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Report from a visit to the Komi Branch of the Russian Academy of Sciences in Syktyvkar, Russia, and from fieldwork in the central Timans, August 1995.

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REPORT

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Title:

Report from a visit to the Komi Branch of the Russian Academy of Sciences in Syktyvkar, Russia, and from fieldwork in the central Timans, August 1995.

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Summary:

The objective of research initiated in Central Timans in August 1995 was to extend and continue the work carried out in the Varanger-Rybachi-Sredni-Kildin area during the years 1990-93. The studies embraced stratigraphy, sedimentation, deformation and metamorphism of Neoproterozoic successions which accumulated in different parts of the same NW-SE-oriented extensional basin. Two areas, Chetlasky Kamen and Vymskaya Ridge in the Central Timans, were selected for examination; unfortunately only the latter area was visited, for economic reasons.

The expedition to two river sections, the Dimtemyol river and the Pokju river in the Vymskaya Ridge, was organised by the Komi Branch of RAS in Syktyvkar. The rivers cross-cut the bulk of the Neoproterozoic succession of the Vymskaya Ridge. Together they expose c. 6.500 m of stratigraphic section represented by dark-coloured clayey to silty shale, mudstone and fine-grained sandstone, and subordinate medium-grained sandstone. On the whole the succession is rather monotonous and, with the exception of one unconformity, appears to be continuous, with no signs of shallow-water deposition or subaerial exposure. The sediments were accumulated from distal, dilute turbidity currents and from suspension, with subordinate reworking by weak bottom currents. An outer shelf, prodelta slope to continental rise and a deep basin could have been the sites of sediment accumulation. There was probably no topographically pronounced basin margin at the time of this sedimentation; alternatively, the margin may have been located at a considerable distance to the southeast. No sedimentary facies directly comparable to the basinal successions in the Varanger-Rybachi-Sredni area have been observed.

The Vymskaya succession was subsequently affected by a SW-directed, regional compressive stress which produced SW-facing, mesoscopic and larger scale NW-SE folds with an associated, penetrative, axial planar cleavage. During this phase of basinal inversion, which is considered to be a part of the latest Proterozoic *Baikalian* orogenic event, regional metamorphism in the Central Timans reached only very low grade, at most upper anchizone. The cleavage has many of the attributes of a solution cleavage. Folds which deform the pervasive cleavage are uncommon along the Dimtemyol and Pokju river sections.

Keywords: Late Proterozoic	Sedimentary rock	Sedimentation
Stratigraphy	Structural geology	

CONTENTS

1 INTRODUCTION AND SCOPE

Neoproterozoic rocks of the Varanger Peninsula, and of the Rybachi and Sredni Peninsulas and Kildin Island have recently been examined in a joint Norwegian - Russian research project. This research, initiated by the Geological Survey of Norway, has embraced several aspects of the development of the sedimentary basin and its subsequent tectonic deformation. Results of this work have been presented in a number of papers which appeared in Norges geol.unders. Special Publication No.7. The 1995 expedition to the Central Timans was a continuation and extension of this research.

The Neoproterozoic rift basin in which the Varanger-Rybachi-Sredni-Kildin successions accumulated constitutes a northwestern peripheral outlier of the Timan-Kanin passive margin basin. One of the main fault zones known from the Timans and from the substratum of the southwestern part of the Pechora Basin can be traced northwestwards to Rybachi and Sredni, and further to Varanger where it forms the well known polyphase Trollfjorden-Komagelva Fault Zone (TKFZ). This fault zone separates different sedimentation and deformation regimes, exactly in the same way as in the Timans.

The Kanin-Timan belt is more than 1000 km in length. The distance between the northwestern tip of Kanin Peninsula and Kildin Island is c.375 km, while the Kildin-Varanger zone extends over some 275-300 km. In total, the Timan to Varanger belt is thus a more than 1500 km long, Neoproterozoic, elongate basinal structure branching off the Urals.

Published descriptions of sections exposed in the Central Timans suggested that there exist some similarities in the development of the sedimentary successions of the Tanafjorden-Varangerfjorden Region (TVR) of the Varanger Peninsula, the Sredni Peninsula and **Chetlasky Kamen**, and between the Barents Sea Region (BSR), the Rybachi Peninsula and **Vymskaya Ridge**. Therefore our **main objective** was to visit these two areas in the Central Timans (shown in Fig. 1), examine the sections and clarify the similarities in facies development reflecting basin tectonics and look at the styles and episodes of tectonic deformation. This would facilitate a better founded correlation between the Central Timan and the remote northwestern periphery of the Late Proterozoic Timanian rifted basin. Unfortunately, in a very late stage of preparation of the fieldwork the investigations in the Chetlasky Kamen were excluded from the programme by the organisers because of the rapidly increasing costs of transportation by helicopter.

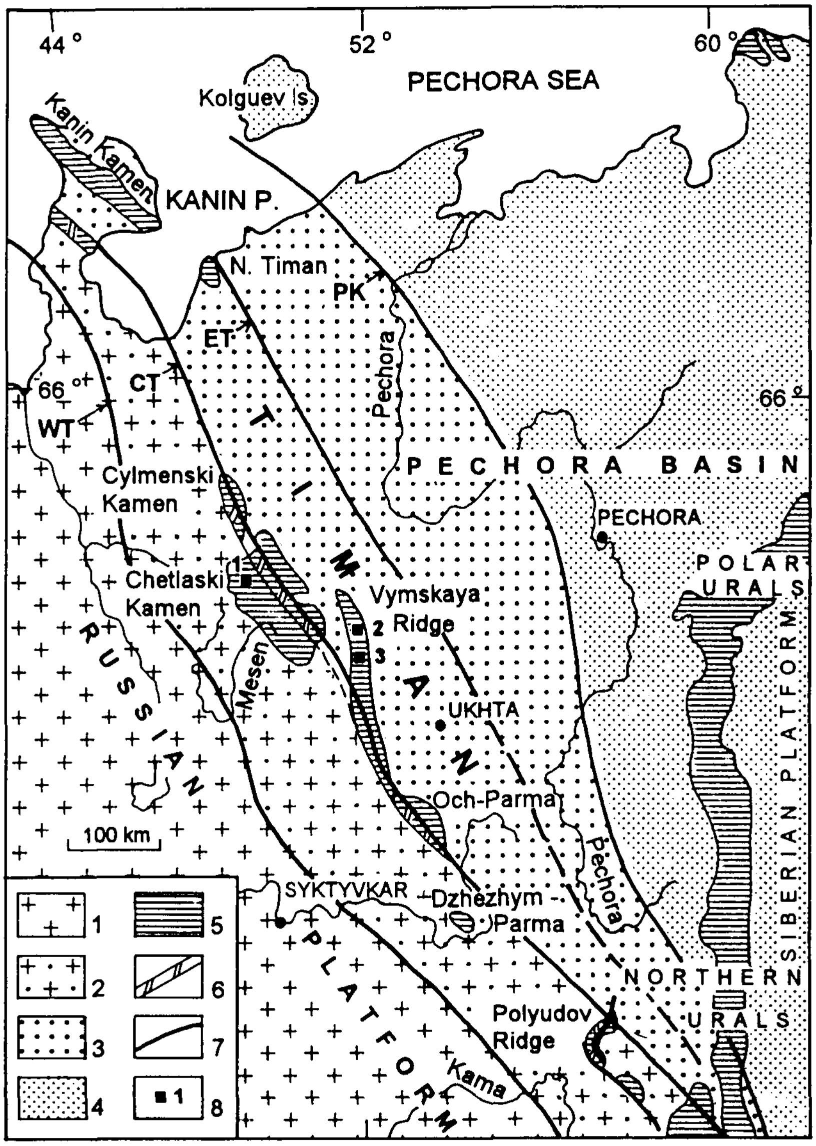

Fig. 1. Simplified map of the Timans and the Pechora Basin, pre-Palaeozoic reconstruction (after Dedeev & Getsen 1987, Getsen 1987 and Olovyanishnikov 1995, with modifications). 1. Russian platform with Upper Proterozoic sedimentary cover. 2-4. Upper Proterozoic passive margin basin. 2. Pericratonic zone; 3. Passive margin to basin floor (miogeoclinal) zone; 4. Basin floor. 5. Area of outcrop of Upper Proterozoic rocks. 6. Upper Riphean stromatolitic dolomite. 7. Polyphase fault zones: WT - Western Timan, CT - Central Timan, ET - Eastern Timan, PK - Pechora-Kozhva. 8. Field camps: (1) Berezovaya-Mezen-Pyzhma river (planned, but not visited), (2) Pokyu river, (3) Dimtemyol river.

2 VISIT TO THE GEOLOGICAL INSTITUTE, KOMI BRANCH OF RAS, SYKTYVKAR

Prior to and after the fieldwork, we visited the Geological Institute in Syktyvkar. Our Russian colleagues, V.O. Olovyanishnikov and deputy director A.M.Pystin introduced us to the director of the Institute, Nicolai P.Yushkin. Professor Yushkin gave us a brief introduction to the organisation of the Institute and its ongoing research. The institute has a scientific staff and administration comparable in size to NGU. There is, however, a broader spectrum of specialist fields, including e.g. palaeontology, biostratigraphy and geology of oil and gas. The institute does not carry out systematic geological mapping.

We were shown around the geological museum of the institute. The museum has two main parts, the principal section comprising an extensive collection of rocks, minerals and fossils, and wall charts illustrating the geology and mineral resources of the Komi Republic. This part is well adapted for non-professional visitors. In addition, there are collections of samples and thin-sections for scientists who visit the institute and wish to study particular topics.

We were also given the opportunity to examine rock samples from the Chetlasky Kamen and Vymskaya Ridge.

After the fieldwork we gave lectures on different aspects of the geology of Norway and on the recent results of our studies of the Neoproterozoic of Varanger Peninsula and the northwestern coastal areas of Kola Peninsula.

3 FIELDWORK IN THE VYMSKAYA RIDGE

Fieldwork was organised and guided by Dr.V.G.Olovyanishnikov and Dr.A.M.Pystin. Dr.Olovyanishnikov has spent most of his professional career studying the geology of the Timans and could therefore provide all the information we needed and show us the principal sections. He also turned out to be an excellent organiser of the field camps. Dr.A.M.Pystin has most of his experience and very good training in fieldwork from the Northern and Polar Urals studying high-pressure metamorphism.

The area which we studied is located in densely vegetated taiga, and bedrock is exposed exclusively along rivers which cut through the Vymskaya Ridge. We were taken by helicopter to the Dimtemyol and Pokju rivers. During the two weeks of fieldwork we studied the river sections which together give a fairly complete stratigraphy and a satisfactory insight into the tectonic deformation and degree of metamorphism of this part of the Timan succession.
The Neoproterozoic lithostratigraphy is shown in Fig.2 along with a correlation with other areas of the Timans according to Olovyanishnikov (unpublished field guide 1995). We had the

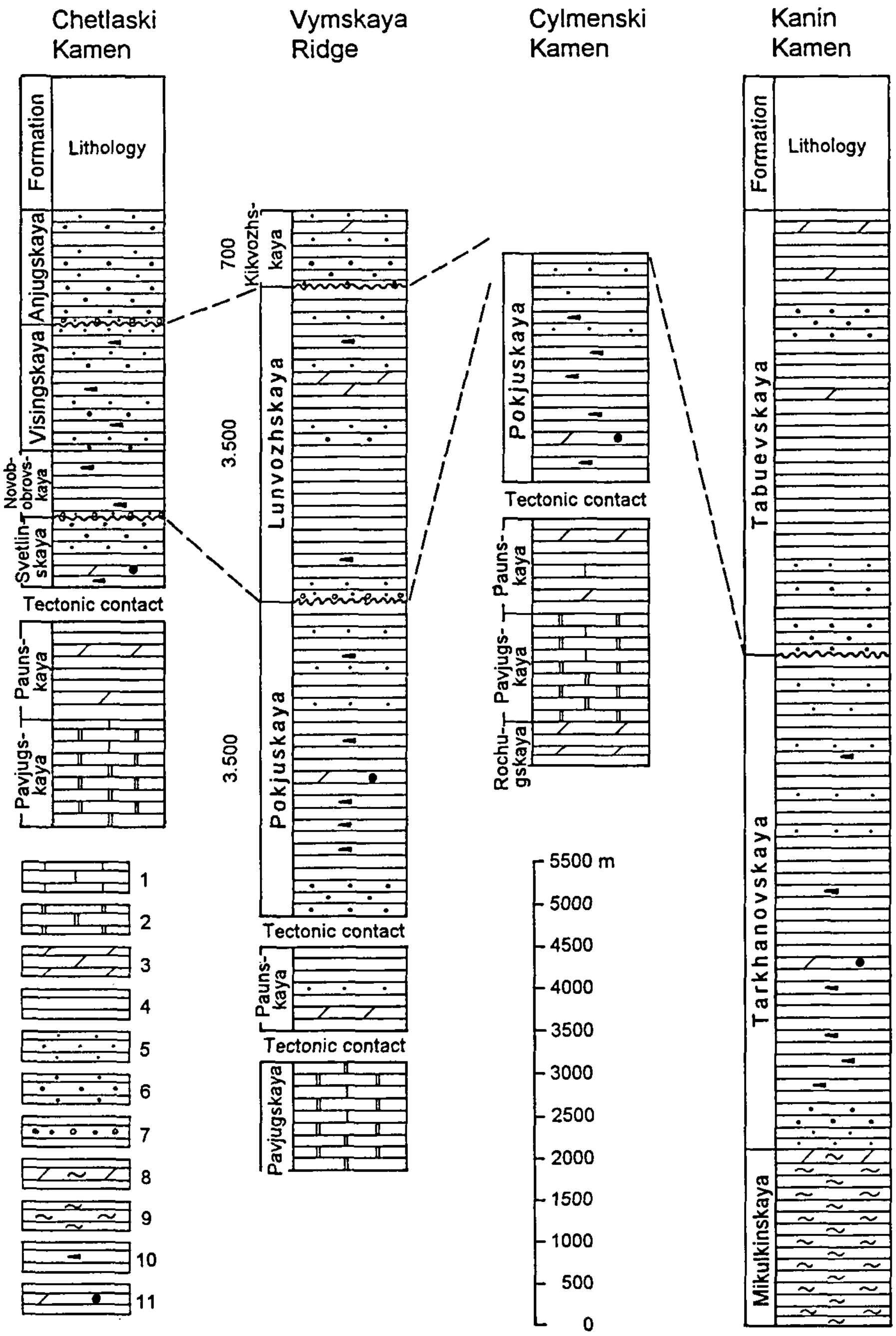

Fig.2. Stratigraphic columns of the Upper Proterozoic successions of Timan and Kanin Kamen. 1 - limestone, 2 - dolomite, 3 - marl and calcareous shale, 4 - muddy shale, 5 - siltstone and quartz-mica shale, 6 - sandstone, 7 - conglomerate and grit, 8 - diopside-amphibole marble, 9 - schist and paragneiss, 10 - dark grey shale enriched in Ti and Mn, 11 - limestone concretions enriched in Mn and Sr. (From Olovyanishnikov 1995).

opportunity to examine and sample the Pokjuskaya, Lunvozhskaya and Kikvozhskaya Formations. In addition, the uppermost part of the Paunskaya Formation was also examined and sampled.

Sedimentological observations were carried out mainly by AS while structural work was carried out by DR. The descriptions which follow are based almost exclusively on field data. They should therefore be regarded as constituting what is essentially a preliminary account, and any reference to this work should be seen in this light.

3.1 Stratigraphic section along the Dimtemyol river

The Lunvozhskaya and Kikvozhskaya Formations are discontinuously exposed along the river (Fig.4). Neither the bottom nor the top of the succession is exposed. The structure is fairly simple with dips towards the northeast and with a few open folds in the upper part of the section. On the map in the guide some thrust-faults are indicated within the section but these are believed to be of minor importance (Olovyanishnikov, pers.comm.1995). The section can therefore be roughly considered as stratigraphically complete.

3.1.1 Lunvozhskaya Formation

This formation is up to 3500 m thick and has been subdivided by Olovyanishnikov (unpubl.guide 1995) into several informal members which are shown by alphanumeric codes in Figs. 3 and 4. The section was not logged in detail; however, examination of the majority of outcrops enabled us (AS) to construct a summary section shown in Fig. 4.

The succession assigned to the Lunvozhskaya Formation is apparently continuous and is monotonous in its lithological composition. It is terrigenous, comprising dark-grey to blackish-grey muddy, silty and clayey sediment with subordinate very fine and fine sand (sporadically medium-grained). Beds are mostly thin to medium, parallel-sided and with non-erosional, sharp lower and upper bounding surfaces.

Sedimentary structures observed throughout the succession include horizontal parallel lamination and lenticular lamination. The parallel lamination is on the mm scale and occurs in clayey-silty beds. Lenticular beds are silty-sandy and are either continuous or occur as rows of isolated lenses a few millimetres thick. Parts of these structures exhibit cross-stratification, but the majority of beds have a massive appearance. Associated with the parallel- and lenticular-laminated beds are a few examples of flaser bedding. Some thin sandstone beds consist of cosets of ripple cross-stratification. Massive sandstones and sandstones with weakly developed graded bedding are subordinate.

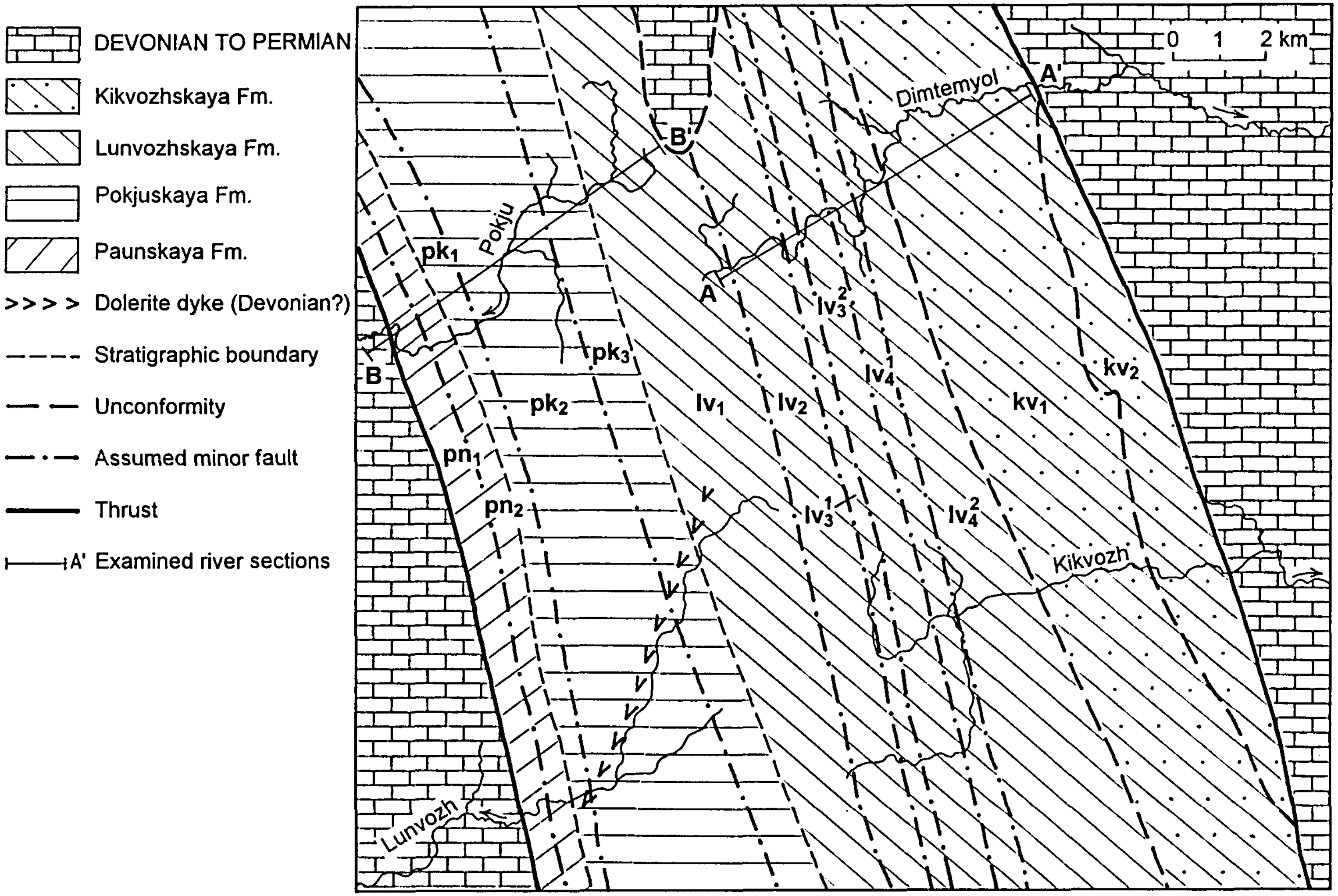

Fig. 3. Geological sketch map of the central part of the Vymskaya Ridge. The lettering refers to informal members of the formations (after Olovyanishnikov 1995).

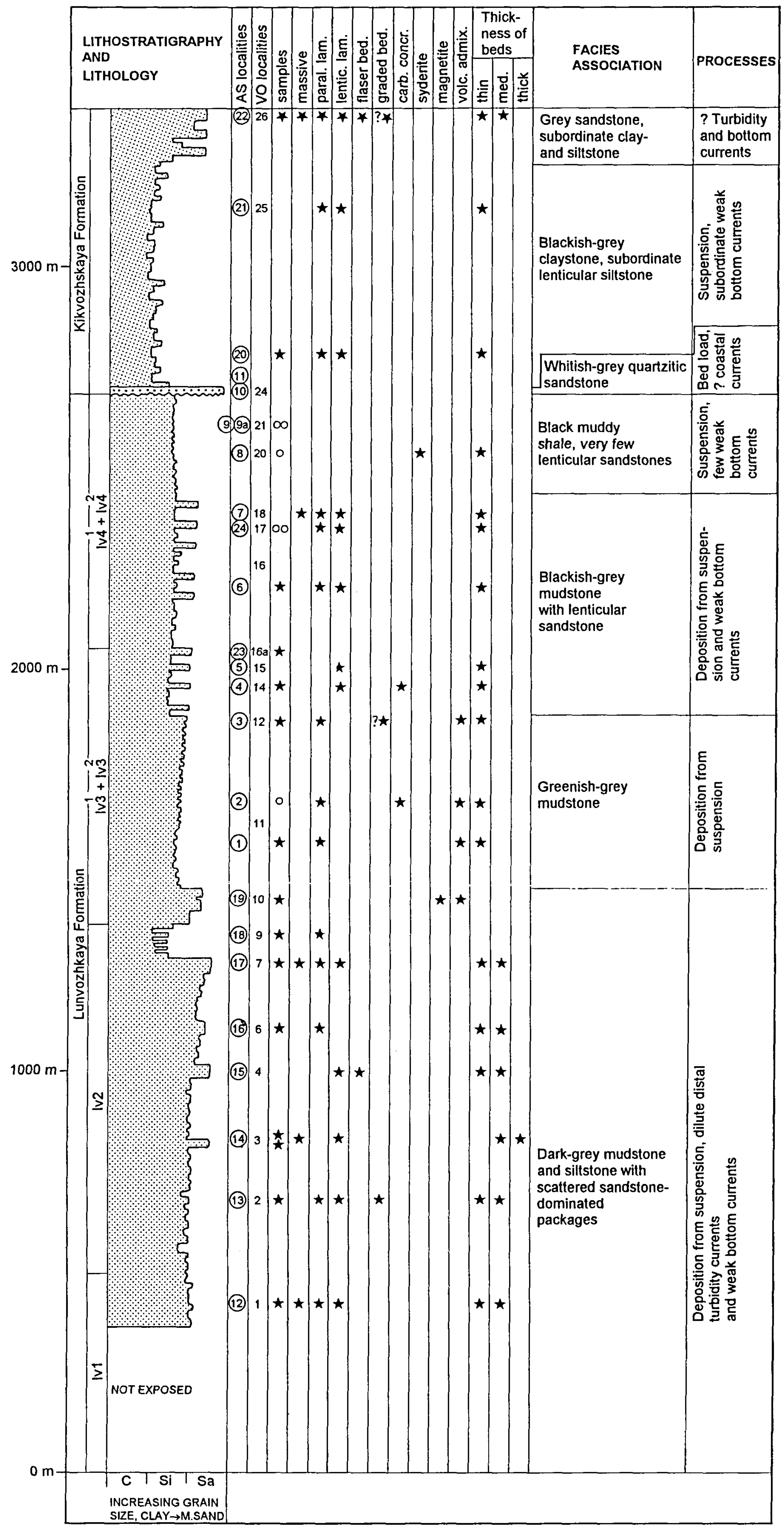

Fig.4. Summary section of the profile exposed along the Dimtemyol river. Locality numbers -- AS (A.Siedlecka), VO (V.Olovyanishnikov). Samples: O - taken for microfossil investigation; X - taken for primary-structural and textural examination.

The sedimentary structures are reminiscent of sedimentation from suspension, and from dilute distal turbidity currents. Current-rippled sands testify to a reworking of sandy material by weak bottom currents. The presence of rows of isolated sandy lenses testifies to a deficit of sand, resulting in the formation of 'starved ripples'.

The examined succession of the Lunvozhskaya Formation may be tentatively subdivided into four intervals, indicated in Fig. 4.

(1) <u>Dark-grey mudstone and siltstone with scattered sandstone packages</u>. This interval embraces top lv1, lv2 and lowermost lv3. and compared to other intervals it has the largest percentage of sandstone beds scattered as packages throughout the predominantly mud-dominated section. The grain size of the sand in these packages appears to be fine to medium. Graded bedding has positively been identified only in this interval. Sandstone packages are a few metres thick and may represent the channel fill or sheet sands of distal parts of a turbidite system. However, erosional bottoms were not observed, and as there was no possibility of following beds laterally the geometry and origin of these sands are therefore uncertain.

(2) <u>Greenish-grey mudstone</u>. This interval embraces the bulk of lv3. The interval consists mostly of thin, parallel-laminated beds and includes some beds with carbonate concretions. This interval contains an admixture of volcanogenic material (Olovyanishnikov, pers. comm. 1995). Mud (silt and clay) was probably accumulated entirely from suspension with not much grain-size separation. No signs of reworking by bottom currents were observed along our river traverse.

(3) <u>Blackish-grey mudstone with lenticular sandstone</u>. This embraces the upper part of lv3 and the bulk of lv4. The interval consists of thin-bedded, parallel-laminated mudstone with sharp parallel-sided bounding surfaces. The majority of the scattered, subordinate sandstone beds are c. 1 cm thick, fine-grained and lenticular. In some places cross-stratification may be observed in these 'one-ripple thick' beds which are either continuous or consist of rows of lenticles. There are also subordinate beds of fine-grained sandstone 20-30 cm thick which are either massive, ripple-cross stratified or exhibit a weak ?graded-bedding (detected by cleavage refraction). Some sandstones contain siderite. While mud and silt were deposited directly from suspension, sand was probably transported by dilute turbidity currents and subsequently often reworked by bottom currents.

(4) <u>Black muddy shale, very few lenticular sandstones</u>. This interval embraces the upper part of lv4. Blackish-grey, parallel-laminated silty-clayey shale constitutes the main lithology here. Lenticular, silty/sandy, 1-2 mm-thick laminae are uncommon. The interval is, in general, dominated by a clayey fraction and is distinctly carbonaceous. This sediment was deposited from suspension in a stagnant euxinic environment.

3.1.2 Kikvozhskaya Formation

The Kikvozhskaya Formation is c. 700 m thick and rests with an erosional contact on the Lunvozhskaya Formation. With the exception of the lowermost c. 10 m of the section, the formation is similar to the subjacent Lunvozhskaya Formation. Lithologically it may be subdivided into three intervals labelled 5
to 7.

5) Whitish-grey quartzitic sandstone. This is the basal unit of the Kikvozhskaya Formation. The sandstone, which has been described in detail by Getsen (1987, p.48), is fine- to medium-grained and contains a varying amount of feldspar and a few granule-sized fragments of clayey shale. It is massive, appears to be moderately well sorted and is cemented by quartz overgrowths. In places haematite stringers suggest the presence of wavy bedding. The sandstone is interbedded with grey muddy shale. Although the actual contact with the substratum is not exposed, there is a pronounced contrast between this sandstone and the subjacent black shale. The sandstone represents a shallow-water, possibly coastal deposit resting upon the 'basinal' black shale. This interface has been interpreted by Getsen (1987) as an unconformity between the Lunvozhskaya and Kikvozhskaya Formations. Although not well exposed, there seems to be a gradual upward transition into the succeeding strata of the Kikvozhskaya formation.

(6) Blackish-grey claystone, subordinate lenticular sandstone. This embraces the bulk of the Kikvozhskaya Formation and marks a return to the conditions which obtained during accumulation of the sediments of the Lunvozhskaya Formation. The blackish-grey, carbonaceous, clayey sediment predominates (content of organic matter >1%, Olovyanishnikov, pers.comm. 1995). The silty-sandy laminae, <1 cm thick, show parallel to wavy lamination with, in places, ripple-cross lamination. The sediment was primarily deposited from suspension; and a few silty-sandy rippled horizons testify to the activity of subordinate weak bottom currents.

(7) Grey sandstone, subordinate claystone and siltstone. This constitutes the uppermost part of the Kikvozhskaya Formation. Thin to medium-thick beds of fine-grained pale-grey sandstone predominate. The sandstone exhibits lenticular lamination, in places flaser-bedding. Less abundant are intervals of blackish-grey mud with lenticles (isolated ripples) of sand, in places impregnated with siderite. Also present are 10-15 cm thick beds of either massive or parallel-laminated sandstone. Cleavage refraction suggests the presence of weak graded bedding. Load casts were observed in one place in a loose slab. This sand-dominated interval represents fine-grained turbidites.

3.2 Stratigraphic section along the Pokju river

The upper Paunskaya Formation, the Pokjuskaya Formation and the lower Lunvozskaya Formation are exposed discontinuously along the Pokju river (Fig.5). Neither the bottom nor the top of the successsion is exposed. As on the Dimtemyol river the structure is fairly simple with dips towards the northeast. There is a minor fault at the boundary between the Paunskaya and Pokjuskaya Formations which does not disrupt the stratigraphic continuity to any major extent. There is an inferred fault (faults ?) and lack of exposure between the Pokjuskaya Formation and the lower Lunvozskaya Formation over a distance of about 1 km along the river. The offset is considered to be of only local importance (Olovyanishnikov, pers.comm. 1995). The stratigraphic gap is estimated to be in the order of c.300 m.

The entire succession is terrigenous, and dominated by fine-grained, dark-grey sediments. As in the succession of the Lunvozhskaya and Kikvozhkaya Formations in the Dimtemyol section, the Pokju section is rather monotonous, being dominated by parallel-laminated, thin-bedded, muddy sediments with subordinate sandy material. In some detail, the succession may be subdivided into several intervals of somewhat different facies associations. These are described briefly below and shown in Fig.5.

3.2.1 Upper Paunskaya Formation and Pokjuskaya Formation

(1) Dark-grey siltstone with sandstone beds at the top. This unit, forming part of the Paunskaya Formation, consists mainly of massive, thin-bedded siltstone with sharp, parallel-sided, bedding surfaces. Subordinately, and higher up in the stratigraphic section, there are parallel-laminated siltstone beds and massive siltstones with parallel-laminated upper portions. The sediment was probably deposited from suspension and from dilute turbidity currents. There appears to be a gradual transition into:

(2) Dark-grey sandstone, subordinate siltstone and mudstone. This facies association embraces the upper part of pn2 and the lower Pokjuskaya Formation, pk1. It consists of thin- to thick-bedded, dark-grey sandstones which exhibit several features typical for turbidites. The sandstones occur in packages c.2-4 m thick (one c.10 m thick) interbedded with blackish-grey, 1-2 m thick shaly units. The sandstone beds are mostly massive, some exhibit rippled intervals at the top, while others are massive with a gradual transition into a silty-clayey laminated interval at the top. Erosional contacts with mud chips derived from the subjacent bed are present in places. Cross-bedding was observed in a lenticular bed of sandstone within one of the packages. Soft-sediment deformation structures and clastic dykelets were also recorded. The silty-clayey packages exhibit parallel-lamination with intercalated sandy, rippled beds up to 1 cm thick. The sandy packages are interpreted as either channel fill or sand sheets which accumulated in the distal part of a turbidite system. In this context the mud-dominated intervals

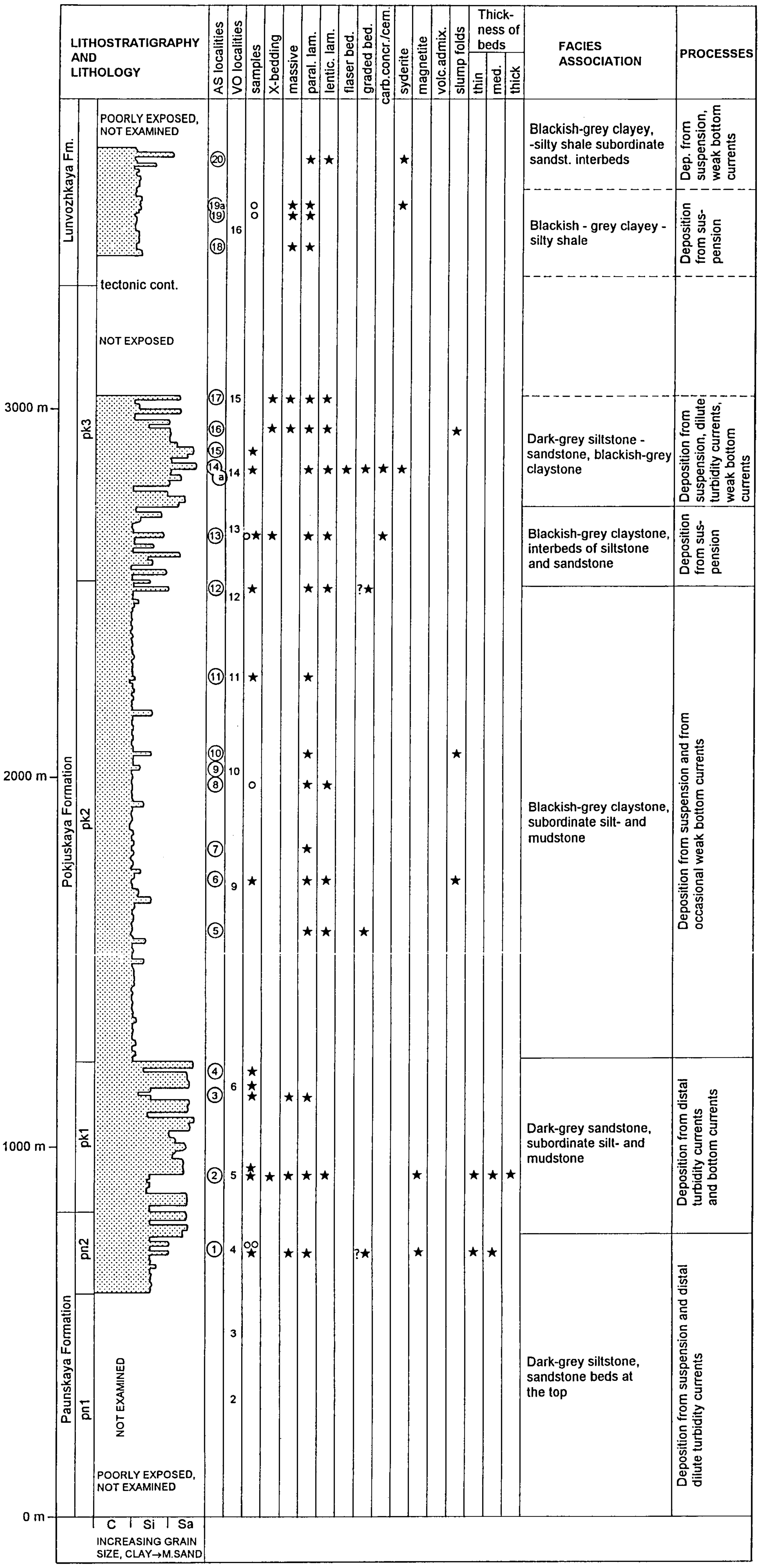

Fig.5. Summary section of the profile exposed along the Pokyu river. Symbols as in Fig.4.

would have been deposited from suspended load in low-concentration turbidity currents and partly reworked by bottom currents.

(3) Blackish-grey claystone, subordinate siltstone and mudstone. This interval embraces pk2 and there is a gradual transition into pk3. It consists of blackish-grey, clayey sediment with subordinate silt-clay beds or very fine-grained sand to clay beds, usually not more than 1 cm thick; these are either parallel-laminated, graded-bedded or in places rippled. Soft-sediment deformation folds have been observed in two places along the section. Thin beds of fine-grained sandstone, indistinctly graded-bedded, appear in the uppermost part of this facies association. The blackish-grey, clay-dominated and extremely finely laminated sediment typifies this interval, which represents a black shale facies deposited primarily from suspension. Occasional weak bottom currents and dilute turbidity currents were also operating in this environment.

(4) Blackish-grey claystone, interbeds of siltstone and sandstone. This interval embraces the lower part of pk3. While it is similar to that immediately below, the number and thickness of siltstone-sandstone beds increases. These beds are usually a few centimetres thick, and are either lenticular and ripple-cross stratified on a mm- to cm-scale, or (exceptionally) exhibit indistinct graded bedding. Some beds display mm-thick horizontal parallel lamination. In relation to the subjacent interval, this facies association was increasingly affected and deposited by dilute turbidity currents, and reworked by bottom currents, in addition to the basinal black shales which accumulated from suspension.

(5)Dark-grey siltstone-sandstone, blackish-grey claystone. This is the middle part of pk3 (uppermost part of the Pokjuskaya Formation observed along the Pokju river). Thin-bedded sandstone-siltstones predominate. Internal structures include horizontal and lenticular lamination, the latter usually occurring in the upper portions of beds. Some beds (5-15 cm thick, in places ut to 30 cm) are lenticularly bedded throughout; in others ripple-cross stratification is preserved. Some massive beds are also present. Intervals containing clay exhibit flaser and lenticular bedding. Deposition of this association ocurred by an interaction of dilute turbidity currents with weak bottom currents and with some sedimentation from suspension.

3.2.2 Lunvozhskaya Formation

The lower part of the Lunvozhskaya Formation and the contact with the subjacent beds are not exposed. The examined outcrops apparently expose parts of the (?)lower Lunvozhskaya Formation not observed in the Dimtemyol section (see Fig.4). The following two facies associations can be differentiated:

(6) Blackish-grey clayey-silty shale. Dark-grey laminated or massive mudstone and blackish-grey clayey shale predominate. Subordinate intervals of lenticularly laminated siltstone-claystone (up to 15 cm thick) occur in the lower part. Deposition from suspension at extremely low rates was the main process responsible for accumulation of this particular sediment..

(7) Blackish-grey clayey-silty shale, subordinate sandstone interbeds. This is the blackish-grey clayey-silty shale as described above, with interbeds of fine-grained sandy and silty beds. The silty-sandy and clayey packages vary in thickness from just a few centimetres to tens of centimetres, and are lenticular- and parallel-laminated, respectively. The silty-sandy beds are 2-3 cm thick and are enriched in ferruginous carbonate cement.

4 DISCUSSION AND SUMMARY

The examined succession, in total c. 6500 m of stratigraphic section, has the following **general characteristics**:

1. The succession is monotonous.

2. It consists of terrigenous sediments, with only a few examples of diagenetic carbonates.

3. The succession is dominated by fine-grained sediments ranging mostly from clay to fine sand. The lowermost part of the Kikvozhskaya Formation is the only exception.

4. The succession is rich in organic matter (intervals with 1-2 % are not uncommon).

5. Sedimentary structures which occur throughout the succession include parallel, millimetre-thick horizontal lamination and lenticular lamination. In places the latter exhibits internal cross-lamination testifying to the origin of the lenticles as current ripples. In addition, there are massive beds and subordinate turbidite beds with various Bouma-sequence intervals present (A, B, B-C, A-B).
6. Slump folds have been recorded in three places along the section.

7. There is no evidence of subaerial exposure.

Processes responsible for sedimentation included:

(1) A continuous 'rain' of fine material suspended in the water column; (2) Dilute turbidity currents;
(3) Weak bottom currents; (4) Slumping.

4.1 Variations in facies association in the stratigraphic column

Although there are no major variations, some changes reflecting a variation in the relative influence of depositional processes are discernible in the Pokjuskaya and Lundvozhskaya Formations. The **Pokjuskaya Formation** appears to be characterised by a predominance of sand and turbidites in its lower part and by a 'black shale facies' in its middle portion. Towards the upper part there seems to be a coarsening-up motif expressed by an increasing influx of silt and fine sand. The lower **Lunvozhskaya Formation** is dominated by 'black shale facies'. The middle and bulk of the upper parts of this formation are mudstone-dominated with subordinate sandy layers and exhibit very weak coarsening-up motifs (see Fig.4). The uppermost part of the Lunvozhskaya shows a return to mainly shaly facies.

4.2 The pre-Kikvozhskaya unconformity

We agree with Olovyanishnikov's interpretation of the contact between the Lunvozhskaya and Kikvozhskaya Formation as an unconformity, even though we have not observed the immediate contact between these two formations. The basal sandstone of the Kikvozkskaya Formation, however, is medium- to coarse-grained, quartzitic , c.10 m thick and there is a gradual upward transition (interbeds) into a dark-grey fine-grained sediment. Although sedimentary structures are not preserved, with the exception of a wavy bedding, this sandstone is tentatively interpreted here as a coastal deposit. In terms of events, the Lunvozhskaya/Kikvozhskaya interface represents an uplift with subaerial erosion followed by a new transgressive event.

4.3 Environments of deposition

4.3.1 Evidence provided by the examined section

On the basis of the information provided by the examined section, the following tentative conclusions may be reached:

1. The bulk of the section represents a mud-dominated offshore facies.

2. The depth of the basin in which the sediments accumulated is uncertain. No storm deposits have been recorded and therefore it is assumed that the succession was accumulated below the storm wave base. Modern sandy storm layers (tempestites) occur mostly at c. 20-30 m depth (e.g. Einsele 1992, p.108). This would suggest that the mud-dominated deposits in the studied succession were accumulated at depths greater than 20-30 m.

3. Turbidites and massive to current-rippled beds assumed to be turbidites, suggest a process of redeposition to offshore areas, which might have been located either on the outer shelf or in a slope/rise area marginal to a basin. This would suggest that a prodelta slope and/or submarine turbidite system were the possible environments of deposition of the studied succession.

4. The turbidite-rich uppermost part of the Paunskaya Formation and the lower Pokjuskaya Formation together represent a c. 500m thick succession. It seems more probable that it represents a submarine turbidite system rather than a delta slope. As to the other parts of the succession there are no reliable criteria to allow us to define more precisely their environments of deposition.

4.3.2 Regional context

Data from other areas of exposure in the Central Timan, in particular from the Chetlasky Kamen, provide additional information useful for interpretation of environments of deposition of the succession exposed in the Vymskaya Ridge. In addition, it is also relevant to include in the discussion the tectonic framework of the pre-Phanerozoic basement of the Timan-Pechora region (e.g. Getsen 1987, Dedeev & Getzen 1987, Beliakova & Stepanenko 1991 and others).

The structure of the Precambrian basement is characterised by several NW-SE-trending polyphase fault zones which were active during the time of formation of the Neoproterozoic basin and its subsequent inversion, and which were also important in the subsequent development of the Pechora Basin. One of these fault zones, the Central Timan Fault Zone (CTFZ), runs southwest of the Vymskaya Ridge and separates what the Russian geologists have called the *'outer zone of the Riphean geosyncline'* or *'Timan miogeocline'* (Olovyanishnikov 1995) from the *'pericratonic slope of the margin of the Russian Platform'*, also called *'Timanian pericraton'*. This fault zone continues to the northwest and eventually merges into the SRFZ and TKFZ (see p.1).

To the northwest of the Vymskaya Ridge, Neoproterozoic successions are exposed in the Chetlasky Kamen where the CTFZ crosses the eastern part of this outcrop area (see Fig.1). A 2000-3000 m thick terrigenous succession is discontinuously exposed in the Chetlasky Kamen, parts of which are interpreted as shallow-marine, high-energy coastal, lagoonal and/or coastal lacustrine accumulations. The succession contains microfossils suggestive of a late to terminal Riphean age (Getsen & Pykhova 1977).

Further to the north, in the Cylmensky Kamen, terrigenous-carbonate rocks, including Upper Riphean stromatolitic dolomites, are exposed along the fault zone. The dolomite is interpreted as a deeper water (50-100 m) deposit in relation to the bulk of the Chetlasky Kamen

succession. The dolomite continues from the Chetlasky Kamen southeastwards along the CTFZ. In the Chetlasky and Cylmensky Kamen, east of the dolomite and the CTFZ, there are mud-dominated successions considered to be analogues of the succession in the Vymskaya Ridge (Getsen & Pychova 1977) (see Fig. 1). As far as we understand, there are exclusively tectonic contacts between the carbonate unit and the adjacent terrigenous successions. In addition, the stratigraphic positions of the successions in all three fault-bounded blocks are unclear and therefore stratigraphic correlation across these contacts is uncertain (e.g. Getsen 1987, Dedeev & Getsen, 1987, Getsen 1991). It is of interest to note that Getsen & Pychova (1977) correlate parts of the succession of the Chetlasky Kamen and Vymskaya Ridge with the Kildinskaya and Volokovaya successions of the Sredni Peninsula and consider the dolomitic formation to be older.
In later papers (e.g. Dedeev & Getzen 1987) a Vendian age has been suggested for parts of the terrigenous successions exposed in the Central Timans.

In spite of these uncertainties it is important with respect to basin development, to discuss the southwest to northeast coast-to-basin zonation determined by faulting in a broadly extensional regime. The Chetlasky Kamen to Vymskaya Ridge zonation of facies indicates that the Vymskaya succession was accumulated in offshore basinal areas which were both far from the coast and submerged to considerable depth. Thus, sedimentation of the mud-dominated bulk of the succession of the Vymskaya Ridge could have been accumulated off the faulted continental margin. The turbidite-bearing and turbidite-dominated portions of the section could, in this context, probably represent distal deposits of the continental rise. To our knowledge, there are no coarse proximal turbidites in any part of the discussed sections. This may indicate that a ramp rather than a marginal escarpment characterised the basin topography in Late Riphean time and that the CTFZ was a somewhat less active fault segment than the SRFZ or TKFZ and was therefore not producing a pronounced relief at this particular time. It is difficult to place the stromatolite-bearing dolomitic unit in this context. Therefore, we anticipate that the dolomite is not time-equivalent to the terrigenous successions of the Chetlasky Kamen and Vymskaya Ridge. It may represent a different (?older) episode of sedimentation and an uplifted block or slide, emplaced into its present position during basin inversion.

It is reasonable to assume that the large volume of terrigenous sediments was supplied to the basin by rivers and that the mud by-passing the coastal and shallow-marine zone (Chetlasky Kamen) was accumulated in environments ranging from outer shelf and prodelta slope, to base-of-slope turbidite systems, and to basinal areas (Vymskaya Ridge).

4.4 Stratigraphic correlation and facies comparisons

One of our objectives was stratigraphic correlation with the Rybachi-Sredni and Varanger Peninsula successions, and sedimentary facies comparisons which would shed light on the basin development. Neoproterozoic successions are present in all these areas. On Varanger, parts are Upper Riphean and other parts Vendian. On Rybachi and Sredni, only Upper Riphean deposits are present (Lyubtsov et al. 1989, Samuelsson 1995, Siedlecka 1995 a,b). In the Central Timan it is at present uncertain whether or not the successions include Vendian strata in addition to Riphean. Therefore, it is uncertain which parts of the Neoproterozoic successions of the Timans are time-equivalent to the Upper Riphean and which to the Vendian of the Varanger Peninsula (not present on Sredni and Rybachi).

The sedimentary facies associations which we have observed in the Vymskaya Ridge succession do not have counterparts in the other areas under discussion. Compared with the Rybachinskaya Supergroup of Rybachi and the Barents Sea Group of the Varanger Peninsula they represent, in our interpretation, a deeper basinal 'black shale' facies and parts of a submarine turbidite system which is much more fine-grained (distal) than those exposed in the other areas of Neoproterozoic basinal sedimentation further to the northwest.

5 CONCLUSIONS

1. The succession exposed on the Vymskaya Ridge represents a monotonous, mud-dominated offshore facies.

2. The succession most likely accumulated in an outer shelf, prodelta slope to continental rise environment and in a deep, euxinic, 'starved basin'.

3. The topography of the margin of the basin was possibly more akin to a ramp rather than a marked escarpment between shelf and basin.

4. A more detailed stratigraphic correlation between the successions of the Rybachi-Sredni and Varanger Peninsulas **and** the Vymskaya Ridge succession is uncertain at the present time.

5. There are no facies analogues of the Vymskaya Ridge succession in any part of the successions in the other mentioned areas.

6. Examination of the section exposed in the Chetlasky Kamen would probably clarify some of the problems of correlation and facies comparison, and would contribute considerably to our understanding of the basin characteristics and development.

6 TECTONIC DEFORMATION

6.1 General and regional aspects

Deformation of the sedimentary rocks exposed in the Vymskaya Ridge of the Neoproterozoic Timanian rift basin can most readily be seen, in almost all outcrops, in the form of a penetrative, steeply dipping cleavage. The tectonothermal event which is reportedly a 'trademark' of the Timans, and during which time the Riphean sediments were variably metamorphosed, cleaved and folded, is termed the **Baikalian**. Discussion is still going on regarding the precise temporal constraints for the Baikalian in this particular orogen -- situated as it is quite far away from the type area for the event, near Lake Baikal. However, in broad terms, based largely on the K-Ar dating method, and mostly from areas in northern Timan, we are dealing with a main regional metamorphic event at around 600-590 Ma, i.e., temporally equivalent to the *Cadomian* of western Europe and the *Katangan* (*Pan-African*) of Africa. As well as this main phase, a second thermal 'event' is reported at around 520-480 Ma, sometimes referred to as Late Baikalian, and equivalent to the *Salairian* of Siberia; and for Caledonian geologists, the *Finnmarkian*.

6.2 Section along the Dimtemyol river

The monotony of large parts of the river profile in terms of lithology and sedimentary facies, as described earlier in this report, is echoed in the development and nature of the tectonic structures and metamorphic fabric. In almost all the outcrops at which observations were taken and planar and linear structures measured, the common thread was that of a northeasterly dipping bedding and a similarly dipping but consistently steeper cleavage (Fig. 6a). (Note -- in this account, bedding is hereafter sometimes abbreviated as S0, and the characteristic, pervasive cleavage as S1).

The comparatively simple bedding/cleavage relationship, its ubiquity, and the very low-grade nature of the metamorphic fabric signify that we are safe in concluding that the lithostratigraphical succession is 'right-way-up'. This is, indeed, always confirmed where sedimentary structures, such as ripple cross-stratification or graded bedding, are actually visible. In many other instances where we did not, or could not directly observe indisputable primary structural evidence of 'way up', the concealed presence of grading within beds was commonly revealed by examples of multiple cleavage refraction. In this relationship the cleavage shows a wave-like upward convexity, curving from a low S0/S1 angle in the finer grained upper part of a bed to a higher S0/S1 angle in the lower, coarse-grained part.

In outcrop, the character of the S1 **cleavage** is closely dependent on the nature of the host lithology. In the mud-rich pelites, which dominate the lithostratigraphy along much of the

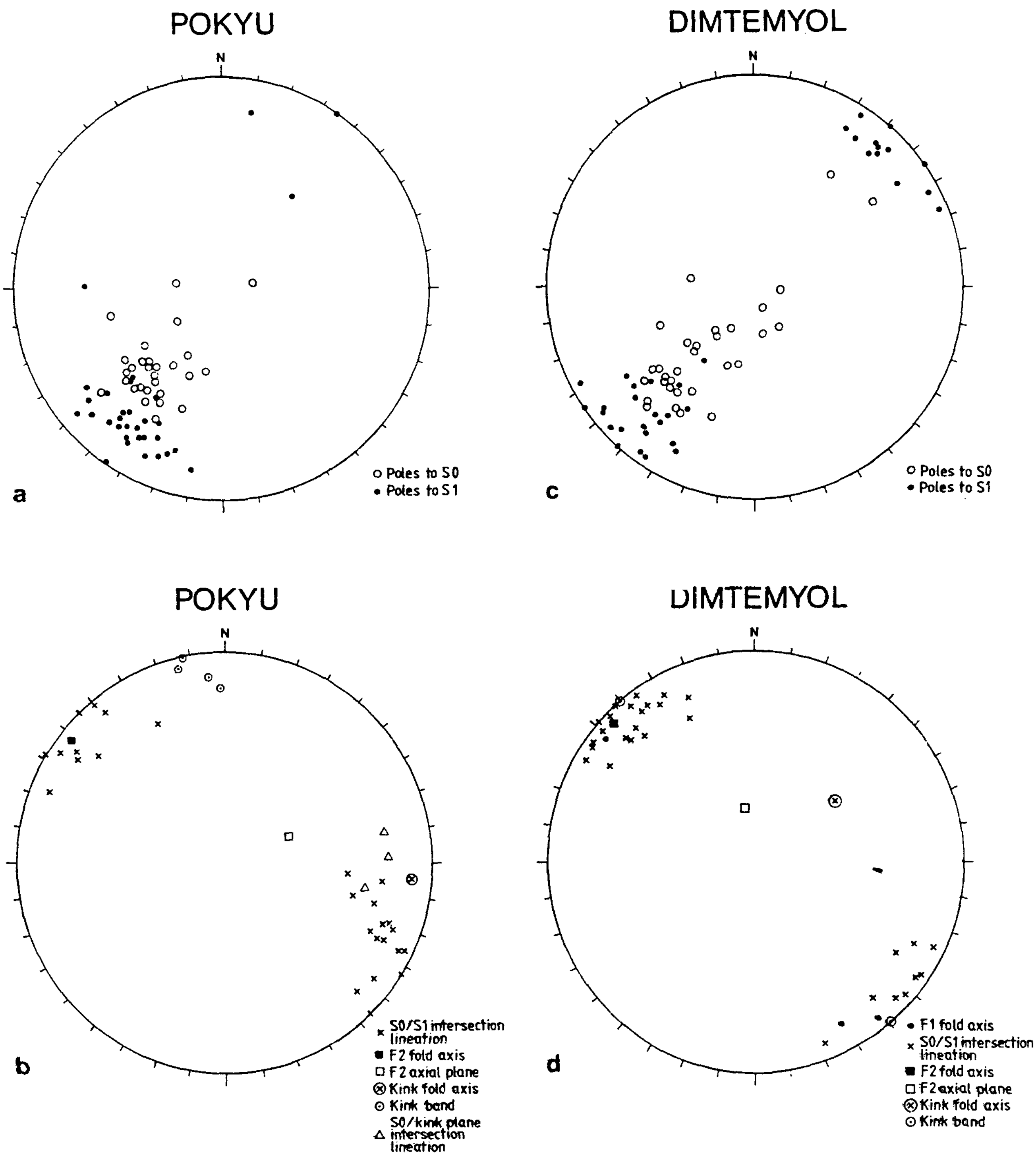

Fig.6. Stereographic plots of mesoscopic structural data from the Pokyu (a,b) and Dimtemyol (c,d) river profiles. Schmidt net, lower hemisphere.

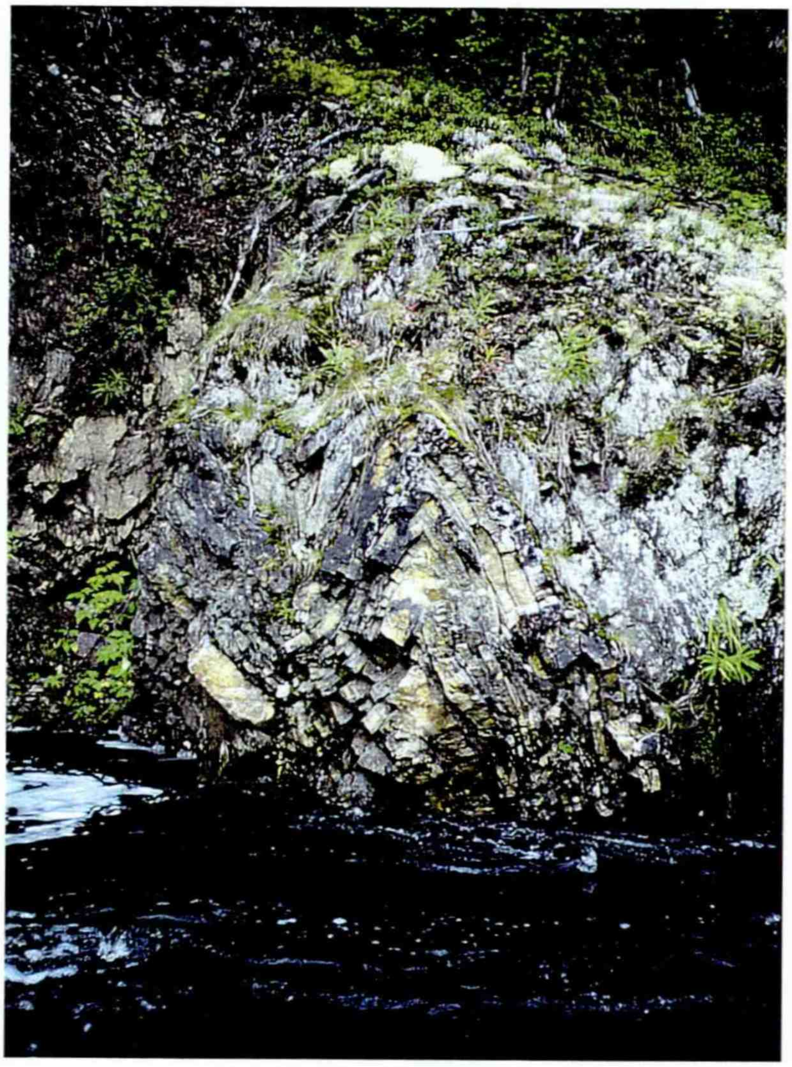

Fig.7. Open to close, near-chevron, F1 folds in the thin-bedded, basal quartzitic sandstone unit of the Kikvozhskaya Formation, Dimtemyol river; looking west-northwest.

Dimtemyol river profile, S1 has the character of a penetrative, continuous, incipient slaty cleavage. Where the original sediment was dominated by clay, or even a very fine-grained silty clay, then there is a tendency towards a change from a continuous cleavage into a tightly spaced, but still parallel cleavage. With increasing grain size the spaced character is emphasized, at the same time as the S0/S1 angle shows a perceptible increase. In siltstones, the cleavage folia begin to lose their parallelism, tending towards a weak sinuous or anastomosing pattern; and with larger grain size they are slightly wider spaced and thus fewer in number. In sandstones, the field character of the S1 is closer to that of a widely spaced, fracture cleavage, where the angle between S0 and S1 can be in the region of 70°-80°, and in a few cases close to 90°.

Although we have not yet had chance to carry out a microscopic study of these rocks, 4 thin-sections have recently been prepared from small hand-specimens of representative, well cleaved, muddy to silty rock-types. A common feature is that in the extremely fine-grained muddier lithologies the cleavage is truly pervasive down to the scale of the single, barely resolvable mineral grain, and is itself marked by dark grey to black, folia or seams of unresolvable material. Where it is easier to see the mineral grains, particularly quartz, in the intrafolial domains, there are many examples of grain truncation by the cleavage folia. This is interpreted as a fairly sure sign that dissolution has occurred, whereby quartz has been dissolved by a pressure solution process, with a result that the dark insoluble residues have accumulated along the cleavage folia. This, in turn, would suggest that the S1 is, in part at least, a solution cleavage, formed initially perhaps by a dissolution of rock material and transport (especially of silica) in solution. To what extent this *solution shortening* has contributed to the overall total shortening expressed by the pervasive cleavage is difficult to estimate because of the lack of suitable strain markers.

The dark mudstones are speckled with tiny metacrysts of magnetite or haematite-magnetite, and in some cases these show the attendant development of fairly symmetrical, quartz-rich 'pressure shadows', with the S1 cleavage folia deflected around the combined metacryst and quartz pressure-shadow areas. These quartz-rich shadows, which constituted local low mean stress areas in the progressively deforming rock, were one form of depository for the migrating, readily dissolved silica. In one thin-section, S1 is concentrated in anastomosing bundles of dark folia which are deflected around lensoid, microscale, asymmetical crinkles of the S0 lamination. Within these intrafolial lenticles, quartz shows a greater concentration than the norm, which is again evidence favouring a process of dissolution during the deformation and low-grade metamorphism of these rocks.

Along this particular river profile, mesoscopic **folds** (F1) with which the pervasive S1 cleavage is associated are extremely rare (Fig. 6b). The best examples are found in the quartzitic sandstone which forms the basal unit of the Kikvozhskaya Formation (Fig. 7). There, several upright anticlines and synclines of near-chevron style deform the thin- to medium-bedded quartzite in a cliff-like, river bank exposure some 20 m in length. Although there is no discernible axial planar S1 cleavage in the massive, white quartzite beds, this can be seen in the interbedded muddy shales as well as in the overlying laminated pelites. Fold axes here plunge at less than 10° towards northwest, while the fold axial planes dip at more than 80° to the northeast. This basal Kikvozhskaya quartzite reappears further downstream, to the northeast, in this case dipping to the southwest; and beyond that, dips are again to the northeast. This means that there are F1 folds of mappable size along this profile, even though the fold hinge zones are not directly observable because of lack of exposure in the critical localities.

Even though mesoscopic F1 folds are few, a good indication of local and regional fold axial trend and plunge is given by the fairly common S0/S1 intersection lineation (Fig. 6b). In cases where this lineation was not easy to see, or inadvertently not measured in the field, it was later constructed stereographically from the S0 and S1 readings.

From the complete data-set from the Dimtemyol profile (Fig. 6 a,b), it is clear that the axial trend of the SW-facing F1 folds and related intersection lineation is c.NW-SE. Plunges are shallow -- a few degrees either to the NW or to the SE, though with a slight bias towards the northwest. The reason for this directional variation is not entirely clear. As S1 varies in strike by up to c.30°, the variation could be attributed to a later regional-scale flexuring. However, it is not inconceivable that the plunge variation may be ascribed, in part, to differential stretching within the assumed XY plane of the local D1 deformation ellipsoid, as has been recorded e.g. on the Rybachi Peninsula (Roberts 1995).

Folds which post-date F1 and deform the S1 cleavage were encountered in only one c.50 m section of the river profile. These are mesoscopic, asymmetrical folds which face down-dip, i.e. to the northeast (Fig. 8), and are more or less coaxial with the F1 folds. Although there is no new cleavage associated with these folds (here called F2), the fairly flat-lying axial planes carry a closely spaced jointing. This is more prominent in silty or sandy beds, and can also be seen in other parts of the river profile where F2 folds are absent.

The only other small-scale structure noted along the Dimtemyol profile, though in just one locality, is that of vertical kink-bands striking c.NE-SW (Fig. 9). The S1 cleavage and bedding are kinked in a dextral sense (looking down on the structure), and the bands are no more than 1 cm in width. As a curiosity, in this same locality the steeply dipping S1 cleavage is deformed at the top of a steep slope by a down-dip facing fold which is clearly derived by recent gravitational sliding (Olovyanishnikov 1995).

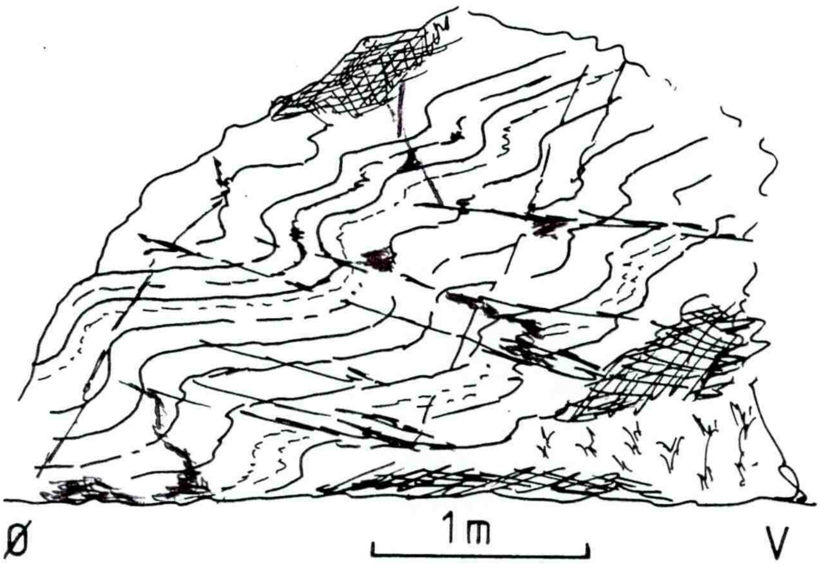

Fig.8. Field sketch of mesoscopic, asymmetrical, post-F1/S1 folds on the south bank of the Dimtemyol river, c.200 m SW of the field camp; looking south. Such folds, which face down-dip, are uncommon in this general area.

Fig.9. Kink bands in cleaved mudstones of the Lunvozhskaya Formation, north bank of the Dimtemyol river c.700 m north of the field camp; looking c.west-southwest.

6.3 Section along the Pokju river

The general strike of lithologies and structures, the cleavage/bedding relationship, S1/S0, and the character of the metamorphic fabric observed along the better exposed profile of the Pokju river differ only in comparatively small detail from those described above from the Dimtemyol profile. Projections of the S0 and S1 data (Fig. 6 a,c) show comparable strikes in the two river sections. Bedding along the Pokju profile is somewhat more consistent in terms of dip values. The S1 cleavage also shows a similar consistency, as well as an almost unidirectional (NE) steep dip (Fig. 6 c). Cleavage strike, on the other hand, shows an overall tendency towards a slightly more WNW-ESE trend than along the Dimtemyol river. This slight swing in trend accounts for the preponderance of SE- to ESE-plunging S0/S1 lineations (Fig. 6 d; compare with Fig. 6 b).

The relationship between cleavage and bedding along the Pokju in all cases indicates that we are dealing with a normal, upward-younging lithostratigraphy; and this is confirmed by all the sedimentary structural evidence that we observed. S1 cleavage refraction patterns also accord with this picture.

In field exposure, the S1 **cleavage** is virtually identical in nature to the same fold-related fabric described above from the Dimtemyol profile, varying from a continuous, incipient slaty cleavage in dark grey to black mud rocks, through a spaced cleavage in silty lithologies to more of a fracture cleavage in sandstones. Four thin-sections were also hurriedly prepared, directly after the fieldwork, from representative muddy to silty rocks from the Pokju river profile. Most of the features described from the Dimtemyol rocks are also recognisable in the thin-sections from the Pokju. Extremely fine-grained mud rocks are pervaded by continuous, parallel folia of black, insoluble residue material, and many of the intrafolial grains, mostly quartz, are truncated by the folia; indicating that a process of dissolution has been operative during this phase of bulk contractional shortening and very low-grade metamorphism.
As in the Dimtemyol profile, tiny magnetite metacrysts are very common in the darker, muddier rock-types. These show varying degrees of mechanical rotation into, or rather towards the S1 plane, and in nearly all cases there are associated 'pressure shadows' of recrystallised quartz. In general, these 'quartz tails' adjacent to the rigid magnetite grains are longer than those observed in the thin-sections from the Dimtemyol profile, in some cases up to 7 to 8 times as long as the width of the actual metacryst. This feature, and the overall character of the S1 fabric noted in the Pokju thin-sections, suggests that the total shortening, and hence overall strain, experienced by the strata along this particular profile was slightly greater than along the Dimtemyol.

Mesoscopic **folds** (F1) associated with S1 were not observed by us in the outcrops to which we were taken by our guides. In the northeasternmost part of the river profile, however, bedding dipping to the west in one long river-bank exposure (with cleavage dipping more steeply, and to the southwest) provided indications that there are mappable anticlines and synclines in this particular area (also noted in Olovyanishnikov 1995). Axes constructed on a stereogram show shallow plunges to slightly north of northwest.

Intersection lineations, in this case provided by S1 cutting S0, were noted at most observation points, and these are taken to depict the F1 axial trend, on a local scale at least. Compared with the Dimtemyol river profile, the majority of such lineations here plunge to the SE-ESE. Those plunging ESE, or even quite close to east in a few cases, show steeper plunges, consequent upon the fact that strike divergence between S0 and S1 is greater in these particular instances.

As along the Dimtemyol, the small-scale structural data from the Pokju profile are thus indicating that a SW-directed compressive stress was responsible for producing the pervasive S1 cleavage. Had F1 mesoscopic folds been present, they would be facing southwest in accord with the consistent cleavage/bedding relationship.

Mesoscopic structures post-dating the metamorphic fabric are uncommon. Open to close, asymmetric folds facing down-dip which clearly deform S1 were found in only one exposure. These folds are coaxial with F1 structures, and have a fairly flat-lying axial plane which lacks any secondary cleavage. Similarly flat-lying close jointing in other parts of the river profile may be coeval with these down-dip, NE-facing folds.

Kink bands, on the other hand, are more common features along the Pokju, especially in central and southwestern parts of the river profile. These are steep to vertical and strike c.E-W (Fig. 6 d), with kink axes plunging to the east. In some parts of the river exposures, such kink bands are abundant; they are generally 1-1.5 cm in width, and there is a fairly regular spacing of 10-15 cm between the bands. (Unfortunately, because D.R. was confined to camp with a foot injury on the critical day, very few of these kink bands were measured). An interesting kinematic feature is that the kinks all show a dextral offset, looking down the kink axial plunge. This monoclinic relationship (no conjugate kink bands were found), which may involve a component of down-step to the south, is indicative of an anticlockwise rotation of the principal compressive stress at some stage after the peak of metamorphism. The kink bands may be broadly Baikalian, but they could also be of Palaeozoic age or even younger.

Finally, it should be mentioned that quartz veins and veinlets are common in parts of both river profiles, and are particularly profuse in some of the darker, muddier, pelitic lithologies. The veins show diverse attitudes to the S1 cleavage. Some lie transverse to the cleavage and are variably buckled, yet are also affected by the cleavage and may be offset along it; others, especially mm-thin veinlets, lie parallel or subparallel to S1, and are clearly affected by extension; and many are disposed at some intervening attitude, and show signs of both buckling and extension. Whatever the case, it seems clear that this veining is broadly synmetamorphic, arising from processes of dissolution and redeposition of readily soluble silica, and in a few cases partly with carbonate.

7 CONCLUDING REMARKS

Based on fieldwork along just the two river profiles, which together provide a fairly comprehensive cross-section through the Vymskaya Ridge, and also on a preliminary examination of only eight thin-sections, the principal features of the comparatively simple structural geology and low-grade metamorphism in this part of the Central Timans can be summarised as follows:-

(1) The original lithostratigraphical succession was subjected to a SW-directed compressive stress which, after an initial phase of presumed layer-parallel shortening, led to the development of SW-facing mesoscopic and larger scale folds (F1) and an associated penetrative, continuous, axial planar cleavage (S1). In all parts of the traversed area, the NW-SE trending S1 is always steeper than bedding.

(2) The regional metamorphism manifested by the S1 fabric reached only very low grade, possibly middle to upper anchizone. The character of the cleavage, notably in thin-section, has many of the attributes of a solution cleavage. The common presence of thin quartz veinlets lends support to this suggestion.

(3) Folds which post-date F1/S1 are uncommon. Where present they are coaxial with F1 but show an opposite sense of vergence, i.e., they are overturned down-dip and face northeast. Although there is no secondary cleavage associated with the flat-lying axial planes of these folds, a close jointing may be present. This jointing can be recognised elsewhere along the profiles.

(4) Kink bands are abundant locally, especially along the Pokju river. They are monoclinic, trending c.E-W, and show a consistent dextral offset looking down-plunge on S0 or S1 surfaces.

The main, penetrative cleavage and fold development, and associated regional metamorphism can be viewed as a probable case of inversion tectonics. Following the development of the basin in an extensional regime, SW-directed contractional stresses were imposed which presumably reactivated basin-marginal and internal faults as compressional structures; this included the Central Timan Fault Zone. These NW-SE trending, major regional fractures have various names in the Russian literature; and our colleague, V.Olovyanishnikov, refers to them as thrusts, e.g. Central Timan Thrust. Some local, internal thrusting has also been inferred by Dr.Olovyanishnikov along the Dimtemyol and Pokju river profiles, especially where exposure is lacking, but this has not been verified.

In northern Timan and the Kanin Peninsula, a similar geological history is recorded, though in this case with the regional metamorphism reaching garnet grade (Getsen 1987). In this northern region, plutonic and hypabyssal rocks are also present, and a volcanogenic component is present in the lithostratigraphical succession. In the case of the Vymskaya Ridge area of Central Timan, no radiometric ages are known, to our knowledge. During our fieldwork, samples of cleaved mudstones were collected for possible illite crystallinity work at some future date. It is also possible to use illites, down to the 2-micron scale, to obtain K-Ar dates; which, in theory, would hopefully provide an age for the very low-grade regional metamorphism. Negotiations are already in progress, via D.R., with a view to having illites dated by the K-Ar method at the University of Leeds, England.

Although our fieldwork in Central Timan concerns the mesoscale -- comparative lithostratigraphy, facies associations, sedimentology, structural geology and metamorphism -- it is but a small brick in the historic-geological, regional scale story of the Timans and its relationship to the Urals. This is a topic which we may take up in a subsequent report or publication. While much of the Timan bedrock is concealed beneath a cover of Devonian and younger sediments, extending northeastwards across the Pechora Basin, there are many drillholes in this region which provide data on the Riphean and Vendian complexes, also to the east of the Timan miogeoclinal zone. Deep seismic reflection profiling has also been carried out, including one long section from near Murmansk on Kola to Berezovo in the Urals, crossing the Timans (A.Egorov, pers. comm. 1995).

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