Caledonian and Baikalian tectonic structures on Varanger Peninsula, Finnmark, Norway, and coastal areas of Kola Peninsula, NW Russia

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Roberts, D. 1996: Caledonian and Baikalian tectonic structures on Varanger Peninsula, Finnmark, Norway, and coastal areas of Kola Peninsula, NW Russia. *Nor. geol. unders. Bull. 431*, 59-65.

Based on data compiled from biostratigraphy, radiometric dating and palaeomagnetic studies, contractional deformation and low-grade metamorphism in the Neoproterozoic to earliest Palaeozoic successions of coastal areas of NE Norway and NW Russia have been constrained to two main stages. (1) Late Vendian to Early Cambrian *Baikalian* deformation, with mainly NW-SE trending folds, affected Upper Riphean sequences on Rybachi and Sredni in Russia. These structures can be followed into the eastern part of Varanger Peninsula. (2) Late Silurian to Early Devonian, *Scandian* deformation and metamorphism, with folds and thrusts of mainly NE-SW trend, are recorded principally in western parts of Varanger, in the Caledonian parautochthon and allochthon. Cross-folds and second cleavages in parts of NE Varanger may also be of Caledonian age.

Within the succession of the Tanafjorden-Varangerfjorden Region of SW Varanger Peninsula, palaeocurrent data indicate that in the post-glacial Mid Vendian to Early Cambrian period an uplifting land mass in the northeast was the major source area for detritus. This is in harmony with the notion of a rising Baikalian orogenic and topographic high during this same period, in and beyond the region now occupied by the Rybachi Peninsula. Combining all the evidence, the Varanger Peninsula thus appears to be in the somewhat unique situation of exposing vestiges of both Caledonian and Baikalian structures and low-grade metamorphic fabrics. Mutually interfering folds and cleavages occur in the eastern half of the Barents Sea Region, notheast of the Trollfjorden-Komagelva Fault Zone.

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Introduction

In recent years, research within the Norwegian-Russian collaboration programme 'North Area' in Northeast Finnmark, Norway, and the Kola Peninsula, NW Russia, has led to several important advances in our knowledge of the Neoproterozoic sedimentary successions occurring on the Varanger, Rybachi and Sredni Peninsulas and Kildin Island (Fig.1) along the coastal fringes of the Barents Sea (several papers in Roberts & Nordgulen 1995). Although investigations of lithostratigraphy and sedimentary facies have formed the backbone of the Neoproterozoic project, research studies have included topics such as structure, low-grade metamorphism, isotopic dating and palaeomagnetic investigations, some of which are still in progress.

An important factor in the tectonothermal history of most geological terranes is the timing of the principal phase of tectonic deformation. In the case of Varanger Peninsula, it has been assumed almost without question that we are dealing exclusively with Caledonian deformation, and by and large a structural architecture ascribed to the Late Silurian-Early Devonian *Scandian* event. Almost a century ago, however, Russian and Finnish geologists had considered that Varanger may well form a western extension of the so-called `Timanian mountain chain` stretching from the Timans (Fig.2), along the northern coast of the Kola Peninsula and immediately offshore (Ramsay 1899, Tschernyschev 1901). Schatsky (1935) later ascribed this Timanide deformation to the *Baikalian* orogeny.

Since that time, little attention has been directed

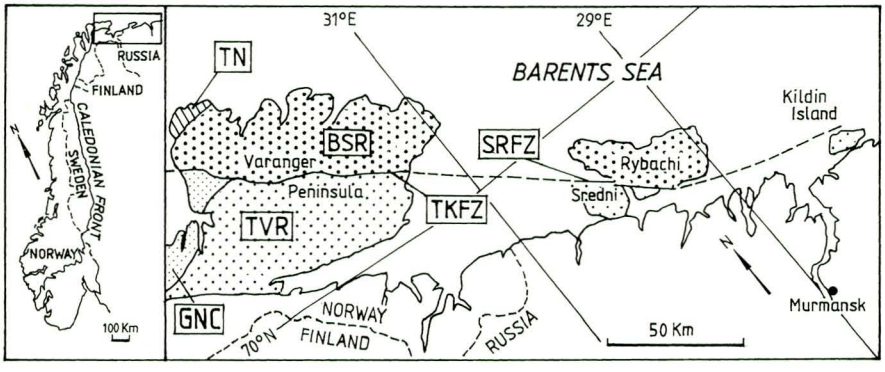

Fig.1. Location map showing the Varanger, Rybachi and Sredni Peninsulas and Kildin Island, NE Norway-NW Russia. The pericratonic (TVR,Sredni,Kildin) and basinal (BSR, Rybachi) domains are indicated by different dotted ornaments. TVR - Tanafjorden-Varangerfjorden Region; BSR - Barents Sea Region; TKFZ - Trollfjorden-Komagelva Fault Zone; SRFZ - Sredni-Rybachi Fault Zone; GNC - Gaissa Nappe Complex; TN - Tanahorn Nappe. The area without ornament is underlain by Archaean to Early Proterozoic crystalline rocks.

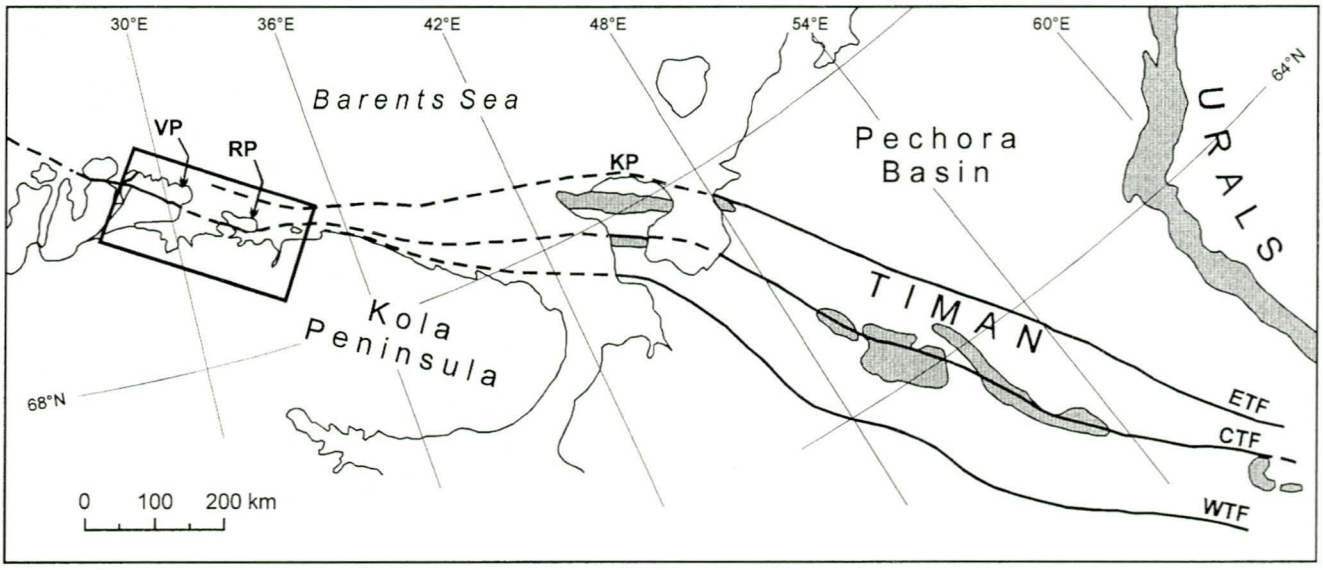

Fig. 2. Location map showing the Timans, Kola Peninsula and the northern Urals. The boxed area is that shown in more detail in Figs. 1 and 3. The shaded areas in Timan and the Urals indicate the areas of main outcrop of Neoproterozoic rocks. Principal faults in the Timans: WTF - West Timan Fault; CTF - Central Timan Fault; ETF - East Timan Fault. The NW-SE trending belt delimited by the WTF and CTF corresponds to the pericratonic domain of Varanger, Sredni and Kildin. Likewise, the basinal domain (equivalent to Rybachi and the BSR of Varanger) is that between the CTF and the ETF. VP - Varanger Peninsula; RP - Rybachi Peninsula; KP - Kanin Peninsula. The structural subdivision of Timan is modified from map versions presented by Getsen (1987), Olovyanishnikov (1995) and Siedlecka & Roberts (1995).

towards these early ideas, although they were mentioned by Siedlecka & Siedlecki (1967) and discussed by Siedlecka (1975) in her comprehensive review of Russian and other early literature of the Finnmark-Timan region. At that time the issue could not be resolved. Specific studies within part of the 'North Area' programme, however, have helped to refine our constraints on the time of the main tectonothermal event. Comparison with structural trends prevailing on Varanger Peninsula has thus allowed reasoned conclusions to be made concerning the likely regional distribution of Baikalian and Caledonian structures. The purpose of this short contribution is to present relevant data which suggest that Baikalian structures almost certainly occur in the eastern parts of Varanger Peninsula.

Geological framework

Details of the formal lithostratigraphies of the Neoproterozoic successions of the Varanger, Rybachi and Sredni Peninsulas and Kildin Island (Fig.1) can be found in Siedlecka & Roberts (1992) and Siedlecka et al. (1995a, b). On Varanger, the polyphase NW-SE-trending *Trollfjorden-Komagelva Fault Zone* (TKFZ) effectively divides the peninsula into two regions, and can be followed southeastwards on to the Rybachi and Sredni Peninsulas, where it has been termed the *Sredni-Rybachi Fault Zone* (SRFZ) (Roberts 1995) (Fig.1).

The southwestern Varanger Peninsula (the Tanafjorden-Varangerfjorden Region - TVR) exposes an Upper Riphean to Cambrian record up to 3.5 km thick, including the Early Vendian Varangerian glacial deposits. The Upper Riphean succession alone is some 2.3 km in thickness. This **pericratonic** realm (Siedlecka & Roberts 1995) also characterises the fluvial, deltaic and coastal marine successions on Sredni Peninsula and Kildin Island, southwest of the SRFZ, although in this case there are no glacial deposits present and the microfaunal evidence favours only Late Riphean deposition (Samuelsson 1995 and in press). In Northeast Varanger Peninsula (the Barents Sea Region - BSR) and on Rybachi, submarine turbidite systems c.3-4 km thick represent a distinctive **basinal** domain, termed the *Rybachi-Varanger Basin* by Drinkwater et al.(1996). Microfaunas here also denote a Late Riphean age. Thus, Vendian and younger deposits are apparently lacking on both the Sredni and the Rybachi Peninsulas.

Structure and metamorphism

Tectonic structures and metamorphic features of the successions on Varanger Peninsula have been described in a number of publications, to which the reader is referred for details (e.g. Roberts 1972, Bevins et al. 1986, Rice et al. 1989, Siedlecka & Roberts 1992, Karpuz et al. 1993). In the case of the Rybachi and Sredni Peninsulas, the most relevant contributions on these particular topics are those by Negrutsa (1971), Roberts (1995) and Rice & Roberts (1995).

The structural deformation and metamorphism of these various successions changes appreciably in crossing the major NW-SE fault zone (TKFZ and SRFZ). Successions in most of the pericratonic domain of SW Varanger (TVR), Sredni and Kildin in general display only lower diagenesis-grade compactional fabrics. Folds, where present at

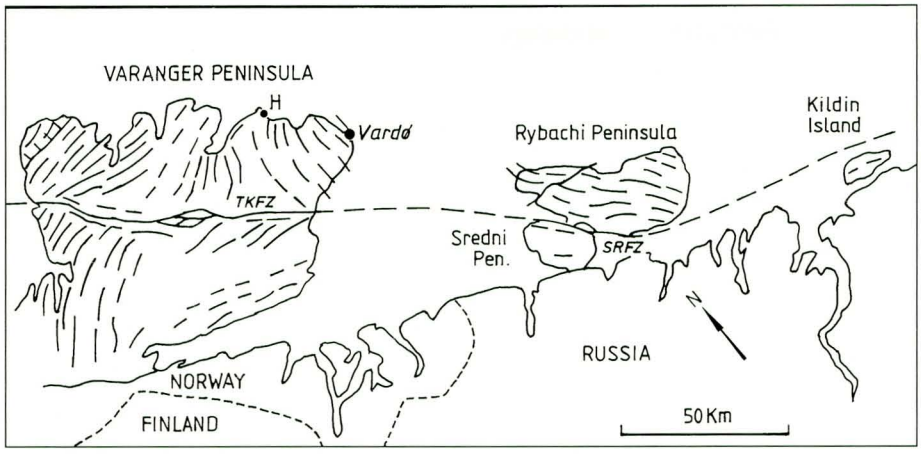

Fig. 3. Simplified map of the Varanger-Rybachi-Sredni-Kildin tract showing the principal structural trends, mostly the axial surface traces of folds but partly the strike of N- to NE-dipping strata in Kildin, Sredni and southernmost Varanger.

all, are gentle upright structures, trend broadly E-W to NW-SE and lack any pervasive axial surface cleavage; and their precise age is uncertain. Towards the west in the TVR on Varanger Peninsula, however, one is passing into the Caledonian parautochthon and ultimately into the Lower Allochthon (Gaissa Nappe Complex - Fig.1), where folds become quite common, trend c.NE-SW (Fig.3), face southeast, and carry a penetrative axial-planar cleavage.

In contrast, in the basinal domain on Rybachi, northeast of the SRFZ, the turbiditic rocks show abundant NW-SE trending and SW-facing, open to tight folds (Fig.3) and an associated, penetrative, tightly spaced or slaty cleavage. Illite crystallinity data (illite 002 peak) record a lower anchizone grade of metamorphism in the northeast, but only upper diagenesis grade moving closer to the SRFZ (Rice et al.1995). The age of this tectonothermal cycle on Rybachi has not yet been determined with any precision; however, several Russian workers have assumed that it equates with the Baikalian of Timan. More information is provided below.

Some 60 km to the northwest, in the easternmost part of the Barents Sea Region of Varanger Peninsula, much the same NW-SE (to N-S) fold-and-cleavage trend is encountered (Fig.3), although cross-folds cause local structural complexities (Roberts 1972, Herrevold 1993). This low-grade metamorphic phase has not yet been dated. Moving towards the northwest within the BSR, the fold-axial trend gradaually swings through N-S to NE-SW and ultimately ENE-WSW (Fig.3), with ubiquitous SE-facing tight folds, local thrusts and the Tanahorn Nappe (Fig.1) signifying their association with the Caledonian orogenic cycle.

Timing of deformation and metamorphism

In considering the currently known constraints on the age, or ages of the folding and very low-grade metamorphism outlined above, the map of principal structural trends (Fig.3) provides a useful backcloth; and one which holds more significance than might at first meet the eye. Since the situation on the Varanger Peninsula is evidently unclear, except, as mentioned, in the far west where Caledonian structures prevail, it is more appropriate to consider first the relevant data from the Russian areas. As well as structural (fold axial) trend, biostratigraphic and isotopic constraints are clearly important, but interesting information can also be gained from palaeocurrent data and from field and laboratory studies on mafic dykes.

Rybachi, Sredni and Kildin

Biostratigraphic evidence from these three areas shows that the successions are wholly Upper Riphean (Samuelsson 1995). Earlier, the stratigraphically highest unit on Sredni Peninsula, the Volokovaya Group (Siedlecka et al. 1995a), had been assigned a Vendian age by Russian workers, but this is now rejected on the basis of recent microfossil studies (Samuelsson 1995 and in press). This also accords better with the fact that there are no Varangerian tillites on Sredni.

The diagenetic compactional fabric present in the pelites on Sredni and Kildin has been dated using the Rb-Sr method on illite subfractions (Gorokhov et al.1995). Early authigenic illite subfractions from two separate formations from the Sredni Peninsula yielded an age of 610-620 Ma. Close to the SRFZ, on Sredni, a widely spaced NW-SE trending cleavage is quite well developed. From one particular formation in this subarea, within the fault zone, Gorokhov et al.(1995) separated a second, even finer, illite subfraction and obtained a Rb-Sr maximum age for this of 570 Ma. This was considered to relate to an influx of non-marine, subsurface water arising from an episode of fault movement along the SRFZ.

On Rybachi, the common NW-SE trending, open to tight, SW-facing folds are believed to represent a stage of basin inversion (Roberts 1995) – termed epikinegenesis (Raznitsyn 1972) in Russian literature – the folds and cleavage gradually dying out towards, and just across, the SRFZ. Accepting that the 570 Ma maximum age noted

above truly relates to fault motion, then this presumably reflects the inversion and widespread SW-directed compressional deformation represented by the structures on Rybachi. Alternatively, the 'maximum-570' age may indicate the end stage of the inversion, such that the peak metamorphic age, reflected in the pervasive cleavage on Rybachi, could be somewhere between 610 (Sredni diagenesis) and 570 Ma.

In contrast, the minimum age for the main deformation on Rybachi Peninsula is poorly constrained. In northwestern areas of the peninsula, a few dolerite dykes up to 6.5 m in thickness cut through the NW-SE-trending folds and cleavage at high angles; i.e., they trend c.NE-SW. An ^{40}Ar-^{39}Ar laser microprobe study gave no definitive emplacement age, suggesting only that the dykes are older than 450-400 model ages (Roberts & Onstott 1995), while palaeomagnetic data favoured a Late Vendian to Cambrian age (Torsvik et al. 1995). The folding and metamorphism of the Rybachi succession, which preceded the dyke intrusion, would therefore seem to fall within the time interval Late Vendian to Early Cambrian, with the Vendian period taken to extend from 650 to 545 Ma.

Turning briefly to the situation in Timan, which has similar pericratonic and basinal palaeoenvironmental zones as in the Rybachi-Sredni-Varanger region (Fig.2), radiometric dating there, mostly by the K-Ar method, has indicated that the Late Riphean succession was deformed and metamorphosed in two stages; (1) a main 'Baikalian' tectonothermal event dating to the period c.600-575 Ma (Malkov 1992, recalculated ages); (2) a less prominent stage of deformation in the period c.505-470 Ma. The age constraints so far available from Rybachi and Sredni thus support the long-standing notion that the principal Baikalian deformation also affected these particular coastal Kola, Neoproterozoic successions.

Varanger Peninsula

Barents Sea Region: Vardø district

As noted earlier, this easternmost part of the BSR is characterised by a principal cleavage and fold axial trend which is roughly NNW-SSE, though with local variations due to c.ENE-WSW cross-folding (Roberts 1972, Herrevold et al., in prep.). It was initially assumed by Roberts (1972) that all folding in this area developed during Late Silurian, Caledonian (Scandian) orogenesis. An explanation for the anomalous, c.NW-SE structural trend and facing reversal was sought in the likely buffering effect of a basement 'ridge' concealed beneath the sea area southeast of Varanger Peninsula. Rice et al.(1989) interpreted the same, WSW-facing structures as tip folds associated with a late-stage, backthrust sense of movement along an inferred sole thrust beneath the BSR, thus appealing to a late Scandian phase of deformation.

Mafic dykes are rare in this particular part of the BSR and have, as yet, offered meagre constraints on the minimum age for the cleavage and fold development. The c.NE-SW-trending dykes are comparatively unaltered and post-date the early, NNW-SSE-trending spaced cleavage. As yet, the only isotopic dating available on these dykes is that of K-Ar data which have provided ages of c.350 Ma (Beckinsale et al. 1975). Combining the biostratigraphic and published K-Ar data, we therefore have a meaningless time interval of at least 300 million years (latest Riphean to earliest Carboniferous) in which to place the tectonometamorphic transformation of the host rocks to these dykes.

Despite the lack of precise radiometric dating, significant clues as to the likely age of these NNW-SSE-trending, syn-cleavage folds can be sought in a consideration of the structural trend (Fig.3) and the character of the cleavage, aided by an examination of satellite images (Karpuz et al. 1993) and comparative field studies both on Rybachi and in this part of the BSR on Varanger Peninsula. To the present author, the structures and fabrics encountered in the Vardø district are very much reminiscent of those seen on the Rybachi Peninsula, the inference being that again we are conceivably dealing with structures of Baikalian age (Roberts 1993, 1995). If anything, the cleavage in the eastern BSR is slightly more domainal in character than that on Rybachi, but this is partly because of lithological differences and the fact that the Baikalian deformation and metamorphism was probably dying out laterally, northwestwards.

Cross-folds of ENE-WSW to NE-SW, or even E-W trend are common in this area, as reflected in the dome-and-basin map pattern (Roberts 1972, Siedlecki 1980, Rice et al. 1989, Aamodt et al. 1996). As such transverse structures are absent on Rybachi (Roberts 1995), it is reasonable to argue that the cross-folds in the eastern BSR are Caledonian folds which have developed as a result of open, SSE-directed macro-buckling of pre-existing Baikalian structures. As well as these mutually interfering folds of disparate age, two cleavages are also present locally (Roberts 1995), but no systematic work has yet been done to assess the regional extent of these cleavages. In such a scenario one would expect the NW-SE, assumed 'Baikalian' cleavage to die out gradually westwards; and the NE-SW 'Caledonian' cleavage to appear and intensify in the same direction.

There has been only one attempt to date a cleavage directly, that of Taylor & Pickering (1981). These authors produced an imprecise Rb-Sr whole-rock date of 520 ± 47 Ma from cleaved pelites in the Kongsfjord Formation near Hamningberg (Fig.3). Although no details were given, the cleavage near the sampling sites is known to strike c.NE-SW. The significance and interpretation of this date has been questioned by Rice et al. (1989) who argued that the first Caledonian deformation in this particular area was of Scandian age.

Eastern part of the Tanafjorden-Varangerfjorden Region

Tectonic deformation in this particular part of the TVR

was clearly less intense than in the BSR directly northeast of the TKFZ. That the TKFZ also represents a metamorphic break is seen in the fact that the rocks in this area have yielded illite crystallinity values indicative only of diagenesis grade (Bevins et al. 1986). There is also no trace of any regionally penetrative, steeply dipping cleavage in this southeastern part of the Tanafjorden-Varangerfjorden Region.

A maximum age both for the diagenetic compactional fabric and for the oldest folds is set by the fact that the youngest formation here, the Stappogiedde, is of assumed Late Vendian age. Work is in progress (Rb-Sr on illite subfractions) in an attempt to date the diagenesis. Here, it can be noted that from the southwestern TVG, Dallmeyer & Reuter (1989) have recorded what they describe as a «diagenetically related disturbance at c.635 Ma».

In general, the stratigraphic succession in the eastern TVR dips at a few degrees to the north with large-scale, gentle, upright folding on c.E-W axes appearing within 10 km of the TKFZ (Fig.3). The axial trend of these folds is thus oblique to the main fault zone. In their trend and en échelon pattern these folds are comparable to post-cleavage folds occurring close to the SRFZ on Sredni Peninsula (Roberts 1995), which are indicators of dextral strike-slip movement. Mesoscopic shear zones trending ENE-WSW and ESE-WNW, with a generally right-lateral shear sense, have also been recorded in the eastern TVR (Herrevold et al., in prep.). Closer to the TKFZ, small-scale NW-SE-trending, SW-facing folds and minor thrusts indicate a phase of SW-directed compression (Karpuz et al. 1993) or possibly transpression. Although the relationship of these SW-facing structures to the E-W folds is unknown, as is the actual age of the folds, it is reasonable to assume that the former are older and quite likely Baikalian.

The precise age of uncommon, c.N-S trending mafic dykes occurring in two places along the southeastern coast of the TVR remains unknown. K-Ar data have yielded a figure of c.350 Ma (Beckinsale et al. 1975) while ^{40}Ar-^{39}Ar pyroxene data are inconclusive (Roberts et al. 1995). One of these dykes has yielded palaeomagnetic data suggesting that its age may be Late Vendian to Early Cambrian (Torsvik et al. 1995). For the time being, at least, we therefore have no reliable upper constraint in this area for the timing of diagenesis or fold deformation.

The importance of hiatuses and angular unconformities in providing records of distant orogenic events is well known, and their potential significance in this Finnmark-Kola region has been noted by Schatsky (1960) and Siedlecka (1975). Accepting that the rocks on Rybachi Peninsula and in the Vardø district of the Barents Sea Region have been affected by a Late Vendian-Early Cambrian Baikalian tectonothermal event associated with basin inversion and uplift, then the northwestern 'tail end' of the Baikalian may conceivably be reflected in breaks in the lithostratigraphy of the TVR. In this regard, the sedimentological investigations of Banks et al.(1971) in the TVR are highly relevant. These authors, and also Edwards (1984), have pointed to an important change in sediment dispersal patterns which occurred shortly after the end of the Varangerian glacial epoch. During this period, i.e. broadly Mid Vendian to Early Cambrian, palaeocurrent data indicate that the major source area for Vestertana Group sedimentation lay somewhere to the present-day northeast. Banks et al.(1971) suggested that this uplifted northeasterly situated «land mass» was probably located somewhere to the northeast of the Trollfjorden-Komagelva Fault Zone, or a related parallel fault.

Although not mentioned in name, the land mass referred to by Banks et al. (1971) as supplying the major volume of detritus to the Vestertana Group was almost certainly the rising topographic high which resulted from the Baikalian basinal inversion, tectonic deformation and metamorphism of the Upper Riphean succession, parts of which are now exposed on the Rybachi Peninsula. Vendian deposits are absent on Rybachi and Sredni, and on Kildin Island, and it is more likely than not that they were never deposited in these particular 'eastern' areas during this period of inversion and diastrophism.

Western Varanger Peninsula; BSR and TVR

The structural deformation and metamorphism of the northwestern halves of both the Barents Sea Region and the Tanafjorden-Varangerfjorden Region have been documented in many papers (full bibliography in Siedlecka & Roberts 1992). In this present contribution, it will suffice to note that the widespread folding and thrusting — SE-facing in the western TVR and SSE-facing in the western BSR — and related metamorphism were acquired as a result of Caledonian orogenesis. In the parautochthon of the western TVR, the youngest formation affected by this deformation is of Early Cambrian age, whereas on the nearby Digermul Peninsula (just west of southwestern Varanger Peninsula) the deformed succession, part of the Gaissa Nappe Complex, extends up into the Tremadoc.

Constraints on the precise timing of this pervasive fold-and-thrust event, however, remain poor. Radiometric data from the Gaissa Nappe Complex are not definitive, an age of c.440 Ma (K-Ar) having been suggested by Dallmeyer et al. (1989) as a maximum for slaty cleavage development. Earlier, a Rb-Sr whole-rock isochron age of c.504 Ma had been obtained on cleaved pelites from the western TVR (Sturt et al.1975), but the reliability of this date has been contested (Dallmeyer & Reuter 1989). Bylund (1994) has reported palaeomagnetic data from two sites in the westernmost TVR, also in the Gaissa Nappe, which provide evidence of an Early Ordovician remagnetisation event in those rocks. Clearly, we are in dire need of reliable, precise dating from these areas. For the present, the general consensus is that the principal tectonometamorphic event is Scandian, in the time interval Late Silurian to Early Devonian.

Conclusions

Based partly on constraints provided by biostratigraphic, radiometric and palaeomagnetic investigations, the timing of deformation and very low-grade metamorphism of the Neoproterozoic to earliest Palaeozoic successions on the Varanger, Rybachi and Sredni Peninsulas can be deduced. A significant element which also has a bearing on the topic is that of fold axial trend and the character of the associated, pervasive, axial planar cleavage. Palaeocurrent data are also shown to provide crucial information bearing on the question of timing of orogenesis.

A principal conclusion is that the Varanger Peninsula is in the somewhat unique situation of exposing the vestiges of both Caledonian and Baikalian tectonic structures and low-grade metamorphic fabrics. In the Rybachi-Sredni-Kildin area in Russia, the tectonothermal event marking the basinal inversion or epikinegenic stage appears to fall in the period Late Vendian to Early Cambrian, corresponding to the Baikalian orogeny of earlier Russian workers. The prominent, Baikalian, NW-SE fold-and-cleavage trend seen on Rybachi Peninsula can be traced without difficulty into the Vardø district of the eastern Barents Sea Region of Varanger Peninsula, where it is affected by common cross-folds of Caledonian, probably Scandian trend. Two cleavages occur locally. Further northwest in the Barents Sea Region, Caledonian structures and metamorphic fabrics gradually become predominant.

The situation regarding timing of deformation in the TVR of Varanger Peninsula is less clear, except of course in the Caledonian parautochthon and Lower Allochthon in the west where Scandian deformation and metamorphism is dominant. In the eastern TVR, where the stratigraphy extends up into the Late Vendian, a reliable upper (minimum) constraint for the deformation is so far lacking, but unconformities may instead be providing reflections of distant Baikalian movements. Sedimentological work in this part of southern Varanger Peninsula has shown that in the post-glacial Mid Vendian to Early Cambrian period the major source for the detritus accumulating in the Vestertana Group was a land mass situated somewhere to the northeast. This is in good accordance with the concept of a rising Baikalian orogenic welt and topographic high in and beyond the region of present-day Rybachi Peninsula.

Acknowledgements

The author is grateful to Roy Gabrielsen, Stephen Lippard and Brian Sturt for their helpful reviews of the manuscript; to Anna Siedlecka for comments at a later stage; and to Valery Moralev and Vsevolod Olovyanishnikov for discussions on aspects of the geology of Timan.

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Manuscript received April-May 1996; final manuscript ready July 1996.