Polarforschung 68: 267 - 274, 1998 (erschienen 2000)

Tectonics and Sedimentation of the Meso- to Neoproterozoic Timan-Varanger Belt along the Northeastern Margin of Baltica

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THEME 8: Polar Urals, Novaya Zemlya and Taimyr: The Northern Connection of the Uralides

Summary: Extending from the Timans in the southeast to the Varanger Peninsula in the northwest, the Timan-Varanger Belt (TVB) comprises predominantly terrigenous Neoproterozoic successions, deformed and metamorphosed at comparatively low grade during the Timanian (Baikalian) orogeny, an event broadly equivalent to the Cadomian of western Europe. In Neoproterozoic time the TVB formed the faulted, extensional southwestern margin of an oceanic basin, the central parts of which are buried beneath the Palaeozoic and younger cover of the Pechora Basin. The major structural element of the basin margin is a NW-SE-trending fault zone that separated two domains of sedimentation; pericratonic to the southwest and basinal to the northeast, which show contrasts in both thickness and sedimentary facies. In the Timan-Kanin-Pechora part of the basin, sedimentation began already in the Middle Riphean, and by Late Riphean time a prominent stromatolitic carbonate ramp formation had built up along the shelf margin. In the NW Kola-Varanger region, however, sedimentation did not start until the (?)Middle-Late Riphean. Thus, with time, the basin extended northwestwards and sedimentation, including deposition of Varangerian tillites in the northwest, continued into the Vendian period. The fault zone which formed the extensional margin of the basin was reactivated during the Timanian orogeny and again in later periods. The Timanian deformation in these exposed marginal areas involved basinal inversion, folding and cleavage development, arising from SW-directed compressive stresses, the main phase of these movements dating to about 600-575 Ma. A variety of felsic to mafic plutons and dykes intruded the folded rocks of the TVB.

Both seismic reflection and deep drillhole data have shown that Meso- to Neoproterozoic strata in the pre-Palaeozoic basement of the Pechora Basin are more intensively deformed and metamorphosed and also include oceanic and arc volcanic sequences and diverse plutonic rocks. Fragments of older basement terranes are also present. Timanian deformation beneath the Pechora Basin was thus much more intense and involved the telescoping of arcs, are roots and microcontinental terranes in a more complex accretionary zone, generally referred to as the Pechorskaya collision zone.

INTRODUCTION

The Timanian mountain chain, an important regional element in Circum-Barentsian geological structure, was first recognised almost precisely 100 years ago (RAMSAY 1899, TSCHERNYSCHEV 1901). SCHATSKY (1935, 1958) further developed this early idea and suggested that the chain represented part of a Late Precambrian Baikalian fold belt which he called the 'Timanides'. Subsequent research by several Russian scientists, in particular ZHURAVLEV and co-workers (e.g. ZHURAVLEV & GAFAROV 1959, ZHURAVLEV & OSADCHUK 1960, 1962, ZHURAVLEV 1972) and RAZNITSYN (e.g., 1962, 1968), brought a wealth of data and ideas on several aspects of the geology of the Timans and also on the relationship between this Neoproterozoic fold belt and the pre-Palaeozoic substratum of the Pechora Basin. In addition, several decades of research by GETSEN (summarised in OLOVYANISHNIKOV 1975, 1987, 1998) have resulted in further and considerable progress in our knowledge of the geology of the Timanides.

The northwestern extension of the Timanian mountain chain was postulated by RAMSAY (1899) and TSCHERNYSCHEV (1901) to occur along the northeastern Murmansk Coast of the Kola Peninsula, on Rybachi, Sredni and Kildin, and to continue far into northern Norway. Potential field and seismic reflection data in offshore areas has confirmed the presence of these folded rocks immediately northeast of Kola (e.g., BOGATSKY et al. 1996). Recently, a modified version of this idea, which had been accepted for decades in several large-scale geological interpretations, received new support from some of the results of a joint Norwegian-Russian research programme carried out during the years 1989-95 on the coastal Neoproterozoic occurrences of the Kola Peninsula and on Varanger Peninsula in Norway (see in ROBERTS & NORDGULEN 1995). The latter area, now inferred to expose the northwesternmost segment of the proposed chain, had already been thoroughly mapped and studied by geologists of the Geological Survey of Norway and other western workers since the mid-1960s. Finally, all three authors of this paper together visited the Central Timans in 1995 (OLOVYANISHNIKOV et al. 1997).

The objective of this contribution is to outline the recent progress and understanding of this about 1800 km-long Neoproterozoic structural element occurring along the northeastern perimeter of the Baltic Shield and Russian Platform. In the text which follows we refer to Schatsky's 'Timanides' as the Timan-Varanger Belt (TVB) in which the Timans themselves constitute the geographically most extensive, southeastern part.

Note: Neoproterozoic = Late (Upper) Proterozoic = 1000 (900) Ma - 545 Ma = Late (Upper) Riphean and Vendian. Mesoproterozoic = 1600-1000 Ma = Lower (Early) and Middle Riphean.

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Manusript received 14 December 1998, accepted 12 October 1999.

STRATIGRAPHY AND SEDIMENTATION

Sediments and sedimentation realms: general features

The Meso- to Neoproterozoic strata of the Timan-Varanger Belt accumulated in response to extensional faulting along the northeastern perimeter of the Fennoscandian Shield. The predominantly terrigenous sedimentary successions also include an extensive belt of carbonate rocks in the Timan-Kanin zone. The rocks are for the most part metamorphosed at only very low grade. On the Kanin Peninsula and in northern Timans, however, metamorphic grade reaches up to amphibolite facies, particularly in the cores of anticlines. Two parallel, NW-SE-trending, elongate, sedimentation domains are present adjacent to the major zone of faulting which played a crucial role in the development and character of sedimentation on either side of this structural element (Fig. 1). The fault zone exposed on the Varanger and Rybachi-Sredni Peninsulas, the Trollfjorden-Komagelva Fault Zone (TKFZ) and Sredni-Rybachi Fault Zone (SRFZ), respectively, can be followed to the southeast along and just off the coast of the Kola Peninsula, partly with the help of geophysical data. It then extends across the Kanin Peninsula and into the Timans where it is known as the Central Timan Fault (CTF). It is fairly well documented that the CTF formed the southwestern margin of a Neoproterozoic (Riphean) basin buried beneath unconformably overlying Cambro-Ordovician rocks of the adjacent Pechora Basin where there are also several other parallel faults. The prolongations of these other faults beneath the Barents Sea are generally poorly known. The CTF-SRFZ-TKFZ, on the other hand, not only continues throughout the Timan-Varanger Belt but also clearly separates the two, above-mentioned, distinct domains of sedimentation: *pericratonic* to the southwest and *basinal* to the northeast, the lithostratigraphical successions of which show contrasts in both thickness and sedimentary facies towards the northwest.

A form of zonation in the Timans, involving lithology, contrasting thicknesses and degree of metamorphism, but not sedimentation domains, had, in fact, already been suggested some 40 years ago (Zhuravlev & Osadchuk 1960).

The lithological development of both the pericratonic and the basinal successions of Varanger, Rybachi, Sredni, Kildin, Kanin, and northern and central Timans varies considerably along strike, a feature which is not unexpected in view of the great distances involved, the likely differential stresses operative along the basin-margin faults, and a varying topography in the adjacent source areas. These variables, along with the fact that the ages of the successions are generally only roughly determined by microfossils and indirectly by isotopic ages of transecting pre-Palaeozoic intrusions, make detailed correlation particularly speculative. Although lithostratigraphic correlations have been proposed by many geologists, it seems obvious that lithologically similar units may well be diachronous, particularly as such great distances are involved along the belt. In the Timans, a discontinuous belt of carbonate and carbonate-terrigenous lithologies occurs between the pericratonic terrigenous successions to the southwest and the basinal to the northeast. On Kildin Island, Varanger Peninsula and farther to the west, within the Caledonides, equivalent Upper Riphean carbonate units are also pressent.

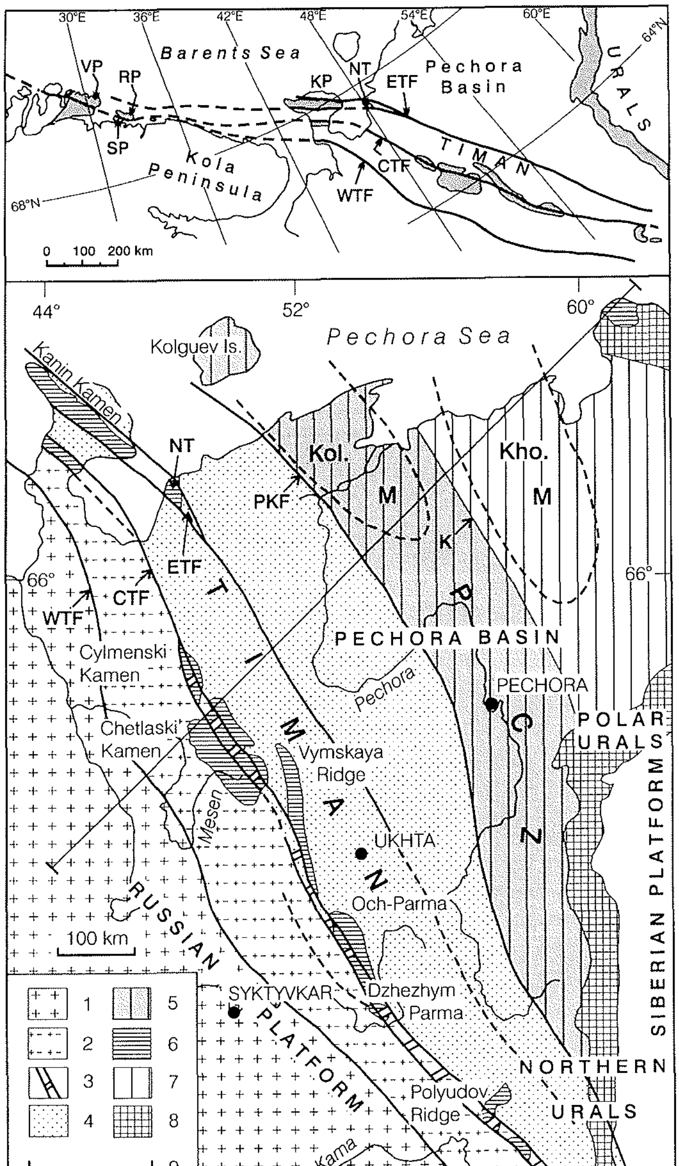

Fig. 1. Top: Outline map showing the Timan-Varanger Belt. KP – Kanin Peninsula; NT - Northern Timan; RP - Rybachi Peninsula; SP - Sredni Peninsula; VP - Varanger Peninsula; CTF - Central Timan Fault; ETF – East Timan Fault; WTF – West Timan Fault. The CTF is shown to continue to the Rybachi-Sredni and Varanger Peninsulas where it is called Sredni-Rybachi Fault Zone and Trollfjorden-Komagelva Fault Zone, respectively. Shaded areas show the outcrop of the Neoproterozoic rocks.
Bottom: Simplified geological-structural map of the Timan Range and basement of the Pechora Basin. 1: Basement; 2: Pericratonic zone; 3: Carbonate shelf margin; 4: Slope-to-basin zone; 5: Pechora collision zone 6: Outcrop of the Meso- to Neoproterozoic rocks; 7: Zone of Timanian accretion, 8: Urals; 9: Line of the section, shown in Figure 4. WTF: West Timan Fault (also called the Pre-Timan Fault); CTF: Central Timan Fault; ETF: East Timan Fault; NT: Northern Timan; PK: Pechora-Kozhva Fault; Kol. M.: L. Precambrian Kolguev massif or terrane; Kho.M.: L. Precambrian Khoreyver massif or terrane. Modified from Olovyanishnikov et al. (1997).

The time span during which the discussed sedimentary rocks accumulated embraces more than 500 million years. Resolving the history of the TVB in more detail would require stratigraphic techniques which are either not available (direct isotopic dating) or very general (biostratigraphy), a fact which poses fundamental problems in work on Precambrian (meta)sedimentary rocks in general.

Biostratigraphic evidence

Microfossils and columnar stromatolites provide the biostratigraphic evidence of the age of these diverse Neoproterozoic successions. In a recent paper, OLOVYANISHNIKOV (1998, pp.103-108) presented an extensive review of all microfossils found in the Neoproterozoic strata of the Timans and Kanin. Taxa of acritarchs referred to in this synopsis were identified by several scientists but only a few had been reported earlier (e.g. GETSEN & PIHOVA 1977). While the assemblages are suggestive mostly of a Late Riphean to Terminal Riphean (Kudash) age, some forms, according to the author, do not preclude a partly Vendian age for the youngest sedimentary rocks both in central and in northern Timans. However, in the revised list of microfossils (38 forms), two of these forms are Cambrian contaminations and the remainder comprise partly Riphean acritarchs and partly forms of long stratigraphic range not suitable for stratigraphic work (Doc. M. Moczydlowska-Vidal, written communication 1998). Therefore, the postulated Vendian age of some of the strata in central Timan is uncertain.

Microfossils extracted from the Neoproterozoic sections of the coastal areas of Kola Peninsula (the Murmansk Coast in the northeast and the Tiersky Coast on the White Sea) were studied in detail by Mikhailova (LYUBTSOV et al. 1989). She described a collection of 151 specimens comprising 43 forms of acritarchs, ten of which were determined at generic level. Only eight of these forms are known to cross the Riphean-Vendian boundary; however, they are not diagnostic of the Vendian. Michailova (LYUBTSOV et al. 1989) concluded that the upper formations of the basinal zone of Rybachi may possibly be Riphean-Vendian due to the fact that the assemblage there is very impoverished compared to the rich Riphean assemblages found elsewhere. This fact, however, in our view, is only what can be expected in a rapidly deposited, mostly coarse-grained succession accumulated predominantly on a submarine fan (SIEDLECKA et al. 1995). SAMUELSSON (1995, 1997) examined a new collection of arcritarchs from Sredni and concluded that these pericratonic strata are of Late to Latest (Karatavian) Riphean age. In fact, only on the Varanger Peninsula have Vendian strata been positively identified in the pericratonic zone; and, in addition, in that particular area there also occur the well known Varangerian tillites of earliest Vendian age. These are absent in the remainder of the Timan-Varanger Belt.

Columnar stromatolites, occurring in the carbonate formations of the Timans, the Kanin Peninsula, the coastal areas of the Kola Peninsula and the pericratonic carbonates of northern Norway, all indicate a Late Riphean age for these carbonate accumulations (BERTRAND-SARFATI & SIEDLECKA 1980, RAABEN 1975, 1994: 48, RAABEN et al. 1995). On Varanger Peninsula they are unconformably overlain by the Early Vendian glacial deposits.

Isotopic ages

There is a considerable number of published isotopic ages on the intrusive and hypabyssal rocks of the central and northern Timans and the Kanin Peninsula, as well as some ages on dolerite dykes that transect the Upper Proterozoic deposits along the northwesternmost periphery of the Timan-Varanger Belt. AKIMOVA (1980) published a synopsis of 141 K-Ar (whole-rock) ages of magmatic rocks and 32 ages of metasedimentary rocks (whole-rock and minerals) produced by several Russian authors since the mid-1960s. Although the reliability of much of these data is in doubt, the majority of the ages indicate Late Riphean to Vendian minimum ages and thus they do not contribute to any refinement of the Neoproterozoic stratigraphy. They do, however, provide some information concerning the timing of metamorphic and deformation events. Recent work by ANDREICHEV (1998) on Rb-Sr isotopic ages of intrusions from northern Timan shows that the majority of dates fall between 500 and 800 Ma, confirming the Neoproterozoic minimum age of the dissected strata. Of interest, however, is the 1100±39 Ma isochron age of a diabase transecting the Proterozoic strata, indicating the possibility that also Middle Riphean metasedimentary rocks may occur in this area. In this connection it is worth mentioning that AKIMOVA (1980) also reported 23 whole-rock and mineral age determinations of c. 1000-1500 Ma (even >2000 Ma in three cases), mainly of metadiabases and diabases cutting the carbonate rocks of central Timan (AKIMOVA 1980, Table 2, nos. 40-62 and p. 83). Another group of dates for diabases transecting the carbonate rocks (from borehole cores) lies in the range 600-700 Ma, which is in accord with the Late Riphean age of the carbonate succession indicated by columnar stromatolites (see above). Assuming that the sampling and dating procedures are reliable, these various data would suggest the presence of two separate carbonate successions, one of Early or Middle and the other of Late Riphean age. Recently, OLOVYANISHNIKOV (1998: 116-117), in his summary interpretation of the Meso- to Neoproterozoic stratigraphy of the Timans and Kanin Peninsula, has suggested that the carbonate rocks both in central Timan and farther north are stratigraphically subjacent to the remainder of the Upper Precambrian successions. This suggestion is based on the higher metamorphic grade of the carbonate unit in central Timan compared to that of adjacent terrigenous units. Although this does not seem to constitute sufficient evidence it is, however, in accordance with the group of high radiometric ages reported by AKIMOVA (1980). There would thus appear to be a serious new implication, namely, that there are two carbonate successions in the Timans of considerably different age.

This review of the data shows that the isotopic ages, which are relevant to the timing of deformation that will be discussed later in this contribution, do not provide any important evidence useful for refining the chronostratigraphy. The >1000 Ma ages of mafic intrusive rocks, however, do confirm that sedimentation in the Timan-Varanger Basin commenced in Late Mesoproterozoic time.

TECTONICS AND SEDIMENTATION: A TENTATIVE MODEL

Although we are fully aware that the stratigraphic record in parts of the belt is fragmentary and uncertain, we nevertheless believe that the data that are available are sufficient to warrant the presentation of a model integrating tectonics and sedimentation in the Timan-Varanger Belt, taking into account the following criteria:

1. The possible existence of strata older than Upper Riphean in the central and northern Timans and on Kanin (see above and also e.g. Getsen 1987, his Fig. 2);
2. The thicknesses and sedimentary facies of the pericratonic and basinal successions;

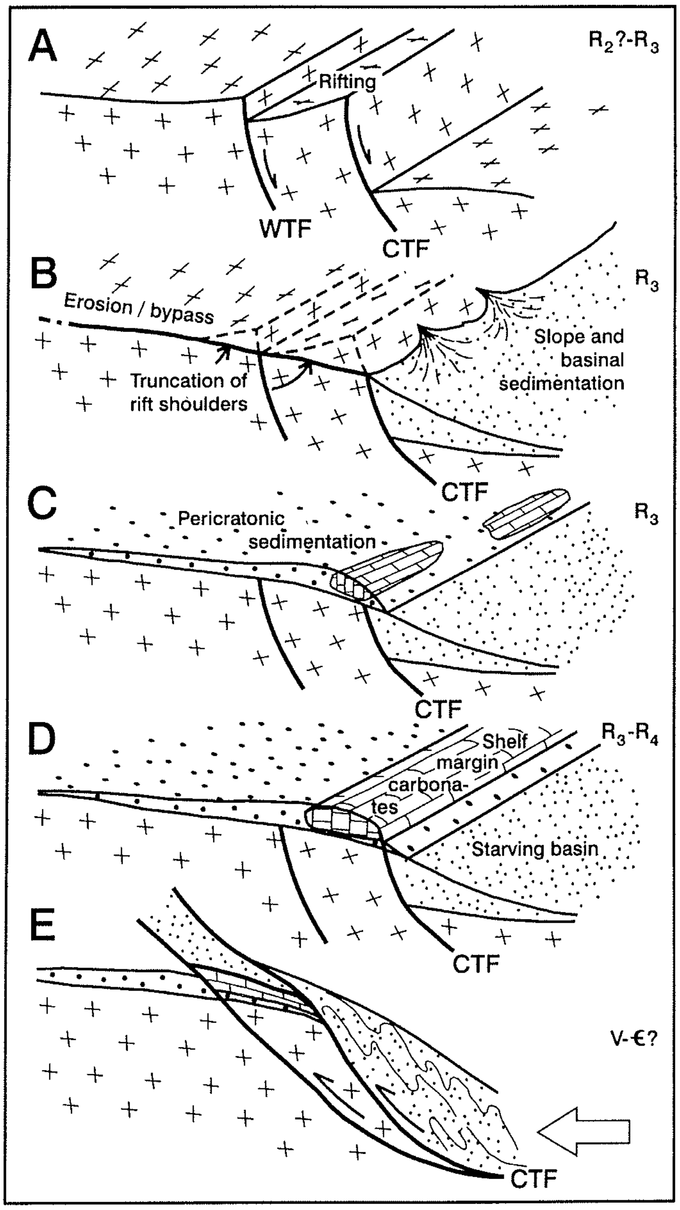

Fig. 2: Tentative model for the development of the Timan-Varanger Basin. A: initial rifting; B: Erosion of the footwall shoulders and accumulation of slope-to-basin deposits; C: shallow-marine pericratonic terrigenous sedimentation and stromatolitic reefs; D: accumulation of shelf-margin ramp carbonates; E: Deformation due to SW-directed compressive stress (open arrow) and inversion of basin-marginal faults. CTF - Central Timan Fault; WTF - West Timan Fault.

3. The geophysical data which help to link the separate areas of outcrop;
4. The well exposed and documented Neoproterozoic geology of the Murmansk Coast and the Varanger Peninsula, which serve in many respects as a 'key' to our understanding of the remainder of this extensive belt.

In response to the initial rifting and downfaulting (Fig. 2A), sedimentation probably began already in the Middle Riphean (?or earlier) in the Timans and Kanin Peninsula while in the northwest, along northeastern Kola and on Varanger, it did not start until the Late Riphean. This suggests that the basin was extending northwestwards with time. While the TVB represents the southwestern marginal area of the opening and deepening basin, its more central areas now form the basement to the Pechora Basin, which is a complex mosaic of oceanic crust, island arc material and microcontinental fragments cut by Riphean and Vendian (Timanian) plutons (Belyakova & Stepanenko 1991, Getsen 1991, Bogatsky et al. 1996, Gee et al. 2000). This scenario is largely in agreement with a previously postulated 'Timan-Ural Geosyncline Model', i.e., an extensive eugeoclinal basin of which the Timan-Kanin zone constituted only the southwestern marginal part, closest to the craton beneath the Russian Platform (e.g. Zhuravlev & Gafarov 1959, Zhuravlev 1972, Getsen 1987). Consequently, an alternative, previously suggested fixist 'Aulacogen Model', involving a major graben, separated from the Polar Urals by a cratonic block (Bogdanov 1961, Schatsky 1964, Siedlecka 1975, Ivanov 1981), has now been abandoned.

Within the TVB, i.e. the marginal part of the basin, truncation of the rift shoulders and erosion on the footwall side occurred in response to the fault-generated relief, and the bypassing sediments were eventually accumulated in the slope-to-basin area (Fig. 2B). Basinal accumulations in the Timans and on Kanin are fine-grained, partly fine turbidites, a fact which indicates that the slope was gentle, and that subsidence and sedimentation were close to equilibrium (Siedlecka & Roberts 1995). In the northwestern extremity of the basin, on the other hand, there are both olistostromes and coarse turbidites in the basinal zone, reflecting the existence of a steep slope with fast subsidence and rapid to locally violent sedimentation (Siedlecka et al. 1995). As the relief gradually decreased the basinal sedimentation became slower and the basin filled out, while the pericratonic sedimentation started lapping off, with sediments eventually accumulating upon the proximal part of the basinal infill (Fig. 2C).

The final phase of sedimentation in the proposed model was characterised by slow sedimentation in the pericratonic areas only, mainly reworking and gradually increasing the maturity of the shallow-marine clastics with little new sediment delivery. This situation created favourable conditions for the development of stromatolites and carbonate precipitation in the marine waters no longer heavily charged by suspended terrigenous fines. A rimmed terrigenous-carbonate ramp was thus created (Fig. 2D). The proposed succession of events provides an evolutionary framework to be tested, refined and modified by further studies; it is thus a tentative model, and is not in any way definitive. Contacts between the facies zones (pericratonic, carbonate, basinal) in the Timans and on Kanin are everywhere faulted and it is only in the northwestern peripheral parts of the basin that the pericratonic Upper Riphean sedimentary rocks actually rest upon the basinal deposits (erosional contact) and where the stromatolitic dolomites occur in the uppermost part of the fairly mature, pericratonic, terrigenous sedimentary succession. We have, in this model, purposely excluded the possible existence of an older carbonate unit (see above) since more documentation is required in support of this hypothesis. In addition, there are unconformities, within the pericratonic successions in particular, showing that there were varying rates of sedimentation and subsidence. As a consequence, the detailed infill history of the basin was much more complex than that outlined here.

A discussion of the abundant geophysical data that are available from the Timan-Kanin-Pechora region is outside the scope of this paper. Prominent positive, linear, magnetic anomalies of NW-SE trend parallel the regional strike in what is essentially a 'magnetic minimum' domain. This anomaly trend is offset here and there by concealed NE-SW-trending faults which are believed to have controlled the intrusion and ultimate distribution of gabbroic, picritic and syenitic magmas. Kimberlitic rocks, eruptive breccias and nepheline syenites have been reported from the areas of intersection of some of these NW-SE and NE-SW faults.

ASPECTS OF DEFORMATION AND METAMORPHISM

Deformation of the discussed Riphean strata along the TVB is illustrated by the three summary sections in Fig. 3. All three sections show that the structure is fairly simple, resulting from *Timanian/Baikalian* basin inversion with the principal compressive stress directed from northeast to southwest (present-day direction). The intensity of deformation and metamorphism has varied, however, in different parts of the belt. In the central Timans, SW-facing mesoscopic and larger-scale folds carry a steep, NE-dipping, penetrative axial-planar cleavage of anchizone grade. In northern Timan and Kanin there is a comparable NW-SE fold axial trend but metamorphic grade is higher, locally extending into amphibolite facies (GETSEN 1987: 67, compilation map). On Rybachi, the turbiditic succession is pervasively cleaved and folded along a consistent NW-SE trend;

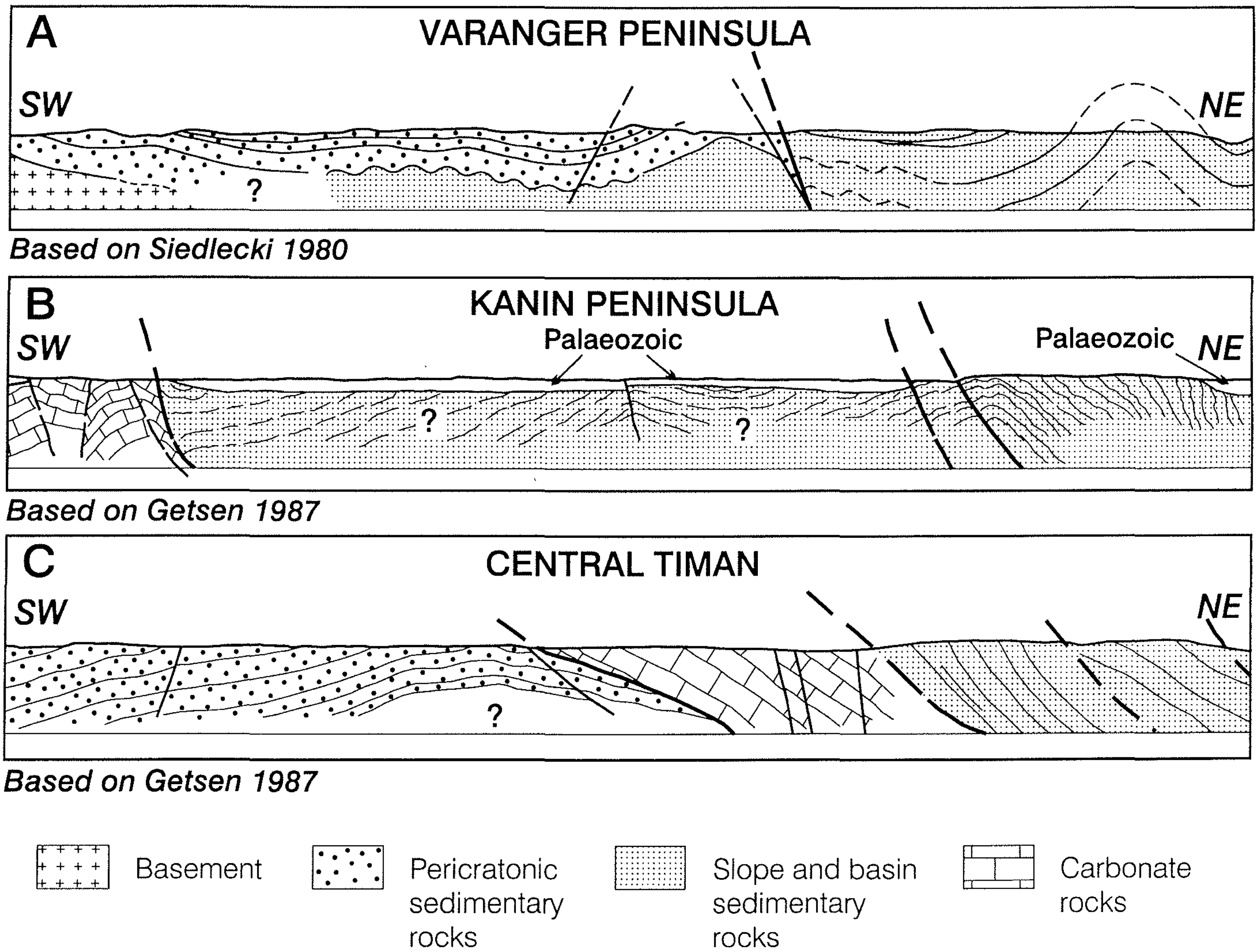

Fig. 3: Summary cross sections showing the main features of the structure in the Timan-Varanger Belt (not to scale).

and the rocks are mostly in anchizone grade (RICE & ROBERTS 1995). On Sredni and Kildin, diagenesis grade prevails. In eastern Varanger Peninsula, the NW-SE fold and cleavage trend is again recognised northeast of the TKFZ, dying out to the west (ROBERTS 1995, 1996) where c. NE-SW-trending Caledonian structures take over.

The section across the western parts of the Varanger Peninsula (Fig. 3A) shows that the basinal succession which crops out mainly northeast of the TKFZ is also present to the southwest, a feature which is easy to explain by onlap during infilling of the basin. In addition, it has been shown that the pericratonic strata there overlie the basinal Riphean sediments over part of the area, as documented by RICE (1994), while the bulk of the pericratonic succession, towards the southwest, rests directly on the Lower Precambrian crystalline basement. The carbonate deposits which terminate the pericratonic succession are not shown in this particular section. On the Kanin Peninsula, basinal deposits are separated from the Late Riphean stromatolitic dolomites occurring in the southwest by a vast area underlain by Palaeozoic strata which probably rest directly on basinal accumulations (Fig. 3B). There are, however, no exposures to verify this interpretation, which is based solely on geophysical data. Finally, the representative section from central Timan shows that the basinal succession, the carbonate formation and the pericratonic strata are in contact along major faults (Fig. 3C).

Although we present a comparatively simple model for the origin of the rifted, extensional, southwestern passive margin of the Riphean basin and its subsequent syn-metamorphic, cleavage-related deformation (see also Fig. 2E), isotopic ages indicate that deformation is likely to have occurred in more than one Late Riphean-Vendian episode. The principal tectonothermal event, however, coeval with basinal inversion, is ascribed to what SCHATSKY (1958) defined as *Baikalian* orogenic movements, which he considered to be equivalent to the Cadomian episode of crustal deformation in other parts of Europe.

GETSEN (1987: 60), on the basis of K-Ar mineral ages (amphibole, biotite, muscovite and K-feldspar), suggested that there were three episodes of metamorphism and magmatic activity in the northern Timan and Kanin Peninsula: at 680 ±20 Ma, 600 ±5 Ma and 530 ±5 Ma. For Central Timan, this same author (GETSEN 1987: 55) reported three groups of ages (isochrons derived from sericite, phlogopite and K-feldspar): at 970 ±20 Ma, 725 ±25 Ma and 590 ±20 Ma. AKIMOVA (1980: 83-84) also considered that there were several magmatic and metamorphic events but believed that the *main* episode of metamorphism and deformation occurred within the interval 570-680 Ma. Another estimate, based on recalculated ages, was provided by MALKOV (1992) who considered that the main tectonometamorphic phase of the Timanides falls in the time range 600-575 Ma; and a second metamorphic stage is put at c. 505-470 Ma. The ages of c. 1000-1500 Ma, earlier reported by SIEDLECKA (1975: 329) and by AKIMOVA (1980), are also of interest in the light of the recent Rb-Sr work by ANDREICHEV (1988) confirming the earlier conclusions on polyphase deformation. This involved emplacement of diabases and gabbrodiabases at 1100 ±39 Ma, an olivine-kersantite gabbro at 702 ±45 Ma and syenites and granites at c. 600 Ma. Finally, GEE et al. (2000) report single-zircon Pb-evaporation ages in the range c. 550-570 Ma from post-tectonic granites and diorites taken from deep drillcores in the Timanian 'collision zone' beneath the Pechora Basin. These Late Vendian ages confirm the model of a Timanian basement to the Pechora Basin.

Evidence from isotopic dating from the Rybachi-Sredni-Varanger region bearing on the age of the basinal inversion and associated penetrative cleavage is comparatively meagre at present, although work is in progress on dating the pervasive cleavage on Rybachi. A ^{40}Ar-^{39}Ar laser microprobe study on dolerite dykes transecting the folds and cleavage on Rybachi gave no definitive intrusive age, but suggested that they were older than Ordovician model ages (ROBERTS & ONSTOTT 1995). Palaeomagnetic data from these same dykes favoured a Late Vendian to Cambrian age (TORSVIK et al. 1995). One solitary dyke from Sredni gave a similar palaeomagnetic age, while the ^{40}Ar-^{39}Ar analysis on this same dyke gave a minimum age of 546 ±4 Ma. This dyke cuts a diagenesis-grade compactional fabric that has been Rb-Sr-dated to 610-620 Ma (GOROKHOV et al. 1995). Illite fractions from along the SRFZ on Sredni have yielded a Rb-Sr maximum age of 570 Ma (GOROKHOV et al. 1995), which has been interpreted (ROBERTS 1996) as providing an approximate age for the basinal inversion in this part of the Timan-Varanger Belt.

Isotopic age determinations from Varanger Peninsula are few in number. K-Ar whole-rock data on dolerite dykes cutting the Late Riphean to Early Vendian strata showed three age groupings: (a) c. 360 Ma, (b) c. 650 Ma and (c) 945-1945 Ma (BECKINSALE et al. 1975; recalculated ages). One of the group (a) dykes has provided a U-Pb zircon upper-intercept age of c. 567 Ma (ROBERTS & WALKER 1997). This particular dyke cuts a cleavage which is interpreted as probably of Timanian age. While the Late Devonian K-Ar ages of this and possibly other dykes on Varanger may relate in some way to a Late Devonian thermal overprint event (see also LARSEN & TULLBORG 1998), this does not reject the possibility that some dykes may have intruded in Devonian time.

In summary, there is a good evidence in the Timans and Kanin, and now with support from isotopic studies on granites from deep drillcores beneath the Pechora Basin, that the peak tectonothermal phase of the Timanian orogeny in this part of the TVB occurred during approximately Mid Vendian time, c. 600-575 Ma. Farther to the northwest, on Rybachi, Sredni and eastern Varanger, the temporal constraints at present are somewhat less precise. The character and trend of the foreland-facing folding and cleavage in these areas, however, are remarkably similar to those encountered in the Timans.

THE TIMANS AND BASEMENT OF THE PECHORA BASIN

New research, aided in particular by seismic reflection data and deep drillholes reaching pre-Palaeozoic rocks beneath the

Pechora Basin, have confirmed the northeastward extension of the Riphean-?Vendian sedimentary succession of the Timans beneath the several kilometres thickness of Palaeozoic and younger cover rocks of this basin. The rocks there, however, are more strongly deformed and metamorphosed, and comprise not only sediments but also volcanic rocks (including tholeiitic basalts and volcanites of island arc affinity) and intrusions. There are also fragments of an older basement present. BELYAKOVA & STEPANENKO (1991) demonstrated the development of intense magmatic activity related to the NW-SE zonation and concentrated along the Pechora-Kozhva Fault (their main deep-seated rift zone). Based on geophysical and now profuse deep drillhole data, BELYAKOVA & STEPANENKO (1991) and GETSEN (1991) suggested that the pre-Riphean crystalline basement was broken into a mozaic of microplates separated by small Riphean basins. Tectonic inversion, closing of the basins, collision of the blocks and magmatic activity have together produced the pre-Palaeozoic basement of the Pechora Basin, a result of Timanian orogeny involving the accretion and telescoping of new and old lithosphere along this part of the margin of Baltica. Thus, an originally passive margin was transformed to an active one by Late Vendian time.

We show aspects of the new model in Fig. 4 as proposed more recently by the first author (OLOVYANISHNIKOV et al. 1995). The main map (Fig. 1) and schematic cross-section (Fig. 4) show the Kolguev and larger Khoreyver massifs, interpreted as older Precambrian terranes, and the so-called Izhma 'microplate', which is the thinned and faulted northeasternmost part of the Russian Platform, rather than a truly separate microplate. In this scenario the entire Timan ridge between the Western and Eastern Timan Faults, and also including northern Timan and Kanin Kamen, is considered to represent the Timanian compressional zone, situated transitionally between the Izhma 'microplate' beneath the basinal realm of the Timans, and the Russian plate margin proper (Figs. 1 and 4). The Central Timan Fault played an important role at this time, functioning as a thrust which carried the low-grade basinal (e.g., Vymskaya Ridge) successions onto the sediments of the pericratonic zone, as for example those exposed in the Chetlaski Kamen. This is a situation which has clear parallels with the deformation patterns observed on the Rybachi-Sredni and Varanger Peninsulas. Farther northeast, beneath the Pechora Basin, there was a more complex, higher grade, Timanian deformation zone located between the Khoreyver terrane and the Izhma 'microplate', the Pechorskaya collision zone. This also involved the volcanic arc rocks (cf.

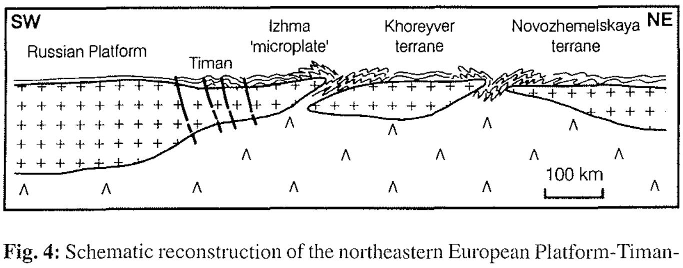

Fig. 4: Schematic reconstruction of the northeastern European Platform-Timan-Pechora region in latest Neoproterozoic/earliest Cambrian time. Crosses: continental crust; inverted V: 'basaltic layer'/upper mantle; continuous lines with folds: deformed Neoproterozoic sedimentary successions.

BELYAKOVA & STEPANENKO 1991) in what is believed, by BOGATSKY et al. (1996), to have represented an initial collision between the Siberian plate and the extreme northeastern edge of Baltica. Terrigenous red bed and tuffaceous deposits of (?)Late Vendian to Cambrian age in the Khoreyver terrane are considered by these same authors to represent molasse deposition following the Timanian orogeny. Elsewhere, beneath and marginal to the Pechora Basin, Lower Ordovician and possibly Cambrian rocks are lying with marked unconformity above the Timanian deformed complexes.

ACKNOWLEDGEMENTS

We are grateful to Doc. Malgorzata Moczydlowska-Vidal for her examination of the list of microfossils from the Timans and for her opinion on the stratigraphic value of this assemblage. We thank also Dr. Valentin Andreichev for making available for us his then unpublished Rb-Sr isotopic ages of rocks in the northern Timan. The comments of the referees, Drs. A. Larionov and J. Golonka, contributed to improvements to an early version of this paper. This account is a contribution to the ongoing work in the Europrobe Timpebar Project, and at the same time a progress report on the collaboration between the Geological Survey of Norway and the Komi Research Centre, RAS, Syktyvkar, Russia.

References

Akimova, G.N. (1980): Geochronology of Precambrian of Timan.- Sovetskaya Geologia 12: 71-85 (in Russian).

Andreichev, V.A. (1998): Isotopic geochronology of the intrusive magmatism of the northern Timan.- RAS, Ural Division, Ekaterinburg, 90 pp.

Belyakova, L.T. & Stepanenko, V.J. (1991): Magnetism i geodinamika Baikalid fundamenta pechorskoj sineklisy.- Izvestia AN SSSR, Serie geologicheskaia, 106-117.

Bertrand-Sarfati, J. & Siedlecka, A. (1980): Columnar stromatolites of the terminal Precambrian Porsanger Dolomite and Grasdal Formation of Finnmark, north Norway.- Nor. Geol. Tidsskr. 60: 1-27.

Bogatsky, V.I., Bogdanov, N.A., Kostyuchenko, S.L., Senin, B.V., Sobolev, S.F., Shipilov, E.V. & Khain, V.E. (1996): Tectonic map of the Barents Sea and the northern part of European Russia: explanatory notes.- Institute of the Lithosphere, Russ. Acad. Sci., Moscow, 101 pp.

Bogdanov, A.A. (1961): On some problems of the tectonics of Europe (in Russian).- Vestnik Moscovskogo Gornogo Instituta, Seriya Geologicheskaya, 5.

Gee, D.G., Beliakova, L., Dovshikova, E., Larionov, A. & Pease, V. (1999): Vendian intrusions in the basement beneath the Pechora Basin, norteastern Baltica.- Polarforschung, this vol.

Getsen, V.G. (1975): The basement structure of the northern Timan and Kildin Peninsula.- „Nauka", Leningrad, 144 pp.

Getsen, V.G. (1987): Tectonics of Timan (in Russian).- „Nauka", Leningrad, 170 pp.

Getsen, V.G. (1991): Geodynamic reconstruction of the NE European part of the USSR in Late Proterozoic.- Geotectonika 5: 26-37 (in Russian)

Getsen, V.G. & Pihova, N.G. (1977): Stratigraphy of the Riphean deposits of the central Timan.- Izv. AN SSSR., Seria Geologicheskaya 6: 69-80.

Gorokhov, I.M, Turchenko, T.M., Baskarov,A.V., Kutyavin, E.P., Melnikov, N.N. & Sochava, A.V. (1995): A Rb-Sr study of multistage illite generation in shales of the Pumanskaya aand Poropelonskaya Formations, Sredni Peninsula, NW Kola Peninsula. (extended abstract).- Nor. Geol. Unders. Spec. Publ. 7: 330.

Ivanov, S.N. (1981): On Baikalides of the Urals and Siberia (in Russian).- Geotektonika 5: 47-63.

Larsen, S. Å. & Tullborg, E. L. (1998): Why Baltic Shield zircons yield late Palaeozoic, lower intercept ages on U-Pb concordia?- Geology 26: 912-922.

Lyubtsov, V.V., Mikhailova, N.S., Predovsky, A.A. (1989): Lithostratigraphy and microfossils of Late Precambrian of the Kola Peninsula.- Kola Scientific Centre AN SSSR, 129 pp. (in Russian).

Malkov, B.A. (1992): Timan Baikalides: myth or reality? - Ukhta Branch, USSR Mineralogical Society, Syktyvkar, 21-29.

Olovyanishnikov, V.G. (1998): Upper Precambrian of Timan and Kanin Peninsula.- Inst.Geol. Komi Scientific Centre RAS, Ural Division, 163 pp. (in Russian).

Olovyanishnikov, V.G., Bushuev, A.S. & Dokhsan'yants, E.P. (1995): The structure of the conjugation zone of the Russian and Pechora plates from geological and geophysical data.- Trans. (Doklady) Russian Acad. Sci., Earth Sci. Section 351 (8), 1228-1232.

Olovyanishnikov, V.G., Siedlecka, A. & Roberts, D. (1997): Aspects of the geology of the Timans, Russia, and linkages with Varanger Peninsula, NE Norway (extended abstract).- Nor. Geol. Unders. Bull. 433: 28-29.

Raaben, M.E. (1975): Upper Riphean as a unit of the general geological scale.- Inst. Geol. AN SSSR 273 „Nauka", Moscow, 247 p. (in Russian)

Raaben, M.E. (ed.) (1994): Stratigraphic glossary, Upper Precambrian.- „Nauka", Moscow 347 p. (in Russian)

Raaben, M. E., Lyubtsov, V.V. & Predovsky, A.A. (1995): Correlation of stromatolitic formations of northern Norway (Finnmark) and northwestern Russia (Kildin Island and Kanin Peninsula).- Nor. Geol. Unders. Spec. Publ. 7: 233-246.

Ramsay, W. (1899): Neue Beitrage zur Geologie der Halbinsel Kola.- Fennia 15: 1-15.

Raznitsyn, W.A. (1962): Riphean deposits of the Timans.- Trudy NIIGA 130 (19), (in Russian).

Raznitsyn, W.A. (1968): Structure of the Central Timans.- „Nauka" Leningrad, 220 p. (in Russian).

Rice, A.H.N. (1994): Stratigraphic overlap of the Late Proterozoic Vadsø and Barents Sea Groups and correlation across the Trollfjorden-Komagelva Fault, Finnmark, North Norway.- Nor. Geol. Tidsskr 74: 43-57.

Rice, A.H.N. & Roberts, D. (1995): Very low-grade metamorphism of Upper Proterozoic sedimentary rocks of the Rybachi and Sredni Peninsula and Kildin Island, NW Kola region, Russia.- Nor. Geol. Unders. Spec. Publ. 7: 259-270.

Roberts, D. (1995): Principal features of the structural geology of Rybachi and Sredni Peninsulas, Northwest Russia, and some comparisons with Varanger Peninsula, North Norway.- Nor. Geol. Unders. Spec. Publ. 7: 247-258.

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.

Roberts, D. & Nordgulen, Ø. (eds.) (1995): Geology of the eastern Finnmark - western Kola Peninsula region.- Nor. Geol. Unders. Spec. Publ. 7, 378 pp.

Roberts, D. & Onstott, T.C. (1995): ^{40}Ar-^{39}Ar laser microprobe analyses and geochemistry of dolerite dykes from the Rybachi and Sredni Peninsulas, NW Kola, Russia.- Nor. Geol. Unders. Spec. Publ. 7: 307-314.

Roberts, D. & Walker, N. (1997): U-Pb zircon age of a dolerite dyke from near Hamningberg, Varanger Peninsula, North Norway, and its regional significance.- Nor. Geol. Unders. Bull. 432: 95-102.

Samuelsson, J. (1995): Biostratigraphy of the Kildin Island and the Sredni and Rybachi Peninsulas, Kola, northwestern Russia – preliminary results (extended abstract).- Nor. Geol. Unders. Spec. Publ. 7: 327-329.

Samuelsson, J. (1997): Biostratigraphy and palaeobiology of Early Neoproterozoic strata of the Kola Peninsula. Northwest Russia.- Nor. Geol. Tidsskr. 77: 1-28.

Schatsky, N.S. (1935): On tectonics of the Arctic (in Russian).- In: Geology and economic deposits in Northern USSR, V.1: 476-509)

Schatsky, N.S. (1958): Les relations du Cambrian avec le Protérozoigne et les plissements Baikaliens.- In: Les relations entre Précambrian et Cambrian.- CNRS Coll. Institute Paris 1957: 91-101.

Schatsky, N.S. (1964): On flexures of the Donetz-type.- Izbr. Trudy II, „Nauka" 544-552 (in Russian).

Siedlecka, A. (1975): Late Precambrian stratigraphy and structure of the northeastern margin of the Fennoscandian Shield (East Finnmark-Timan Region).- Nor. Geol. Unders. 316: 313-348.

Siedlecka, A., Lyubtsov, V.V. & Negrutsa, V.Z. (1995): Correlation between Upper Proterozoic successions in the Tanafjorden-Varangerfjorden Region of Varanger Peninsula, northern Norway, and on Sredni Peninsula and Kildin Island in the northern coastal area of Kola Peninsula in Russia.- Nor. Geol Unders. Spec. Publ. 7: 217-232.

Siedlecka, A. & Roberts, D. (1995): Report from a visit to the Komi Branch of the Russian Academy of Sciences in Syktyvkar, Russia, and from fieldwork in the central Timansd, August 1995.- NGU Report 95: 149, 24 pp.

Siedlecki, S. (1980): Geologisk kart over Norge, Berggrunnskart Vadsø M 1: 250 000.- Nor. Geol. Unders.

Torsvik, T.H., Roberts, D. & Siedlecka, A. (1995): Palaeomagnetic data from sedimentary rocks and dolerite dykes, Kildin Island, Rybachi, Sredni and Varanger Peninsulas, MW Russia and NE Norway: a review.- Nor. Geol. Unders. Spec. Publ. 7: 315.326.

Tschernyschev, T. (1901): On geological structure of the Timans and on relation of the Timan Fault to other regions of northern Europe.- Zapiski Mineralogicheskogo Obstchetva 34: 29-33 (in Russian).

Zhuravlev, V.S. (1972): Comparative tectonics of the Pechora, Caspian and North Sea exogonal depressions of the European Platform.- 232 Moscow „Nauka", 399 pp. (in Russian).

Zhuravlev, V. S. & Gafarov, R.A. (1959): Scheme of tectonic of the north-east Russian Platform.- Doklady AN SSSR, Geologia 128, no. 5: 1023-1025 (in Russian).

Zhuravlev, V.S. & Osadchuk, M.I. (1960): Structural and facies zonation of the Riphean folded basement of the Timans.- MOIP Bull., Geol. Series 35,3: 89-102 (in Russian with English Summary).

Zhuravlev, V.S. & Osadchuk, M.I. (1962): Tectonic position of the Kislorucheskaya Formation in composition of the Riphean folded basement of the Timans.- Doklady AN SSSR 146, 5: 1156-1159 (in Russian).

Zhuravlev, V.S., Zabrodin, V.E., Raaben, M.E. & Chernyy, V.G. (1966): On stratigraphy of Basement of the Timans.- MOIP Bull., Geol.Series 41,2: 49-75 (in Russian).