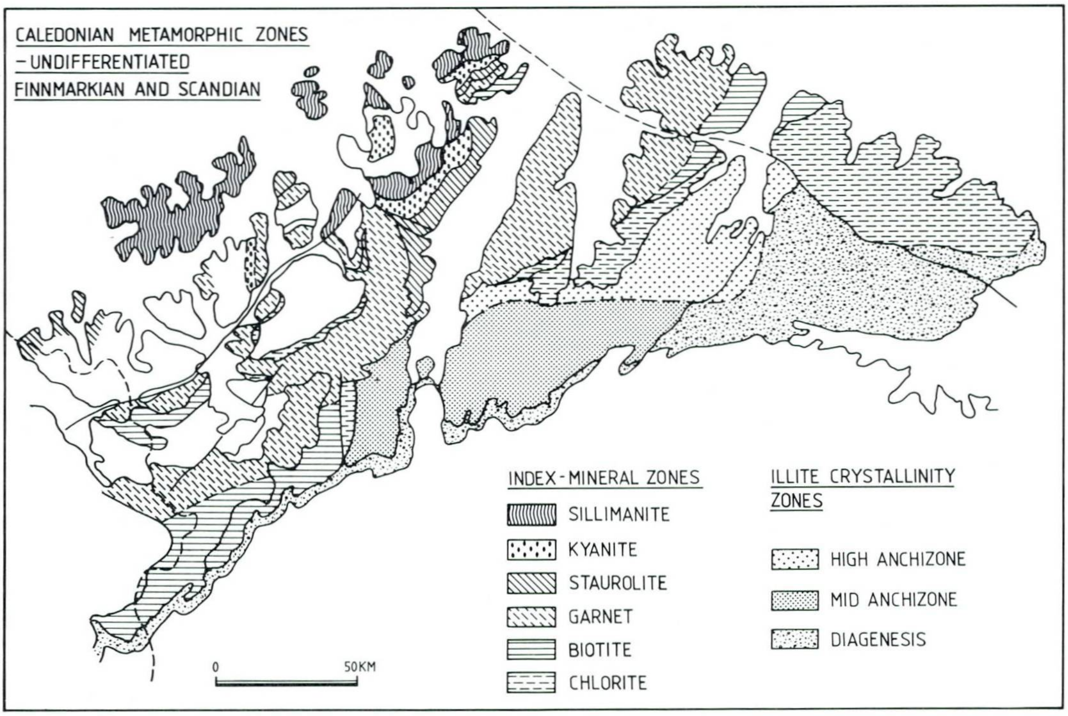

Fig. 4. Metamorphic zones within the Caledonides of Finnmark. The map shows the known metamorphic index-mineral and illite crystallinity zones. Except for the Magerøy Nappe, wherein the metamorphism is known to be Scandian, the zonation has not been differentiated with respect to the Finnmarkian and the Scandian phases. Within the Kalak Nappe Complex in particular, the zonation is probably polyphase (Finnmarkian plus some measure of Scandian). The map is compiled from data from several sources: from articles cited in the text, including maps of smaller areas in Andersen (1982) and Gayer et al. (1985): from preliminary data on illite crystallinity within the Gaissa Nappe, autochthon and Barents Sea Region by Drs. R.E. Bevins and D. Robinson: from discussions with K.B. Zwaan, NGU: and from the writer's own unpublished data. The dashed lines indicate uncertainty in the precise location of the boundaries between zones, because of insufficient or irregular sample coverage. The middle/upper anchizone boundary in the Gaissa nappe, for example (see Plate 1 for Gaissa location), is conjectural: this boundary could as well be aligned ca. N-S on the basis of the present sample data. The blank areas in the west are those of either Precambrian elements or Caledonian plutionic rocks.

Regional metamorphism

A feature of the Finnmarkian allochthon is that of increasing metamorphic grade in successively higher nappes. In the middle and upper parts of the Kalak Nappe Complex, for example, porphyroblastic minerals in appropriate pelitic lithologies include garnet, staurolite, kyanite and sillimanite (Roberts 1968, Rice 1984), and in some areas it has been possible to draw mineral isograds (e.g. Gayer et al. 1985) (Fig. 4). At lower levels in the Kalak the aluminosilicates are absent, but garnet is still common. In general, porphyroblastesis, and thus the metamorphic peak, extended into the period immediately postdating the development of the regional schistosity. Again, there is the question as to how much of this mineral growth relates to the Finnmarkian orogenesis and whether some of the later crystallization of e.g. biotite and even garnet may be a result of burial heating of the Kalak by the overriding, now eroded, Scandian nappes.

Metamorphic studies in the lower nappes and parautochthon are in their infancy, but an important advance has been made by Drs. R.E. Bevins and D. Robinson utilising illite crystallinity in pelites. Samples from formations in the Gaissa Nappe east of Porsangerfjord generally fall in the medium to high anchizone (Fig. 4) of very low-grade metamorphism (R.E. Bevins, pers.comm. 1984/85 and manus. in prep.). In contrast, samples from the Laksefjord Nappes have epizone crystallinities. From the autochthon/parautochthon transition zone of Varangerfjord, samples fall in the field of diagenesis/lower anchizone. Crystallinities from

Barents Sea and Løkvikfjell Group rocks show epizone values, which highlights the Trollfjord-Komagelv Fault as a major metamorphic boundary. Drs. Bevins and Robinson have also sampled from the Dividal Group near Lakselv, just below the Gaissa thrust; here, diagenesis crystallinities were encountered, which fits with field evidence of a bed-parallel compactional fabric in this unit (D. Roberts, unpubl. data). Johansen (1984), working in the Dividal southeast of Alta, beneath the Kalak thrust, has estimated temperatures of c. 200°C for the diagentic clay mineral parageneses of these pelitic rocks.

Regional metamorphic conditions in the rocks of the Magerøy Nappe varied from greenschist facies in the southeast to high amphibolite facies in the north and northwest (Andersen 1981, 1984b). High-grade conditions, locally with growth of sillimanite, also prevailed during the formation of the ductile mylonite of the sole thrust (Ramsay & Sturt 1976). The thermal effects of this nappe and thrust zone were sufficiently great as to produce a 'Scandian' Rb-Sr whole-rock isochron age from Finnmarkian migmatites in western Magerøy (Andersen et al. 1982). Elsewhere in West Finnmark, the Scandian event is also recorded in K/Ar mineral ages (p.), and has been detected in preliminary ^{40}Ar/^{39}Ar dating work by Dr. R.D. Dallmeyer (pers.comm. 1985).

As well as the Finnmarkian and Scandian regional metamorphic episodes, diagenetic/metamorphic processes were almost certainly initiated earlier, before the onset of these orogeneses, in the form of burial metamorphism in the deep, sediment-filled basins, but such fabrics were subsequently overprinted by Caledonian dynamothermal mineral growth.

Principal faults

Fault systems, other than those of the contractional fault regime outlined above, constitute an important element in the tectonic development of the Caledonides, but tend to be neglected in many discussions of geological evolution. In this account, rather than present a comprehensive analysis of faulting, emphasis will be placed on just one or two of the principal fractures.

Taking the Finnmark Caledonides as a whole the major, vertical, fault sets fall in the quadrant between NW-SE and WSW-ENE. Within any one small area, certain trends may predominate and in some cases these fault sets can be readily associated with the stress field which obtained during the Caledonian deformation (e.g. Roberts 1971, Worthing 1984). Nevertheless, there appears to be sufficient evidence now favouring the notion that many of these structures are long-lived dislocations along which there have been several components of displacement.

The NW-SE-trending *Trollfjord-Komagelv Fault Zone* (Siedlecka & Siedlecki 1967) of Varanger Peninsula (Plate 1) was initially considered as a reverse-fault with SW-directed movement, though new field evidence eventually came to light which favoured dextral strike-slip as the dominant displacement (Roberts 1972, Johnson et al. 1978) (see p.). Harland & Gayer (1972) also suggested that the T-K Fault was a transcurrent fracture and marked the boundary between the Baltic and Barents plates. Subsequently, Kjøde et al. (1978) concluded, from palaeomagnetic data (p.), that dextral strike-slip displacement of up to 1000 km had occurred along the fracture during the development of the Iapetus Ocean in the Late Precambrian-Cambrian period. Other such NW-SE palaeotransform faults may exist elsewhere in Finnmark and Troms, now camouflaged by the cover of Caledonian nappes.

The T-K Fault can be traced into the Ribachiy Peninsula of USSR as well as northwestwards south of Nordkinn Peninsula (Siedlecka 1975) and north of Magerøy. Interestingly, a prolongation of the fault transects the offshore NE-SW-trending Hammerfest Basin (Gabrielsen 1984), which did not begin accumulating a thick sequence of sediments until Middle Jurassic time. Reactivation of the T-K Fault thus appears to have extended into the Mesozoic-Cenozoic period. In this part of Finnmark there are many faults and other fractures (with associated breccias, and in one case, on Magerøy, a post-Scandian diabase dyke) which are parallel or subparallel to the trend of the T-K Fault (Roberts & Andersen 1985), as well as several offshore (e.g. Ersov et al. 1974, Åm 1975). It is conceivable that many of these faults are long-lived fractures with several components of displacement from Early Palaeozoic (or Precambrian?) time to Tertiary or even younger.

Faults of NE-SW trend are also important structures within the Caledonian allochthon. The *Vargsund Fault*, for example, extends southwestwards across Kvænangen into the Nordreisa district of Troms (Zwaan 1985). This appears to show components of both normal dip-slip (down towards NW) and strike-slip (Zwaan & Roberts 1978, Worthing 1984). Most of the major, vertical NE-SW faults on Sørøy, which carry breccias or gouge, have downthrows to the northwest although some show evidence of dextral strike-slip movement (horizontal slip striæ) in addition to dip-slip (Roberts 1971). Some of this fault movement has been ascribed to Mesozoic (North Atlantic opening) and Tertiary displacements. The consistent downstep to the northwest does, in fact, accord with features known from the offshore Troms-Finnmark Fault Complex (Gabrielsen 1984). In this connection it is of interest that Bartley (1982) considers 'late' NE-SW faults in southwest Troms to be of Mesozoic age, related to rifting prior to opening of the Norwegian Sea.

Time of deformation and metamorphism

Evidence bearing on the time of Caledonide orogenic deformation derives from two sources; biostratigraphy and isotopic age-determination data. Prior to the initial radiometric dating work of Sturt et al. (1967) the principal tectonothermal event had been assumed to be of Silurian age. Fossils on Magerøy were Lower Silurian (Henningsmoen 1961); and even the subsequent discovery of a Tremadoc fauna on Digermul Peninsula (Reading 1965) did little to arouse suspicion that the Caledonian orogen in Finnmark might be more complicated than hitherto believed. Today, although the biostratigraphic story in the nappes is little changed, the wealth of radiometric age data is such that the effects of the Finnmarkian orogenic phase can be recognised throughout large parts of the metamorphic allochthon.

The Finnmarkian evorogenesis itself covers a lengthy episode of Early Palaeozoic history, from ca. 540 to 490 Ma B.P. (Sturt et al. 1978) or even slightly younger, and as noted earlier embraces several pulses of deformation and metamorphism. The radiometric data have shown that the doformation and regional metamorphism occurred according to a general pattern, initially affecting the sediments and basement of the orogenic interior and then gradually migrating outwards, through time, towards the Baltoscandian foreland (Sturt & Roberts 1978, Sturt et al. 1978, Ramsay et al. 1984a, Rice 1984). This wave of deformation and associated metamorphism, as well as later uplift and cooling, thus commenced in what are now the highest nappes in the allochthon pile, in the upper Kalak, and progressively shifted southeastwards. Thrusting, although a part of this overall deformation, is slightly later than the synmetamorphic folding but this too migrated towards the craton, successively detaching the subjacent folded rocks as thrust-sheets and nappes, one by one, in what is essentially a piggyback thrusting model. Studies of the thrusting history and thrust-sheet geometries have also confirmed this diachroneity of Finnmarkian orogenic deformation (Chapman et al. 1985, Townsend et al., in press).

In general, radiometric age-dating in the Finnmark Caledonides has hitherto relied on the Rb-Sr and, in part, K/Ar methods (see e.g. Sturt et al. 1967, 1978, Pringle 1973). Nephelines from Seiland and Sørøy taken from nepheline-syenite dykes cutting polydeformed metasediments yielded K/Ar ages of 488 - 500 Ma (recalculated according to Dalrymple 1979), interpreted as the age of intrusion. Subsequently several Rb/Sr isochron ages in the range 540 - 490 Ma were reported from synorogenic plutonic rocks in the Seiland province (Sturt et al. 1978). The Rb/Sr method was also employed in attempts at determining the age of the regional schistosity or slaty cleavage (Pringle 1973, Sturt et al. 1975, 1978, Taylor & Pickering 1981), in the range 520 - 493 Ma. B.P. More recently, sampling has been carried out by Dr. R.D. Dallmeyer to determine incremental-release ^{40}Ar/^{39}Ar cooling ages recorded by minerals defining the pervasive slaty cleavage or schistosity in the metasediments. Preliminary results of the work on whole-rock slate samples from the Laksefjord and Gaissa Nappes suggest that cleavage formation occurred at c. 485 ± 5 Ma (R.D. Dallmeyer, pers.comm. 1985 and in press).

Based on calculated shortening values from studies of cross-sections, Chapman et al. (1985) have estimated a rate of propagation of the Finnmarkian orogenic deformation of more than 0.5 cm/y^{-1}, a figure which is similar to that obtained from other thin-skinned mountain belts.

The Scandian event in Finnmark is represented primarily on Magerøy, where there is a biostratigraphic constraint for at least the maximum age of deformation. A Rb-Sr isochron age of 411 ± 7 Ma for the synorogenic Finnvik granite (Andersen et al. 1982) provides a good indication of the time of Scandian metamorphism; at the transition from Silurian to Devonian time. Earlier, Sturt et al. (1967) had reported K/Ar mineral ages of 428 - 392 Ma (recalculated according to Dalrymple 1979) from alkaline rocks from the higher parts of the Kalak Nappe. Elsewhere, definite evidence of the Scandian phase is lacking, although some later fold structures, cleavages and mineral growth within Finnmarkian nappes have been related to this orogenic cycle (Zwaan & Roberts 1978, Andersen 1981). Sturt et al. (1975) and Ramsay et al. (1985a) have outlined the possibility that the present-day position of the Finnmarkian nappes may be attributed to major translation in the Finnmarkian phase with reactivation, and final emplacement in the Scandian. This may have been the case for the highest nappes, including the Kalak sole thrust which has local ultracataclasites cutting ductile mylonites.

Features supporting the notion of Scandian reactivation of the Kalak thrust include: (1) the relative, dextral displacement of the Kalak thrust along the Trollfjord-Komagelv Fault is less than that for the folds and thrusts exposed below the Kalak level along this same fracture: (2) the base of the Kalak marks a more prominent break in metamorphic grade and structural grain than is the case elsewhere within the Finnmarkian allochthon, suggesting later movement after the initial Finnmarkian, foreland-directed, nappe assembly. On grounds of diachroneity, as noted for the Scandian at other places in Scandinavia (Roberts & Gee 1984), then this late component of Kalak displacement may be of earliest Devonian age.

Summary

The stratigraphical successions which constitute the frontal autochthon and Finnmarkian-deformed allochthon range in age from late Riphean to earliest Ordovician (lower Tremadoc). Different parts of these sequences lie unconformably upon subjacent Archaean or Proterozoic (Svecokarelian) rocks in both the autochthon and the allochthon. In the Kalak Nappe Complex the unconformable cover-on-basement relationship has been recognised at several levels in the tectonostratigraphy. In this composite nappe pile, basement gneisses or supracrustals form a major component, tectonically incorporated during the late Cambrian/earliest Ordovician Finnmarkian orogeny. The highest major nappe unit, the Magerøy Nappe, is composed largely of early Silurian sediments metamorphosed and deformed during the late Silurian/earliest Devonian Scandian event.

The Finnmarkian deformation and metamorphism began in the orogenic interior, far to the 'west', in middle to late Cambrian time; the rocks in the upper Kalak were metamorphosed in highest amphibolite facies at some 25-30 km crustal depth. At this time, sediments were still being deposited along the foreland of the Baltoscandian margin. This orogenic deformation migrated diachronously east- to southeastwards into shallower crustal regimes, ultimately affecting the successions now occurring in the lower nappes and parautochthon in post-lower Tremadoc time. In consequence, grades of regional metamorphism wane southeastwards, into subgreenschist facies (medium- to high-anchizone) in the Gaissa Nappe and lower anchizone in the parautochthon. Diagenetic fabrics characterize the sediments of the autochthon.

The SE-ESE-directed thrusts are syn- to post-metamorphic dislocations and also developed through time, in piggy-back fashion, from northwest to southeast. The lower nappes show abundant evidence of listric thrusting, imbricate zones, duplex structures, and the overall features of ramp-flat thrust deformation characteristic of the external zones of thin-skinned mountain belts. The folded parautochthonous rocks below the northeast extension of the Gaissa thrust are believed to be floored by a blind thrust. In the west, the Svecokarelian Raipas rocks in tectonic windows are considered to be parautochthonous or allochthonous.

Radiometric age determination evidence for the Finnmarkian indicates that deformation, metamorphism and igneous intrusion in the Kalak occurred in the period 540 - 500 Ma B.P.; and in the lower nappes and parautochthon from c. 510 to c. 480 Ma.

Scandian deformation and metamorphism affects first and foremost the Magerøy Nappe and occurred around the time of the Silurian-Devonian transition. The basal thrusting of the Magerøy Nappe occurred under amphibolite facies conditions, and was directed east-southeastwards. Other evidence for Scandian deformation and heating of the Finnmarkian nappe pile comes from geochronology. The rocks of the Kalak Nappe Complex, in particular, appear to show this, and ultracataclastic thrust fabrics cutting early mylonites may relate to this phase.

Faults are important structures, commonly neglected in tectonic syntheses. Many of the principal faults in Finnmark are long-lived fractures, initiated in Precambrian or early Palaeozoic time and rejuvenated repeatedly into later Palaeozoic, Mesozoic and Cenozoic time. The NW-SE Trollfjord-Komagelv Fault of Varanger Peninsula is considered to have functioned as a paleotransform fault, with several hundred kilometres right-lateral slip, during late Precambrian-Cambrian time. Subsequent componental movements along this megafracture zone include a Mesozoic-Cenozoic displacement which affects an offshore sedimentary basin. Many of the NW-SE faults in this part of Finnmark could also be comparatively young structures. Similarly, major NE-SW faults are thought to be multiphase, with their latest, NW-downthrows probably having occurred in Mesozoic time in connection with the opening of the Norwegian Sea.

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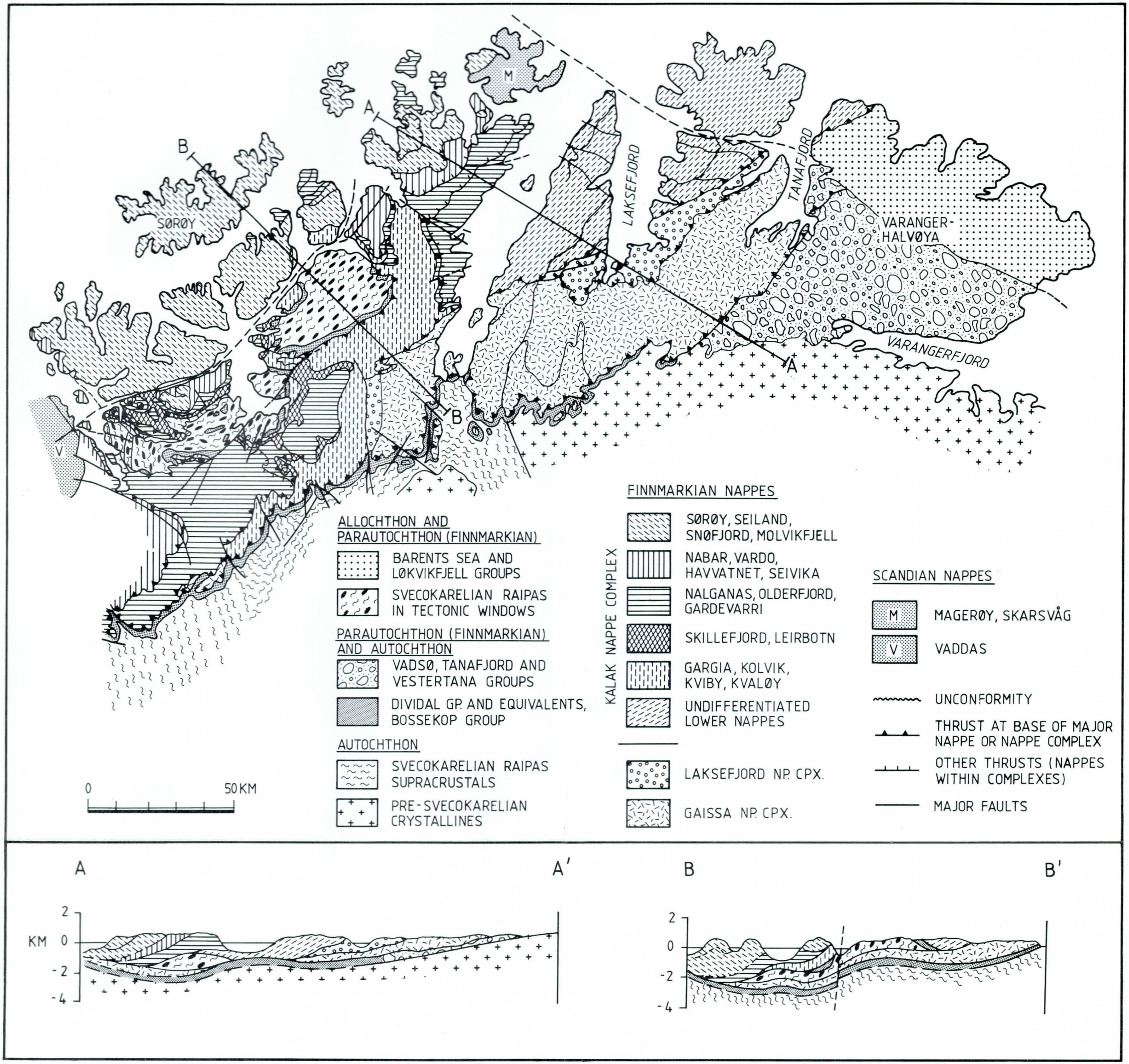

Plate 1 Detailed tectonostratigraphy of the Finnmark Caledonides, modified from Ramsay et al. (1984). Two cross-sections, with X5 vertical exaggeration, are also shown. Subdivision into separate nappes within the Kalak is, in fact, much more complex than shown here. Several of the main nappes distinguished in the different areas have been grouped together in the legend for technical reasons. Although in some cases correlation is fairly well established (e.g. Gargia = Kolvik), in other cases it is tentative. T-K.F. - Trollfjord-Komagelv Fault; V.F. - Vargsund Fault.