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THE ACCRETION OF OPHIOLITIC TERRAINS IN THE SCANDINAVIAN CALEDONIDES[1]

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ABSTRACT

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The timing of ophiolite emplacement is discussed and it is demonstrated how the accretion of ophiolitic terrains is related to the Finnmarkian Orogeny. The continental miogeocline, of the Scandinavian Caledonides is shown to relate to the pre-Finnmarkian continental margin, and that it was effectively destroyed during the Finnmarkian Orogeny. The final assembly of the tectonostratigraphy of the Scandinavian Caledonides, is however the result of superimposed orogenic cycles. The pattern of development bears many resemblances to that of the Appalachian orogen in North America.

INTRODUCTION

The Scandinavian Caledonides in their pre-thrust configuration, have traditionally been envisaged in terms of the geosynclinal concept and divided into an eastern miogeosynclinal and a western eugeosynclinal belt (STRØMER.1967; STRAND & KULLING.1972). The relationship between these belts is complicated by deformation, metamorphism and large-scale thrust translations; the latter telescoping assemblages and juxtaposing nappes that contain diverse elements. In the last decade it has been realized that this simplistic view is no longer tenable and GEE (1975) together with ROBERTS & GALE (1978) presented models for the evolution of the Scandinavian Caledonides in terms of the Wilson Cycle where the patterns were viewed as relating successively to the opening and destructive phases of the ancient Iapetus Ocean. Thus GEE (1975), in his synthesis, considered Caledonide evolution in terms of an Iapetus opening phase during late Precambrian times with major ocean floor spreading during the Cambrian, and subduction initiated during the Ordovician which culminated in a collisional event (Scandian) in latest Silurian to earliest Devonian time. Broadly similar reasoning was employed by ROBERTS & GALE (1978). These models thus view the orogenic evolution as essentially relating to one major climax – the Scandian, and although these authors comment on the earlier (Finnmarkian) orogenic development it does not play an essential role in their model. Surprisingly this is also a feature which is not discussed in a recent paper by STEPHENS & GEEN (in press).

The early Caledonian deformation (late Cambrian - early Ordovician) of the Finnmarkian, however, assumes major importance in view of subsequent studies. The Finnmarkian Orogeny (STURT ET AL., 1978; RYAN & STURT. in press) represents a major climatic cycle that affected the continental rise prism and that produced widespread polyphasal deformation and metamorphism together with translative thrusting onto the Baltic Craton. It is now apparent that the Finnmarkian also involved the obduction of (a) major slab(s) of oceanic crust as ophiolites onto the deforming rise prism (STURT ET AL., 1983). Thus the ancient continental margin can no longer be recognized, as the formerly attached oceanic crust has been either subducted or obducted. The vestiges of ocean floor are now seen as ophiolites, which represent allochthonous material derived from a sea-board terrain and from an unknown position in Iapetus.

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WILLIAMS & HATCHER (1982, 1983) have recently reviewed the development of the Appalachian Orogen, in North America, and point to the difficulty of applying the Wilson Cycle concept in its simplest form. They drew attention to how vestiges of the Iapetus Ocean are nowhere coupled to the eastern margin of the ancient North American craton. As a result such Iapetus relics and the extensive eastern terraines cannot be shown to have a primary connection to the North American miogeocline, and are thus designated as *Suspect Terrains*. These suspect terrains are in essence analagous to certain of the tectono-lithofacies belts of WILLIAMS (1978).

WILLIAMS & HATCHER (1982, 1983) invoke a complex and multi-stage history during the successive Taconic, Acadian and Alleghenian orogenies. Implicit in their arguments is the virtual destruction of Iapetus, as a major ocean, during the earlier Taconic Orogeny. Their model envisages the accretionary process in terms of 'head-on' collisions, with respect to the western ophiolite-containing terrains, and by oblique (strike-slip) movements emplacing the eastern terrains.

The Scandinavian Caledonides bear many resemblances to the Appalachians in spite of their development on the opposite side of Iapetus. The major stage of Iapetus destruction apparently occurred during the Finnmarkian Orogeny and the ophiolitic terrains were accreted to the Baltic Shield at that time; though in the view of STEPHENS & GEE (1981, in press) they accreted to Laurentia and were first moved over the Baltic Shield during the later Scandian Orogeny. I favour the first of these views and will discuss the evidence on the subsequent account. The post-accretionary history was complex and the Ordovician and Silurian saw a plethora of sedimentary basins, volcanism, plutonism and major syn-sedimentary faulting. The palaeogeographic patterns were furhter complicated by deformation, metamorphism and translative thrusting during the later Scandian Orogeny. The rocks were subsequently subjected to deep-seated erosional stripping prior to the deposition of the Devonian molasse and then underwent a third climactic cycle – the Solundian Orogeny – involving substantial thrusting, folding and low-grade metamorphism (STURT, 1983). The Finnmarkian in its timing is slightly older than the Taconic Orogeny, and little evidence is present in the Appalachians for an orogeny corresponding to the Scandian although this correlates well with the main Caledonian orogeny in the British Isles (ANDERSEN ET AL., 1982). The Solundian broadly equates with the Accadian of the Appalachians, and recent work by the author points to the possibility of Variscan tectonics affecting parts of the Baltic craton.

As a result of a collaborative endeavour (I.G.C.P. project 27), geologists in Norway and Sweden have provided information for a tectonostratigraphic map of the Scandinavian Caledonides: This map has been compiled by D. Roberts and A. Thon (Norway) and by D. G. Gee and M. B. Stevens (Sweden) and will be published in colour, in 'The Scandinavian Caledonides and related areas' by John Wiley & Sons in 1984. This map is reproduced in black and white in Fig. 1 and the principal ophiolite localities have been inserted. The map employs a terminology of autochton/parauthochton; lower, middle, upper and uppermost allochthons and this will be used in the subsequent text.

In the present account I will discuss the pre-accretion form of the ancient continental margin of the Baltic Craton and show how the accretion of the ophiolite terrains occurred. Naturally the views stated will be those to which I subscribe, though alternative interpretations will be discussed.

THE CONTINENTAL MIOGEOCLINE – CONTINENTAL RISE PRISM

The identification of the Miogeocline, in Central Scandinavia, has been made essentially by GEE (1975, 1978) from a consideration of facies belts, and has recently been refined (STEPHENS & GEE, in press) to include the Lower and Middle Allochthons and the lower part (Seve Nappes) of the Upper Allochthon. These studies view Riphean to Silurian sedimentation as essentially a continuum with no major deformative events until the Scandian Orogeny, and as such they consistently ignore any possible effects of the Finnmarkian Orogeny. This is perhaps curious as, in its type area, the Finnmarkian Orogeny affects a corresponding lithostratigraphic package which is in an essentially similar tectonostratigraphic position (RAMSAY ET AL., in press; ZACHRISSON & STEPHENS, 1984). In addition recent geochronological investigations show that the rocks of the miogeocline, in the Central Caledonides, have been extensively affected by Finnmarkian deformation and metamorphism (CLAESSON, 1980, DALLMEYER ET AL., 1983). This immediately poses the question of the significance of the miogeocline; i.e. did it represent the continental margin of the pre-Finnmarkian Iapetus as claimed by STURT ET AL., 1983 or does it represent a continuously developing miogeocline though into Silurian times and destroyed only by the later Scandian Orogeny (STEPHENS & GEE, in press)? This is obviously one of the major questions concerning the sequential evolution of the belt.

Let us first, however, address ourselves to a description of the miogeocline. Continental basement of the Baltic Shield can be traced semi-continuously, from the Caledonian front, beneath the nappe stack via a series of tectonic windows to the west coast. The presence of thin platformal sediments of Riphean-Ordovician age on this basement, as pointed out by KUMPALAINEN & NYSTUEN (in press), indicates the easternmost position that the great late Precambrian 'sparagmite' basins of the SE-Caledonides could have occupied in a pre-thrust configuration. KUMPALAINEN & NYSTUEN (o.c.) show how thick Riphean-Cambrian clastics accumulated in a series of grabens and half-grabens, on an extension of the Baltic Craton, westward of the present-day coastline. These clastics now occupy nappes, in the Lower and Middle allochthons, and have been translated several hundreds of kilometres to their present sites. In Finnmark, however, similar rocks can be traced continuously from the autochthon into the middle allochthon

(RAMSAY ET AL., in press). This implies a formerly continuous and extremely wide continental shelf (> 600 km) in the west, which is now telescoped in the nappe pile (STURT ET AL., 1978, 1983, RAMSAY ET AL., in press). This difference in pattern may have been influenced by the great Trollfjord-Komagelv Fault with its, pre-thrust, right-lateral displacement of > 500 km (KJØDE ET AL., 1978).

KUMPALAINEN & NYSTUEN (in press) show how the pre-Vendian sedimentation of the southern and central Caledonides evolved in isolated or semi-isolated basins; with just the western of Tossåsfjellet Basin opening westwards as a continental shelf. Only in post-Vendian times this part of the Baltic Craton gradually submerged, which led to a Lower Cambrian marine transgression. In the autochthon/parautochthon of East Finnmark, on the other hand, shallow marine shelf deposition which opened westwards characterised Upper Riphean through Cambrian sedimentation; with the exception of the glacial interval during the early Vendian (JOHNSON ET AL., 1978). These differences can be explained in various ways but they may well imply that the pre-Finnmarkian miogeocline had a configuration somewhat different from that suggested by the present tectonically controlled orientation of the orogenic belt.

The difference in original position of the southern basins is also reflected in their volcanic record. The 'eastern' or Hedmark Basin (FURNES ET AL., 1983) contains typical continental tholeiites (approx. 650 Ma) whereas the 'western' of Tossåsfjellet Basin (Särv. Nappe) hosts the well-known Ottfjellet diabase dyke-swarm also ca. 650 Ma. The latter has a geochemistry largely of mid-ocean ridge basalt (MORB), but with partly alkaline affinities, which is considered compatible with the incipient opening of the Iapetus Ocean (GEE, 1975; SOLYOM ET AL., 1979; CLAESSON & RODDICK 1983; STURT ET AL., 1983). The age of the dykes, ca. 650 Ma, is thought to effectively date the opening phase of Iapetus. Many of the amphiobolites in the overlying Seve Nappes are thought to have a similar significance (GEE, 1975; STEPHENS & GEE, in press). ANDREASSON ET AL., (1979) indentified similar dykes in the Leksdal Nappe, of the northern Trondheim region, and ascribed a corresponding significance to them. Pre-D_1 (undated) diabase dykes in the Nalganas Nappe of west Finnmark reveal similar geochemical patterns to the Ottfjållet dykes and are considered to also represent the incipient ocean opening stage (HUMPHREYS ET AL., in press). It is also of interest to see that diabase dykes of similar age (ca 640 Ma) have been recorded from the Barents Sea Group, north of the Trollfjord-Komagelv Fault; though they have not been reported in either the autochton or parautochthon south of the fault (BECKINSALE ET AL., 1975).

The most complete section of the miogeocline and rise prism is that through the Finnmarkian autochthon and allochthon, i.e. Kalak Nappe Complex, which spans the Lower and Middle allochthons. The constituent nappes of the Kalak Nappe Complex are all relatively thin-skinned basementcover couplets (Fig. 2). The basement, within each nappe, always consists of Precambrian continental crust although varying in type from nappe to nappe (RAMSAY ET AL., in press). The cover is always the distinctive Sørøy sequence (RAMSAY, 1971), although this is only fully developed in the uppermost nappes. This sequence comprises the thick psammite-dominated Klubben Group at the base (presumed Riphean-Vendian) passing up through the mica schists of the Storelv Group into the Lower Middle Cambrian marbles of the Falkenes Group. The Falkenes Group is overlain by graphitic schists (invariably Kyanite rich) of the Aafjord Group. All of these form a typical shallow water shelf association and are persistent both laterally and vertically in the nappe stack. The Hellefjord Group, at the top of the succession, is only found in the highest or most distal nappes and comprises a thick sequence of turbidites, representing probably continental slope deposits. The turbidites, in addition to continent derived material, received a considerable input of basic volcanic detritus (ROBERTS, 1968, 1980) although there is no record of contemporaneous volcanic activity in the rocks of the rise prism. This led STURT ET AL., (1983) to postulate that subduction, with westward polarity, was initiated in Middle to Upper Cambrian times, and that the volcanic detritus was arc-derived. The dating of Finnmarkian orogenesis, in the type-area, falls into the time-span 535-485 Ma (STURT ET AL., 1978). The deformation occurred in two major episodes (D1 and D2) and the metamorphic maximum was apparently placed inbetween. The metamorphism of the higher allochthonous nappes is characterised by the widespread development of kyanite and by pressures in the range 6-10 kbar (STURT & TAYLOR, 1972), the nappes being now stacked in inverted order of metamorphic grade. This may imply that some subduction of the continental rise prism occurred during D1 and that the translative continentward thrusting took place during D2. In this context it is of great interest at $^{39}Ar/^{40}Ar$ mineral plateau ages have recently been obtained indicating Finnmarkian effects from the western extension of the Baltic Shield, on Senja (DALLMEYER, 1983 pers.comm.). This fits well with cleavage ages from slates in the autochthon and parautochthon of E. Finnmark (STURT ET AL., 1978, TAYLOR & PICKERING, 1981).

The age of metamorphism in the miogeoclinal area of the Central Caledonides has been a matter of debate. It is apparent that the Seve assemblage contains Sveco-Norwegian (Grenvillian) basement (REYMER, 1979) and that the gneisses and sediments have been affected by Scandian metamorphism (CLAESSON, 1982). The mylonites of the Tännäs Augen Gneiss Nappe, underlying the Särv Nappe, have given an age of 485 Ma (CLAESSON, 1980) which shows evidence of Finnmarkian deformation. Recently DALLMEYER ET AL., (1983) have obtained $^{39}Ar/^{40}Ar$ mineral plateaus ages in the range 480-450 Ma from amphibolites within the Seve complex. These results imply that the rocks of the miogeocline, in the Central Caledonides, have been affected by the Finnmarkian Orogeny although its effects are masked to a considerable extent by Scandian metamorphic overprint.

In the Vaddas Nappe, of the northern Caledonides, a major unconformity beneath an Upper Ordovician/Silurian sequence cuts down through the Finnmarkian complex (Fig. 2). This unconformably post-dates the two major folding phases and the amphibolite facies metamorphism of the lower sequence (RAMSAY ET AL., in press). A similar unconformity is observed above the Lyngen Ophiolite, and in the overlying sequence an extensive clast population, derived from the Finnmarkian metamorphic complex, has been identified (MINSAAS & STURT, in press). The Lyngen Ophiolite was affected by eastward-verging asymmetric folds prior to the unconformity and these would best equate with Finnmarkian D2. Rocks of the continental rise prism are apparently missing beneath the Karmøy and Norheimsund (Fig. 1) ophiolites, which are positioned close to the cratonic platform sequence. It is of considerable interest here that the pelagic cap rocks, of these ophiolites, have been deformed and metamorphosed during several phases into garnet grade prior to the Middle Ordovician, and that they presumably also record Finnmarkian orogenesis (STURT ET AL., 1983).

It would thus appear that the continental miogeocline/ continental rise prism was effectively destroyed during the Finnmarkian orogeny and that this orogeny also affected at least part of the obducted ophiolite assemblage. This would appear to answer the question that the miogeocline was in fact a feature of the pre-Finnmarkian continental margin.

THE ACCRETIONARY OPHIOLITIC TERRAINS

Rocks of the ophiolitic suite, in the Scandinavian Caledonides, have been the subject of many investigations in recent years. They were anticipated in model papers by GEE (1975) and ROBERTS & GALE (1978) in which a Cambrian continental margin of Atlantic type was envisaged with subsequent Middle Ordovician island arc activity, coincident with the initiation of subduction. ROBERTS & GALE (1978) proposed a configuration with Ordovician island arcs off the Baltic Craton which subsequently were thrust eastward during the Scandian Orogeny. The discovery of ophiolites *per se* (STURT & THON, 1978; PRESTVIK & ROALDSET, 1978) proved the involvement of Iapetus oceanic crust in the framework of the orogen and set the scene for subsequent work.

Recent descriptions (FURNES ET AL., 1980, 1984; STURT ET AL., 1983) show how ophiolitic complexes are located at a number of sites in the upper and uppermost allochthons, virtually along the entire belt, from Karmøy in the south to Lyngen in the north (Fig. 1). The ophiolites apparently belong to two stages of development:-

1-An early group (Group I) which represents vestiges of the Cambrian Iapetus that suffered varying degrees of Finnmarkian deformation and metamorphism (STURT ET AL., 1983). These ophiolites also show well-developed ocean floor and upper mantle deformation and metamorphism. Some of these ophiolite slices were involved in the construction of (a) Pre-Ordovician ensimatic island arc complex(es).
2-A younger group (Group II) of post-Finnmarkian 'rooted' ophiolites which developed during the Lower and Middle Ordovician. These are regarded to represent failed or limited spreading in a back-arc milieu, and hence to resemble such ophiolites as the Sarmiento and Tortuga complexes of southern Chile (ROBERTS ET AL., 1984; FURNES ET AL., in press).

The sub-division of the ophiolitic complexes into a younger and an older series has considerable implications for geotectonic modelling and implies an early (Lower Ordovician) stage of ophiolite obduction (Group I). If correct this means that the pattern of subsequent continental margin evolution would be considerably different from the Atlantic type margin assumed for the Iapetus spreading phase. This later pattern is, however, not the subject of this review which is primarily concerned with the accretion of the Group I ophiolites.

As yet there is no way of ascertaining from which position in the Iapetus system that the Group I ophiolites were derived. Obviously, considerable amounts of oceanic crust will have been lost during subduction. Hence, in the reasoning of WILLIAMS & HATCHER (1982, 1983) all of the ophiolitic terrains must be viewed as *Suspect Terrains*. Certain of the Group I ophiolites, however, bear geochemical and geological signatures of having been involved in the construction of ensimatic island arcs.
This is seen in the geochemistry of the late dyke suite of the Karmøy ophiolite (PEDERSEN, 1982), the petrology of the Geitung volcanic unit of the Lykling Ophiolite on Bømlo (AMALIKSEN, 1983; FURNES ET AL., in press), the ensimatic volcanic arc suite of the Funsjø volcanics in the eastern Trondheim region (GRENNE & LAGERBLAD, in press) and through geochemical evidence from dykes in the Narvik area (BOYD, 1983). The 535±46 Ma age for the Geitung Volcanics (FURNES ET AL., 1984) shows that a considerable proportion of the Group I ophiolites must represent Cambrian or older oceanic crust. This is confirmed by the pre-Tremadoc age of the Funsjø Volcanics (GRENNE & LAGERBLAD, in press).
The Group I ophiolites furthermore are unconformably overlain by Ordovician sediments the oldest of which are Upper Middle Arenig (RYAN ET AL., 1980).

Let us now consider the evidence that the Group I ophiolites were obducted onto the proto-Baltic Shield during the Finnmarkian orogeny:-

1. The rocks of the ophiolite suite and of the underlying continental rise prism are cut by a major terrain-linking unconformity which indicates that ophiolite accretion had been completed prior to the erosional stripping of the uplifted belt. This will be discussed in more detail in a subsequent section.
2. The Karmøy Ophiolite is cored by pre-Ashgill (Middle (Ordovician?) granitoids of the West Karmøy Igneous Complex. These granitoids bear abundant xenoliths of continental

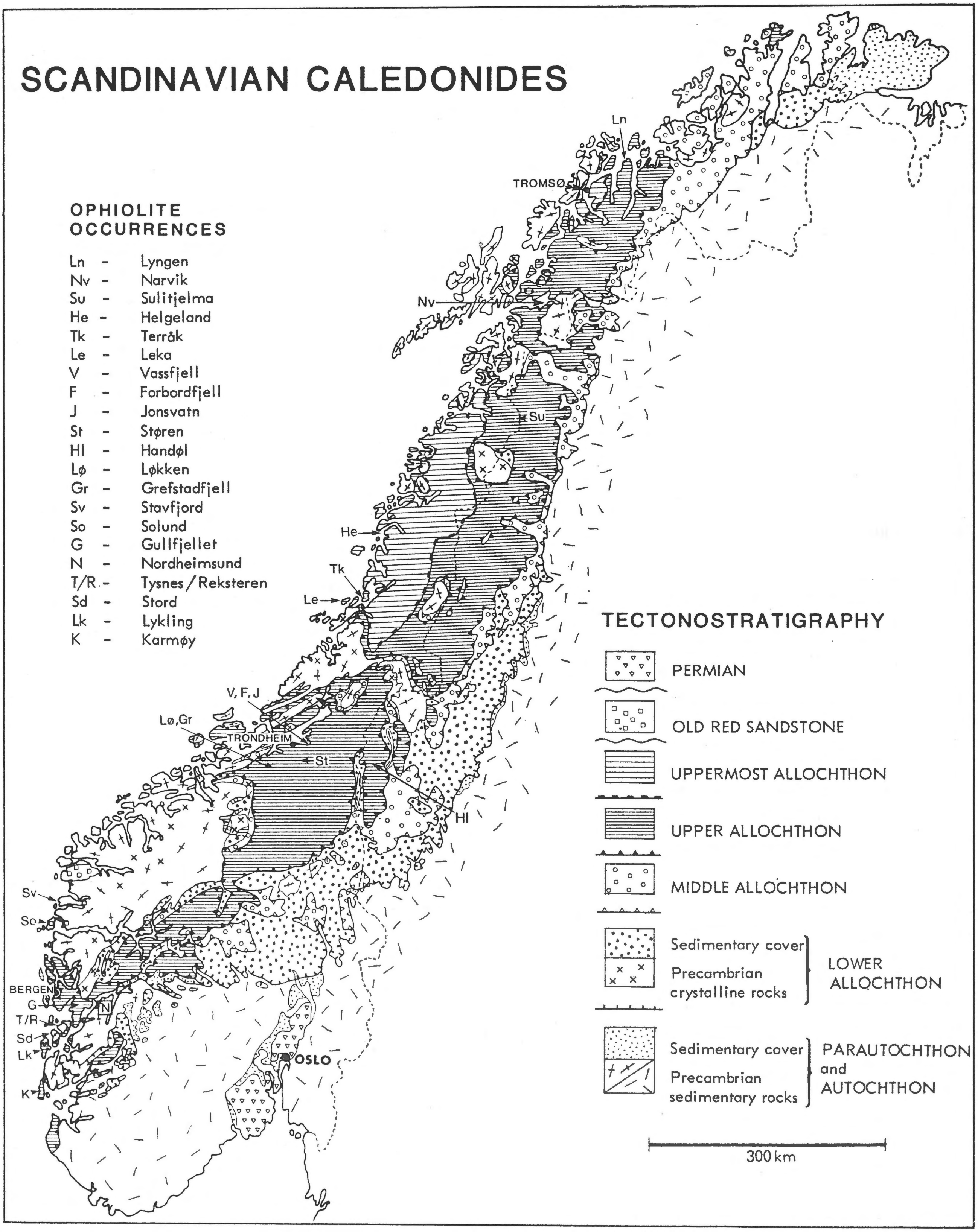

Fig. 1
Locations of the ophiolite fragments recognised up to the present time in the Scandinavian Caledonides. Modified from Sturt et al. (1983).

crystalline basement, which have been brought up through the ophiolite complex (STURT ET AL., 1980, LEDRU, 1980). This would demonstrate that the Karmøy Ophiolite had overthrust continental crust presumably prior to the Middle Ordovician.

3. The Lykling Ophiolite, of Bomlø, was first folded and than covered by a bimodal suite of typical continental volcanics (Siffjø Volcanics) of Middle Ordovocian age.

These volcanics resemble those of the Basin and Range and typify a particular type of continental volcanism on the landward side of a subduction-controlled continental margin.

4. The recently discovered Handøl Ophiolite, in the lower Køli Nappe (GEE & SJØSTRØM, 1984) is affected by Finnmarkian metamorphism and separated from the Seve assemblage by an amphibolite facies blastomylonite zone. GEE & SJØSTRØM (1984) relate the ophiolite emplacement to the early Ordovician amphibolite facies metamorphism in the Seve nappes.

5. Anomalously high contents of chlorite, Mg, Fe, Cr and Ni have been recorded from shales of Middle and partly of Lower Ordovician age in the Oslo region (BJØRLYKKE & ENGLUND, 1979). The most likely source is the erosion of uplifted, obducted ophiolitic terrains.

6. The Karmøy, Lykling, Gulfjellet, Norheimsund and Lyngen ophiolites bear distinctive imprint of Finnmarkian deformation and metamorphism. This implies their involvement in the continental rise prism during the Finnmarkian Orogeny.

7. The age of the ensimatic arc formation corresponds closely to that obtained for the Finnmarkian D1 deformation, and suggests that the two may have a common origin. It will be recalled that the turbidites of the Hellefjord Group received an influx of basic volcanic detritus from a presumed western source, most logically the marginal ensimatic arc. This would imply a continuity of the ocean-arc-trench-continental rise prism system prior to Finnmarkian orogenesis, and that both the arc formation and initiation of Finnmarkian tectonism were related to subduction.

The evolutionary pattern described above has interesting consequences concerning the Finnmarkian Orogeny and its essential mechanism. Let us consider the implication of the last point mentioned above where a scenario is set of westward subduction that produced a marginal ensimatic arc. The age of this arc seems to be well established as late Cambrian and to coincide closely with the initiation of Finnmarkian tectonics. When we consider also the extensive evidence of pre-Middle Ordovician deformation and metamorphism of the Group I ophiolite complexes it is difficult to escape the conclusion that their obduction and orogenic tectono-thermal development was an integral part of the Finnmarkian Cycle.

It has been proposed (STURT ET AL., 1983) that the turbidites of the Hellefjord Group formed in a continentfacing forearc trough related to the ensimatic arc formation. If this was the case one would expect to find more evidence of the forearc in other parts of the Upper Allochthon. One such occurrence is found in the Upper Køli nappes for which STEPHENS & SENIOR (1981) have suggested that the rocks of the Krutfjellet unit had been deposited in a forearc basin. They considered that this basin was 'fed by both a distal terrestrial source as well as by the arc itself', and also concluded that the forearc basin was positioned off the then Baltic continental margin. STEPHENS & GEE (in press) show how the Krutfjellet rocks had suffered penetrative deformation and methamorphism during 'an early and/or Middel Ordovician event'. The recent dating by DALLMEYER ET AL., (1983) provides well-defined $^{39}Ar/^{40}Ar$ plateau ages, for hornblendes from the Upper Køli nappes, in the range 510-480 Ma. This implies that the rocks of the Krutfjellet unit may in fact represent part of the Finnmarkian forearc sequence. If this is the case a connection from the migeocline through successively the trough, fore-arc, marginal arc and eventually Iapetus can be envisaged along the length of the belt.

The existence of such a pattern with westward subduction, beneath the marginal arc, would account for eventual subduction of part of the continental rise prism. This would explain the widespread incidence of kyanite grade metamorphism in the rocks of the rise prism, and the evidence for high-P metamorphism shown by the Seve eclogites. Such a condition would eventually develop into a gravitational instability of the type proposed by AUDLEY-CHARLES (1981) from the Timor region. This would result in a consequent continentwards thrusting involving continental crust, sediments of the rise-prism and of the fore-arc, volcanics of the marginal arc, and of the ocean-floor. Thus it would appear that the major period of accretion of the ophiolitic terrains occurred during the Finnmarkian Orogeny. Subsequent to this the ophiolites reacted as part of the Baltic Shield. The renewed subduction during the Ordovician, implies that there was still Iapetus ocean floor in a sea-board position.

There is by no means unanimity concerning this model for ophiolite accretion and indeed STEPHENS & GEE (in press) present a very different view. Their thesis envisages the Group I ophiolites as having first accreted onto the Laurentian Plate to be subsequently thrust over and onto the Baltic Craton, uniquely as a result of the Scandian collisional event. This model will be further discussed in the ensuing text.

THE POST-OPHIOLITE ACCRETION UNCONFORMITY

One of the most dramatic advances in our understanding of the Scandinavian Caledonides during the past decade has been the recognition of a major belt-length unconformity in the Upper and Uppermost Allochthons (STURT & THON, 1976, 1978a, 1978b; NATERSTAD, 1976; TRAGHEIM, 1981; THON ET AL., 1980; BOYD, 1983; STURT ET AL., 1983, in press; RAMSAY ET AL., in press; GRENNE & LAGERBLAD, in press; MINSAAS & STURT, in press; NADERSEN ET AL., in press and THON, in press). The unconformity apparently also post-dates the accretion of the allochthonous ophiolitic terrains. The nature and significance of this unconformity will now be discussed.

The unconformity is only obvious in the upper and uppermost allochthons, and only minor effects are seen in the autochthon-parautochthon and the lower allochthon. One of the features observed in such areas is a series of non-sequences within the uppermost Cambrian and the Tremadoc (THORSLUND, 1969; STRØMER, 1967, STRAND & KULLING, 1972; LINDSTRØM ET AL., 1983). KULLING (in STRAND & KULLING, 1972) commented on a major transgression in the Jämtland sequence which occurred during the lowermost Arenig of Hunneberg stage. He also showed how the oldest sediments, deposited on basement in the Olden Nappe are of probable Upper Arenig age (see figure 138 in STRAND & KULLING, 1972). This implies either non-deposition of the Cambrian and Tremadoc or a major uplift with erosional stripping of the sequence.

In the Oslo region, most of the Lower Ordovician is missing in the Skien-Langesund district and in other parts there are indications of shallow water and of possible non-deposition during this period (BJØRLYKKE, 1974). The input of ophiolite-derived material, recorded in geochemical anomalies, also provides evidence for major uplift and erosion of the western belt. The lack of a major unconformity in these terrains presumably reflects distance from the locus of deformation in the rise prism at the western edge of the formerly extended Baltic Platform. In East Finnmark, however, slaty cleavage ages from the autochthon/parautochthon imply that effects of Finnmarkian deformation had spread onto the craton.

In the higher allochthons, on the other hand, the unconformity is pronounced; and indeed one of the characteristic features of the Group I ophiolites is the manner in which they are deeply dissected by an erosional unconformity (STURT ET AL., 1983). This also postdates orogenic deformation and metamorphism of the ophiolitic complexes.

There may be considerable sub-unconformity relict relief and in some cases fossil weathering profiles are preserved on the substrate (STURT ET AL., 1983, in press; MINSAAS & STURT, in press). The immediately overlying deposits vary from sub-aerial (fluviatile sediments, volcanics) to shallow marine deposits. In a number of localities the unconformity also cuts into the metamorphic rocks of the Finnmarkian rise-prism. In northern Norway the unconformity is present in the lowest part of the Upper Allochthon i.e. in the Vaddas Nappe. Here in the Vaddas and Kåfjorddalen areas the unconformity cuts deeply into the Finnmarkian substrate. The sub-unconformity sequence contains the classical Sørøy stratigraphy which in turn rests on a Precambrian gneissic basement plinth. These rocks had been deformed and metamorphosed during several phases prior to uplift, erosional stripping and deposition of an Ordovician-Silurian cover sequence (RAMSAY ET AL., in press; BINNS & GAYER, 1980). These younger sediments in turn rest on all members of the Sørøy sequence including its basement. In the nearby Lyngen area the Lyngen Ophiolite occurs at a higher tectono-stratigraphic level. This is again overlain by an unconformable succession of Upper Ordovician and Silurian strata (MINSAAS & STURT, in press). The unconformity cuts deeply into the ophiolite and a considerable subunconformity palaeo-topography has been recorded. Studies of the conglomerates and grits, in the younger sequence, reveals major clast populations which represent both ophiolitic detritus and clasts of Finnmarkian metamorphics. This implies that, during the erosion of the ophiolite, a nearby Finnmarkian metamorphic terrain was exposed that contributed a considerable supply of detritus (MINSAAS & STURT, in press). These observations raise the status of the unconformity to that of a terrain-linking one (STURT & RAMSAY, in prep.), and provide adequate proof that the Lyngen Ophiolite had accreted to the Baltic margin already in pre-unconformity times. This also gives a minimum age for the accretion of the ophiolitic terrains.

Unconformities are by their nature diachronous and cannot be used in terms of time-plane definition. The time-gap represented by an unconformity, at any given locality, depends on the dating of sequences both above and beneath the discordance. Unfortunately, good faunal control, particularly from the Lower and Middle Ordovician, is lacking over vast tracts and hence precise sequence-dating is fraught with considerable difficulty. Indeed large areas, including the whole of the uppermost allochthon, have not yielded either macro- or microfaunas. Thus in the higher allochthons assignment of stratigraphic age is often dependent upon lithofacies correlations, presence of unconformities (where recognised), patterns of magmatism and geochronology. The Ordovician and Silurian in the belt represent periods of complex geotectonic evolution and thus the basin configurations, locus and type of volcanism and of syn-depositional tectonics must have changed continuously. This makes the correlation or indeed identification of time-dependent lithofacies, through the complex package of allochthonous units, extremely difficult. The problem of resolving exact palaeogeographies is only in its early stages and much further work is required before this is properly understood.

The oldest known rocks above the unconformity occur within the Støren Nappe, of the Trondheim area. These are dated by graptolites as Upper Middle Arenig (OFTEDAHL, 1980; RYAN ET AL., 1980). In Sunnhordland the post-ophiolite unconformity underlies continental volcanics (Siggjo Complex), dated as Middle Ordovician (FURNES ET AL., 1984). These rocks are in turn unconformably overlain by the Ashgill containing Vikafhord Group (FURNES ET AL., 1984; BREKKE, 1983). In most areas the oldest datable part of the sequence is the Ashgill, which is usually represented by carbonate-dominated sediments. The Ashgillian sediments are in general reasonably fossiliferous. In some areas considerable thicknesses of sediments and volcanics underlie the level of the Ashgill, and no precise assignment of age can be given. Trondheim is the only area, whithin the higher allochthons, where there is good faunal control throughout the Ordovician. There are many features which point to marked tectonic instability during the Lower and Middle Ordovician as seen in:

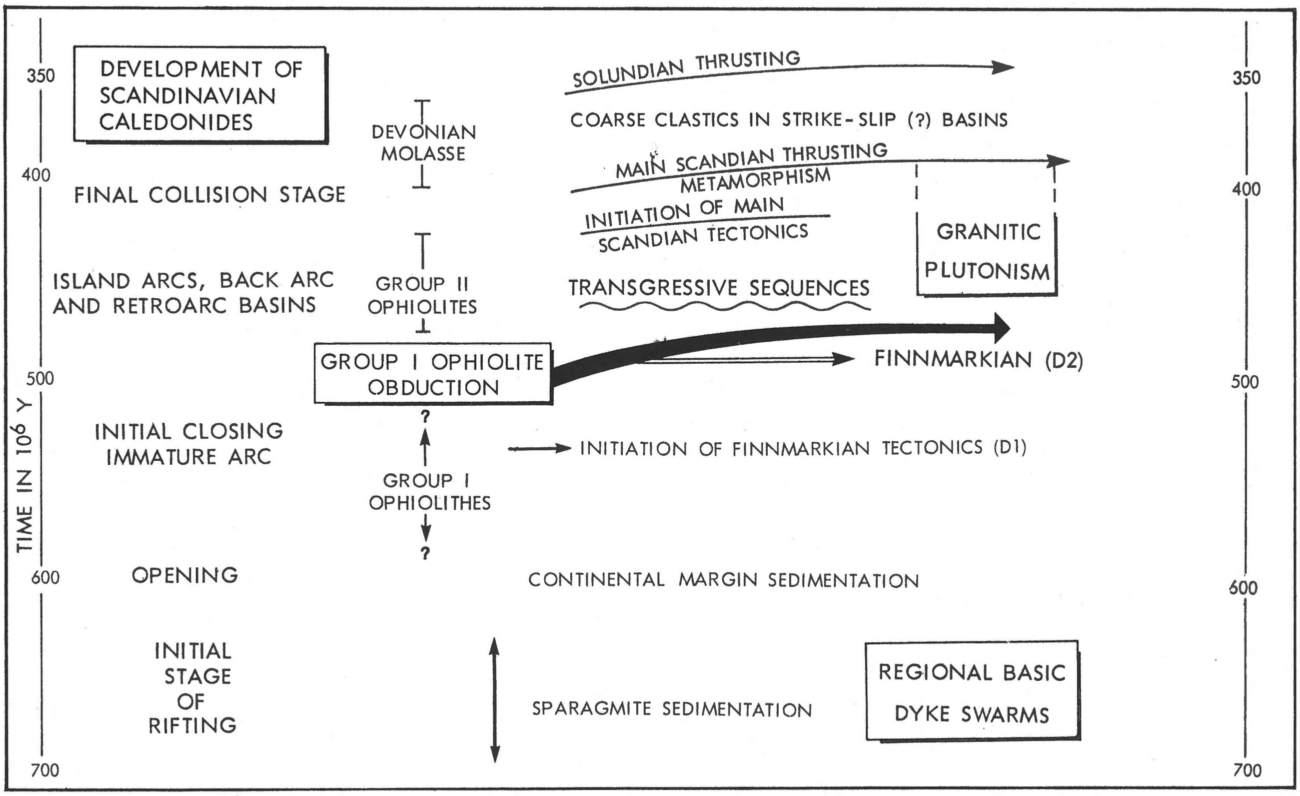

Fig. 2
Iapetus development history, and the time of generation of the two groups of Norwegian ophiolites in the context of the evolving orogen. Modified from Sturt et al. (1983).

1. The record of calc-alkaline volcanism and plutonism;
2. The rooted ophiolites, of the Trondheim area, which record crustal extensional processes;
3. Syn-deposition tectonics;
4. Presence of unconformities within the sequence.

The Sunnhordland region is a good case in point where the Vikafjord Group (on Bømlo) lies unconformably on the eroded more than 2000m thick Siggjo Volcanic Complex. The latter is also unconformable upon the Lykling Ophiolite. On nearby Stord, at Dyvikvågen, the Ashgill lies directly unconformable on the Ophiolite (THON ET AL. 1980) and at this locality the Siggjo volcanics are missing. This attests to tectonic activity prior to deposition of the Ashgill, presumably block-faulting and tilting, possibly accompanied by weak folding which was followed by uplift and erosional stripping. This example shows how stratigraphic patterns may change rapidly in even a very small area and underlines many of the difficulties of correlation, particularly where sequence-dating is often only by inference.

One of the principal and, as yet, unresolved problems of the central Scandinavian Caledonides concerns the exact stratigraphic relations within the Seve and Køli nappe complexes. The seve nappes contain a variety of gneisses, amphibolites and metasediments (psammites and schists). The metasediments are considered by most authors to represent the higher metamorphic grade equivalents of the Riphean-Cambrian sequence of the underlaying Särv Nappe. The Køli nappes contain a sedimentary-volcanic association essentially of Ordovician and Silurian age, and have been generally regarded as representing the younger part of a continuous succession with the metasediments of the Seve, although the two units are considered by most authors as being generally separated by tectonic contacts (GEE. 1975; GEE & ZACHRISSON. 1979; STEPHENS & GEE. in press). Recently it has become increasingly clear that the Seve in fact represents a polymetamorphic terrain and that in its older parts, important deformation and metamorphism occurred, probably early in the Ordovician (STEPHENS & GEE. in press).

Geochronological studies of Seve gneisses, from northern Jämtland and Västerbotten, show that these have experienced Sveco-Norwegian (Grenville) metamorphism (REYMER. 1979, REYMER ET AL.. 1980) and thus by implication they must represent basement to the Køli metasediments. CLAESSON (1982) has shown that the high-grade metamorphism of the Åreskutan area is essentially of Scandian age, although he recorded also indications of an earlier, ca. 1500 Ma, event. More recently DALLMEYER ET AL.. (1983) have reported $^{39}Ar/^{40}Ar$ cooling ages, in the range 480-450 Ma, from Seve amphibolites and ascribed these as recording Finnmarkian metamorphism. These authors also showed how the older part of the Køli complex has been affected by Finnmarkian metamorphism. These results taken together with CLAESSONS (1980) dating of the mylonites in the Tännäs augen gneiss show how the Middle and Upper allochthons of the central Caledonides have been extensively affected by the Finnmarkian Orogeny.

Thus the tectono-stratigraphic relations in the Seve-Køli assemblage have to be reappraised and it would now appear possible to view their relationships in terms of the north Norwegian model (see also ZACHRISSON & STEPHENS, 1984). It is suggested here that the Seve nappes together with those of the underlying Middle Allochthon are the analogues to the Finnmarkian nappe stack, and that the Køli nappes are the analogues to the Vaddas and overlying nappes of the north Norwegian section (Fig. 2). This would imply that the Seve and the oldest part of Køli nappe complexes together with the rocks of the underlying Middle Allochthon had been involved in continent-directed thrusting during the Finnmarkian Orogeny, although their final mise-en-place must be a product of the later Scandian and Solundian orogenies. A view broadly similar to this is now advocated by GEE & SJØSTRØM (1984).

Thus the Seve-Køli *problematica* can now be viewed in a new light which brings the geology of this part of the Central Caledonides in line with the well established relationships in other parts of the Scandinavian Caledonides. It also becomes imperative to reassess the critical field relationships within the Seve and Køli complexes and attempt to identify the unconformities which can be predicted within this assemblage:

1. Between Seve metasediments and a gneissic basement plinth;
2. Between Køli metasediments (Ordo-Sil) and the Seve which would act as a basement, in similar manner as the Finnmarkian metamorphic complex does in the Upper Allochthon of northern Norway;
3. Between Køli metasediments (Ordo-Sil) and ophiolitic basement and/or Finnmarkian forearc sequences.

The belt-length nature of the unconformity is of fundamental significance and it shows that the entire Finnmarkian orogenic belt was uplifted and erosionally stripped during the Ordovician. That rocks of the rise prism, fore-arc sequences, ensimatic arc sequences and ophiolites are all dissected by this terrain-linking unconformity gives elegant proof to the timing of accretion of the ocean-derived allochthonous terrains.

DISCUSSION

Evidence has been presented, in this paper, to demonstrate that the major stage in the accretion of ophiolitic terrains to the Baltic Shield was an integral part of the Finnmarkian Orogeny.

It has also been shown that the pre-Finnmarkian continental margin in essence consisted of a continental miogeocline/rise prism formed and that its destruction relates to the Finnmarkian Orogeny. The latter involved continentward thrusting, polyphasal folding and metamorphism, syn-orogenic plutonism and the obduction of ophiolitic terrains (including ophiolites *per se* and material of ensimatic island arcs). This orogeny was followed by major uplift and erosional stripping during the Early Ordovician. The orogen was finally covered unconformably by a sequence of Ordovician and Silurian strata. The major belt-length unconformity, at the base of this younger sequence, can be shown to be of a terrain-linking type.

In spite of the weight of arguments in favour of this model, there remain problems that are based, not least, on the apparent North American affinities of the Lower and Middle Ordovician faunas of the Trondheim region (NEUMAN & BRUTON, 1984; BRUTON & BOCKELIE, 1980; BRUTON & HARPER, in press). This led to suggestions that the Trondheim sequence had developed close to the Laurentian margin and was separated from the Baltic Craton by an Iapetus Ocean of considerable width. Palaeontologists, however, are not unanimous in this interpretation of the Trondheim fauna, and indeed JAANUSSON (pers. comm. 1982) states that a considerable portion of this fauna can be identified in the East Baltic region and in other parts of the eastern margin. JAANUSSON thus feels it unneccessary to invoke separation by a wide Iapetus Ocean. This, however, remains a problem and will only be resolved when more data are available.

STEPHENS & GEE (1981, in press), strongly influenced by the North American affinity of the Trondheim fauna, proposed that the ophiolitic terrains had been initially obducted westwards onto the Laurentian Craton prior to the Upper Arenig. They concluded also that the 'early' Ordovician deformation and metamorphism, of the ophiolitic terrains, occurred at this site. Following BRUTON & BOCKERLIE (1980) it was suggested by STEPHENS & GEE (o.c.) that, with the possible exception of the Køli arc volcanics, the Ordovician arc volcanism occurred uniquely against the Laurentian margin. This led naturally to the thesis that such arc volcanics, together with the ophiolites, was only thrust over the Baltic Craton during the collisional Scandian Orogeny.

This view has to be seen in context of the proposition that the Baltic miogeocline/rise prism represents a feature of continuous development from Late Precambrian through Silurian times, and that its destruction related uniquely to the Scandian Orogeny. It has been demonstrated in the present paper that this view can no longer be accepted and that the miogeocline/rise prism represents a feature that only belonged to the pre-Finnmarkian continental margin, thus removing one of the basic tennets of this hypothesis. It should be pointed out that GEE (in GEE & SJØSTRØM, in press) now also recognizes Finnmarkian deformation and metamorphism of the rise prism, in the Central Caledonides, and that this was coeval with the obduction of ophiolitic terrains onto the Baltic Shield.

In the Appalachian segment of the belt it has been shown that

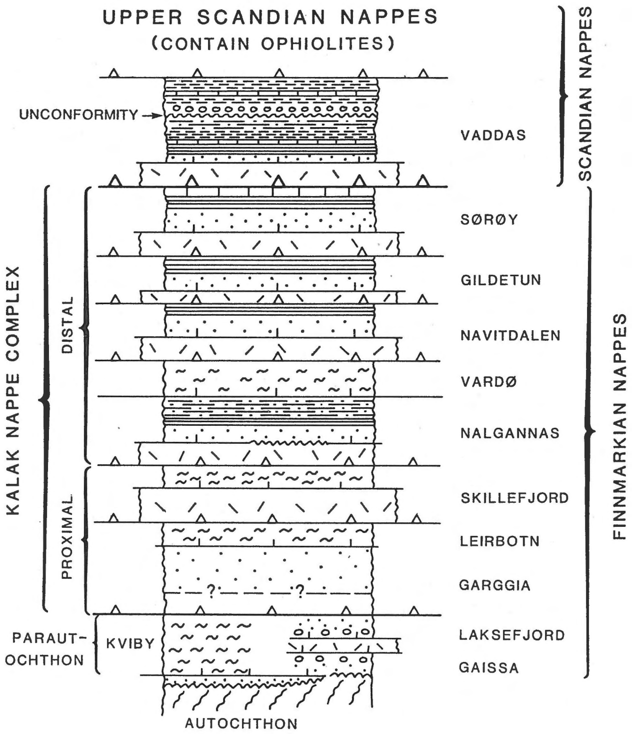

Fig. 3
Tectonostratigraphic sequence of the Finnmarkian nappes. Ornament: randomdashes – pre-Karelian basement; Curved dashes – Karelian rocks.
In Caledonian cover sequences: dots – Klubben Group; lines – Storelv Group; vertical lines – Falkens Group; dashes – Aafjord Group; dash-dots – Hellefjord Group. Plicated lines – unconformable contacts. Modified from Ramsay et al. (1984).

the primary accretion of ophiolitic terrains to the North American Craton occurred during the Taconic Orogeny, although the final assembly of the tectonostratigraphy is the result of the superimposed Acadian and Alleghenian orogenies. Similarly in the Scandinavian Caledonides, although the primary accretion of the ophiolite terrains took place during the Finnmarkian Orogeny, the final assembly of the tectono-stratigraphy occurred during the later Scandian and Solundian orogenies (Fig. 3).

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