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Neoproterozoic sedimentary rock successions of the Barents and White Sea Coasts of the Kola Peninsula, Northwest Russia

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Summary:

The Neoproterozoic sedimentary rock successions occurring along parts of the northern and southern coasts of the Kola Peninsula in NW Russia were, for a long time, poorly known to western geoscientists. In this report, detailed descriptions are given of the various groups and formations that constitute the lithostratigraphical successions in the different areas, based on the results of joint Russian-Norwegian project work in the early 1990s and also on earlier Russian mapping and geochemical sampling programmes. The information provided on these successions, their microfossil assemblages, and on their subsequent *Baikalian* deformation and very low-grade metamorphism, is clearly of great value to geologists working on comparable Neoproterozoic successions in eastern Finnmark.

A chapter of the report is devoted to the hydrocarbon potential of these Neoproterozoic sedimentary rock successions, both on land and in the immediate offshore shelf areas. Several formations are found to have high contents of hydrocarbon gases and also quite high organic carbon contents. Some details of analyses are given in the report. In general, although these Neoproterozoic rocks have now probably lost most of their oil and gas potential through Late Palaeozoic migration to overlying Phanerozoic successions with good reservoir characteristics, it is still possible that these rocks may carry limited epigenetic hydrocarbon accumulations – though of gas rather than of oil -- of some commercial importance in certain favourable structural situations in the near-shore shelf areas.

Keywords: Neoproterozoic	Stratigraphy	Sedimentary rocks
Sedimentation	Structural geology	Oil and gas
Kola Peninsula	Russia	

CONTENTS

NEOPROTEROZOIC SEDIMENTARY ROCK SUCCESSIONS OF THE BARENTS AND WHITE SEA COASTS OF THE KOLA PENINSULA, NORTHWEST RUSSIA

Valery V. Lyubtsov, Alexander A. Predovsky & Vladimir Z. Negrutsa
– with contributions by **Anna Siedlecka and David Roberts**

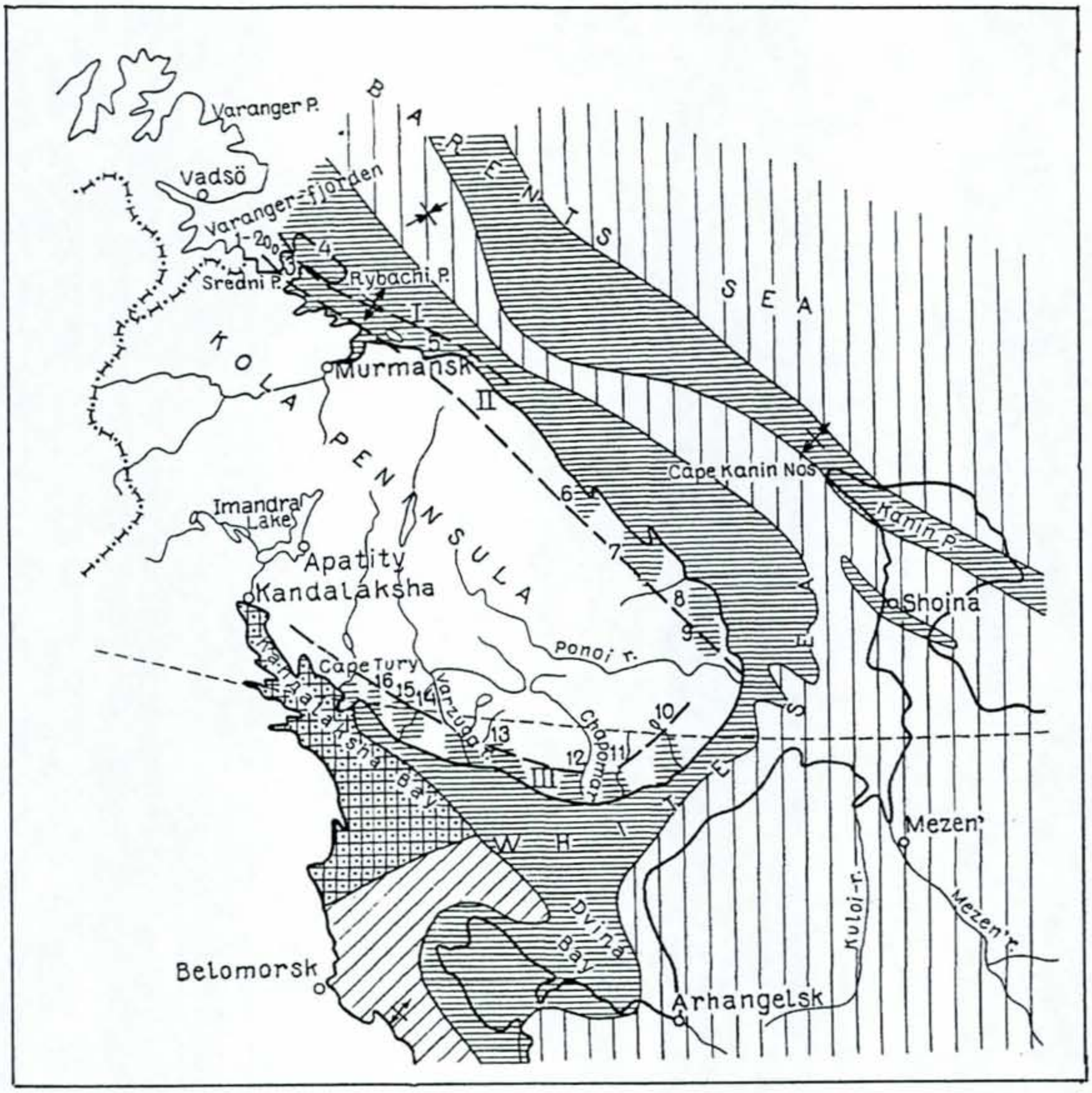
1. INTRODUCTION

The Late Neoproterozic sedimentary successions occurring along the northern and southern coasts of the Kola Peninsula of NW Russia represent only a minor part of a more extensive Neoproterozoic sedimentary province which is confined mainly to the area of the Barents and White Seas (Fig. 1) (Dibner et al. 1970, Makievsky et al. 1974). The successions are generally only weakly deformed and rest upon Archaean gneiss and granite (Figs.1 & 2), mostly on the Sredni and Rybachi Peninsulas, Kildin Island and along the Tersky Coast in the southern Kola Peninsula. Neoproterozoic sedimentary rocks are also preserved in small areas along the northern and eastern coasts of Kola, in graben depressions. These particular successions are not described in this report.

The most complete sections of the Neoproterozoic rocks are exposed on the Sredni and Rybachi Peninsulas, and on Kildin Island. The geological structure of the northwestern part of the region therefore provides a key to understanding the general character of the Neoproterozoic on a more regional scale.

The first geological descriptions of the Rybachi and Sredni Peninsulas and Kildin Island were presented by Boetlingk (1830) and Ramsay (1890, 1897-1899, 1911). In 1912, Fieandt published the first geological map of Rybachi, Sredni and Kildin. Later, the Russian geologists Polkanov (1925, 1933, 1934a, b, 1936) and Tenner (1936), and a Finnish geologist, Wegmann (1929), carried out geological studies on the Rybachi Peninsula. On Rybachi, the investigated sequences were found to be more deformed than in the adjacent areas, and to carry a regional cleavage and, locally, numerous quartz veins. On the basis of these features, Polkanov suggested that the Rybachi sequences were older than those on Sredni, and that the former were thrust above the latter along a major thrust-fault. In Polkanov's interpretation, the Rybachi allochthonous sequence was considered to be the lowermost part of the Sredni-Rybachi rock complex, a view which he believed is supported by the section exposed on the Varanger Peninsula in Norway. The Rybachi succession, according to Polkanov (1925), is overlain by the sandy-clayey and carbonate rock sequence of Kildin Island, and by the formations occurring on the Sredni Peninsula, the latter being comparable to the upper part of the succession on Kildin. Polkanov estimated the total thickness of the Rybachi-Sredni-Kildin succession to be 2000-2500 m. Later, Wegmann (1929) came to the same conclusion regarding the Rybachi-Kildin stratigraphy and presented a more detailed subdivision of the Rybachi sequence, particularly in its western part.

Agapjev and Vronko (in Lyutkevich & Kharitonov 1958) suggested that the thrust-fault which borders the southern margin of the Rybachi Peninsula is comparatively minor. In this same publication, Vronko reinterpreted the dislocation as a normal fault, along which the younger rock complex of Rybachi had been downthrown relative to the sedimentary sequence of Sredni. More recently, this complex fault has been regarded as a long-lived structure with several components of movement (Roberts 1995), and has been termed the Sredni-Rybachi Fault Zone. The fault can be followed to the northwest on to the Varanger Peninsula where it is known as the Trollfjorden-Komagelva Fault Zone.



Neoproterozoic sedimentary rocks (offshore and onshore)

Lower Proterozoic (White Sea, offshore) Archaean

Axes of first-order synclines Axes of first-order anticlines

Palaeozoic and partly Mesozoic (offshore)

Arabic numerals indicate: 1, 2 - Bolshoy and Maly (Kheinya Sari) Aynov Islands. 3, 4 - Sredni and Rybachi Peninsulas. 5 - Kildin Island. 6 - Ivanovskaya Bay. 7 - Svyatoi Nos Peninsula, Golovnoi creek. 8 - Kashkarakka and Peschanka rivers. 9 - Ostry and Gubnoi creeks. 10 - Babja, Glubokaya, Sosnovka and Snezhitsa rivers. 11 - Chapoma river. 12 - Chavanga and Strelna rivers. 13 - Varzuga, Kitsa and Yulitsa rivers; Kitskoye lake; Tolstik Cape; Lodochny creek. 14 - Salnitsa and Olenitsa rivers, Kashkaransky creek. 15 - Kuzreka river. 16 - Tury Cape. I-III -- Zones of distribution of Neoproterozoic rocks: I – Rybachi, II – Kildin, III – Terskaya.

Fig.1. Simplified and schematic geological map of the Neoproterozoic rocks of the Kola Peninsula and adjacent offshore areas of the Barents and White Seas (modified from Makievsky et al. 1974 and Lyubtsov 1980).

Faults with displacements of several tens of metres are not uncommon on Sredni and Rybachi. The faults commonly strike NW-SE or NE-SW. In Vronko's opinion (in Lyutkevich & Kharitonov 1958), the presence of a major NE-SW trending fault with a 250-300 m offset along the river Vykat accounts for the lower elevation of the Volokovaya Group (Fig. 2) relative to the position of older rocks of the Zemlepakhtinskaya Formation.

In later years, Keller et al. (1963), Chumakov (1978) and Konoplyova (1976) considered Polkanov's interpretation of the general age relationships of the sequences on Rybachi, Sredni and Kildin to be correct.

The Neoproterozoic successions on the Sredni and Rybachi Peninsulas and Kildin Island strike NW-SE and have a gentle, monoclinal, northeastward dip. They can be considered as the fragmented southwestern limb of a major synclinal structure which is traceable into the Barents Sea (Fig. 1) (Makievsky et al. 1974). Tenner (1936), Agapjev and Vronko (in Lyutkevich & Kharitonov 1958) and other research workers reported that the Neoproterozoic successions are deformed by minor folds and faults.

In the Neoproterozoic rocks of other regions of the Kola Peninsula (river Chapoma, Cape Tury), the degree of tectonic deformation, from the data of Sergeeva (1973) and our own observations, is similar to that described above. The Turyinskaya Formation (described in Section 3.6.1.) is exposed in a narrow zone in the southernmost part of Cape Tury. The sedimentary rocks occur in a syncline, the northern limb of which is faulted and dips southwards along a set of faults towards the White Sea. The Turyinskaya Formation is characterised by small-scale folding, the fold axes plunging gently towards either the northwest or the southeast. The rocks have a fault-block structure and are mylonitic at the basal contact with the subjacent crystalline basement.

Structural zonation of the Neoproterozoic rocks in the northwestern Kola Peninsula was first proposed by Keller & Sokolov (1960). These authors distinguished two structural-facial zones: an inner, *platformal* zone that includes Sredni Peninsula, Cape Motka of the Rybachi Peninsula, and Kildin Island; and an outer, *miogeosynclinal* zone (which we would now call *miogeoclinal*) that embraces the Rybachi Peninsula. This zonation has been confirmed in general by the observations of Negrutsa (1971), Sergeeva (1973) and Lyubtsov (1975, 1979), as well as by the results of our project work within the Norwegian-Russian collaboration programme 'North Area' (e.g. Siedlecka et al. 1995a, b, Siedlecka & Roberts 1995). Other terms have also been adopted for these sedimentation zones or regimes - *pericratonic* for the platformal zone, and *basinal* for the miogeoclinal zone (Siedlecka & Roberts 1995, Olovyanishnikov et al. 1997 and in press).

On the Kola Peninsula as a whole (Fig. 1), three distinct zones of Late Neoproterozoic rock distribution can therefore be distinguished: Rybachi, Kildin (including the Sredni Peninsula) (Keller & Sokolov 1960) and Tersky. In the Kildin and Tersky zones the rocks are only gently folded (at limb dips of 5-15°, rarely more) and virtually unmetamorphosed. In the Rybachi zone, the rocks are deformed into upright to southwest-verging, open to tight folds, metamorphosed to cleaved mudstones and phyllites, faulted, transected by quartz-carbonate veins and dolerite dykes, and locally affected by metasomatism. Features common to all the three zones are the predominance of terrigenous sedimentary rocks which exhibit evidence of synsedimentary deformation, and the presence of diagenetic concretions consisting of carbonate minerals and carbonate-argillaceous material. The overall sedimentary facies development and composition suggests different environments of sedimentation: a continental regime in the Tersky zone, a coastal-shelf regime in Kildin, and an active submarine slope in the Rybachi zone. Palaeocurrent orientations indicate a general northward transport of material from the eroding land surface; subaqueous slumping structures in the rocks of the Rybachi zone show the same principal direction of movement.

A noteworthy feature is the predominant NE-SW to NNE-SSW orientation of the principal axis of compressive stress following the period of basinal sedimentation, a stress regime that eventually gave rise to the NW-SE folding which is so prominent especially on Rybachi. There is also a general increase in the degree of deformation, and hydrothermal-metasomatic and low-grade metamorphic alterations, towards the north-northeast. The overall palaeogeographic and tectonic zonation of the Kola Peninsula in Neoproterozoic time thus suggests that there was a transition from a continental area in the south and southwest to an area of oceanic sedimentation in the northeast.

The Neoproterozoic complex, as reported by Agapjev and Vronko (in Lyutkevich & Kharitonov 1958) and later by Negrutsa (1971), Sergeeva & Sinitsin (1973), Lyubtsov (1973, 1975) and Siedlecka et al. (1995a), unconformably and transgressively overlies the deformed rocks of the Palaeoproterozoic and Archaean basement. In the Neoproterozoic basal conglomerate and gravelstone, Polkanov (1936), Negrutsa (1971) and Sergeeva (1973) found fragments of various pre-Neoproterozoic rocks, indicative of a long pre-Neoproterozoic hiatus accompanied by peneplanation of the basement and formation of a weathering crust (Lyubtsov & Predovsky 1975a). The existence of a pre-Neoproterozoic or Early Neoproterozoic weathering crust is of practical importance, since it suggests the possibility for the development of placer accumulations of useful minerals. The presence of palaeoplacer occurrences of heavy minerals in the Upper Riphean successions of northern Kola has been mentioned by Negrutsa (1971); these include palaeoplacers of zircon in the Zemlepakhtinskaya Formation on the Sredni Peninsula.

The pre-Neoproterozoic basement rocks beneath the lowest exposed formation of the Kildinskaya Group on Sredni do not exhibit any evidence of deep weathering. This can be accounted for by the transgressive character of the Kildinskaya Group, i.e. the most weathered basement rocks and the lowermost basal strata of the Kildinskaya Group do not crop out here, since they are buried beneath the Sredni Peninsula. It can also be anticipated that weathered basement rocks may be present beneath the lowermost formations of the Rybachi complex.

The stratigraphy of the Neoproterozoic successions of the Kola Region can be better understood by considering the geology of adjacent areas, i.e. northern Norway, the Timans and the Kanin Peninsula. Of special significance for correlation of the sequences of the Kola Region with those in Finnmark are the data obtained by Siedlecka & Siedlecki (1967, 1971), Siedlecki (1975), Roberts (1972, 1993, 1995), Siedlecka (1975, 1985, 1995), Bertrand-Sarfati & Siedlecka (1980), Siedlecka & Edwards (1980), Siedlecka et al.(1992 a, b, 1995 a, b), Siedlecka & Roberts (1992, 1995), Rice & Roberts (1995), Roberts & Onstott (1993, 1995), Roberts & Karpuz (1995) and Torsvik et al. (1993, 1995) on Varanger Peninsula. Comparisons of the lithostratigraphies recognised on the Rybachi and Sredni Peninsulas with those established on Varanger have been presented by Siedlecka et al. (1995a, b).

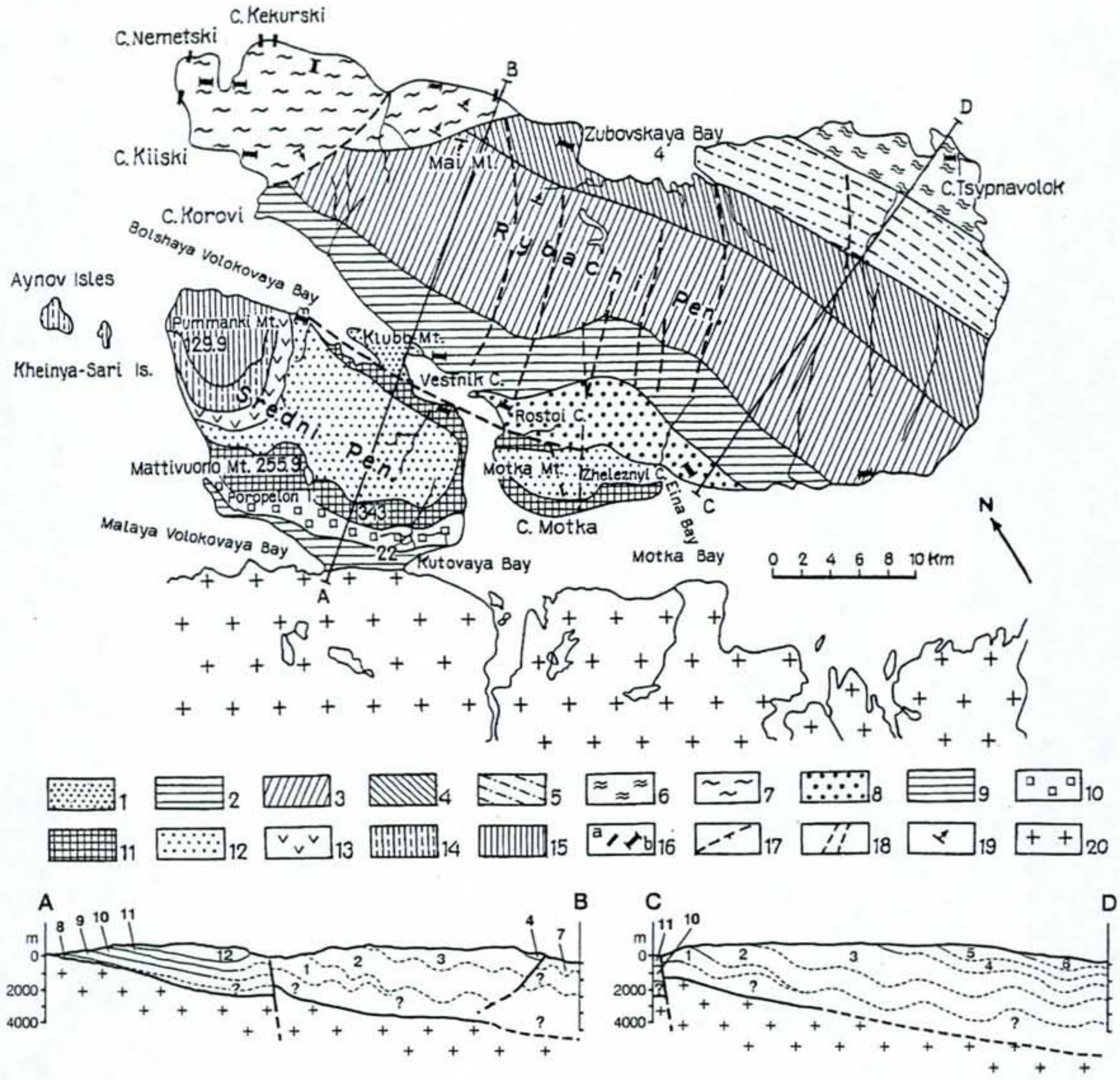


Fig. 2. Simplified and schematic geological map of the Rybachi and Sredni Peninsulas, and the Maly (Kheinya-Sari) and Bolshoi Aynov Islands. Compiled by V.V. Lyubtsov and A.A. Predovsky with the use of data from Vronko and Agapjev (in Lyutkevich & Kharitonov 1958) and Negrutsa (1971), with modifications by Siedlecka (1975) and amendments derived from a Landsat-TM satellite image (Roberts & Karpuz (1995). In the cross-sections, for clarity, only the formation numbers are given (see legend). The question marks indicate possible concealed, older formations.

Einovskaya Group. Upper Riphean formations: 1 – Motovskaya (polymict conglomerate, subarkose); (2) Lonskaya (conglomerate, shale and sandstone); (3) Perevalnaya (greywacke and subgreywacke).
Bargoutnaya Group. Upper Riphean formations: (4) Maiskaya (conglomerate, gritstone and greywacke); (5) Zubovskaya (siltstone and greywacke); (6) Tsypnavolokskaya (greywacke siltstone with hydromicaceous and chloritic cement); (7) Skarbeevskaya (shale and siltstone).
Kildinskaya Group. Upper Riphean formations: (8) Kutovaya (quartz sandstone); (9) Iernovskaya (sandstone); (10) Palvinskaya (subarkose, quartzite), corresponding to the combined Korovinskaya, Bezymyannaya and Chernorechenskaya formations of Kildin Island; (11) Poropelonskaya (subgreywacke, shale); (12) Zemlepakhtinskaya (sandy subgreywacke, arkose); (13) Karuyarvinskaya (variegated rocks, marls, siltstone and shale). The Poropelonskaya, Zemlepakhtinskaya and Karuyarvinskaya formations are correlated with the Pridorozhnaya and Slantsevozersakaya formations of Kildin Island.
Volokovaya Group. Upper Riphean formations: (14) Kuyakanskaya (shale, subgreywacke, quartzite); (15) Pumanskaya (shale, subgreywacke).

Other symbols: (16) dykes, (a) according to recent literature, (b) according to Fieandt (1912); (17) faults; (18) large fracture zones; (19) strike and dip of bedding; (20) granitoids of the pre-Riphean crystalline basement.

2. LITHOSTRATIGRAPHIC SUCCESSIONS, TECTONIC DEFORMATION AND MAFIC DYKES

Two separate lithostratigraphic successions are represented in the Rybachi-Sredni-Kildin region, on either side of the Sredni-Rybachi Fault Zone. In the platformal or pericratonic domain on Sredni Peninsula, Kildin Island and the Cape Motka area of Rybachi there are two main units, the Kildinskaya and Volokovaya Groups, each subdivided into several formations (Negrutsa 1971, Lyubtsov 1975) (Fig. 2). On Rybachi Peninsula, northeast of the main fault zone, in the basinal or miogeoclinal domain, the lithostratigraphic succession comprises two groups, the Einovskaya and Bargoutnaya Groups (Fig. 2), each subdivided into three formations. In addition, there is a separate unit in northwest Rybachi, the Skarbeevskaya Formation. Overall, we consider the successions on Rybachi to lie stratigraphically below those on Sredni and Kildin.

2.1 The Sredni-Kildin-Cape Motka area

As the only exposure of the basal contact of the Neoproterozoic rocks with the subjacent crystalline basement granitoids is to be found on the Sredni Peninsula (Boetlingk 1830, Ramsay 1897-1899, Fieandt 1912, Fig. 2 in Polkanov 1934a, p.205), the description starts with this particular sequence. In general, the sedimentary succession of the Kildinskaya and Volokovaya Groups has been metamorphosed at only very low grade – diagenesis grade (Rice & Roberts 1995) – and bedding surfaces dip at low angles (5-15°) to the northeast.

A segment of the basal sedimentary contact of the Kutovaya Formation against a Palaeoproterozoic microcline granite was, in fact, first exposed by excavation (Negrutsa 1971) immediately south of the innermost part of Kutovaya Bay (Fig. 2). This contact, on an uneven granite surface, undoubtedly represents a nonconformity, at the very base of the Neoproterozoic succession (Lyutkevich & Kharitonov 1958, Negrutsa 1971, Lyubtsov et al. 1978, Siedlecka et al. 1995a).

Along the western coast of the Sredni Peninsula, at the contact between the Kildinskaya and Volokovaya Groups, the rocks are dipping towards the northeast at an angle of 8-10°. The occurrence of variegated rocks of the Karuyarvinskaya Formation of the Kildinskaya Group in the valley of the river Vykat and on the northwestern coast of Sredni (Fig. 2) indicates the presence of an erosional unconformity. The southwestern part of the block containing the rocks of the Volokovaya Formation is faulted. It is possible that, just there, the variegated rocks of the Karuyarvinskaya Formation are tectonically excised. The contact between the Kuyakanskaya and the Karuyarvinskaya Formations is quite clearly erosional, thus suggesting the presence of a stratigraphic hiatus.

On the Sredni Peninsular the succession is only weakly folded. The folds are generally small and symmetrical, with limb dips of up to 15-20° and amplitudes of up to 40 m. Fold axes are oriented either NW-SE or N-S and have gentle plunges (10-12°) towards either the northwest or the southeast.

In the southeastern part of Sredni, the sandstone beds of the Iernovskaya and Palvinskaya Formations are deformed by gentle transverse folds with wavelengths ranging from 25 to 300

m. Northeast of Mt.Ierno-Aivi, beds of the Palvinskaya Formation are observed to gently bend down dip, with dips varying from almost horizontal (3-5°) to 15°.

An interpretation of small-scale satellite images (Soyuz), performed jointly with Gendler (Lyubtsov et al. 1978), showed that the structure of Sredni comprises an assemblage of blocks separated by zones of intensive faulting. To correlate sections within individual blocks, it would be necessary to carry out detailed stratigraphic investigations. It should be remembered, though, that at least some of the block separation might be of synsedimentary origin. From the examination and interpretation of the satellite images, the successions of the Kildinskaya and Volokovaya Groups look homogeneous and structurally similar. The rocks are gently dipping almost everywhere, except close to the NW-SE trending fault zone along the northeastern coast of the peninsula. In areas that are not affected by faulting, the angle of dip is almost constant everywhere.

Kildin Island is located along the eastern continuation of the zone of Neoproterozoic pericratonic sedimentary successions (Fig. 1). The question as to the precise relationship between the sedimentary rocks of Kildin Island and the crystalline basement of Kola remains open and will necessitate special drilling and detailed geophysical studies. Polkanov (1936) suggested the presence of a fault with a large downthrow between the island and the mainland, and this appears to have been confirmed by geosound ranging data (Gurevich et al. 1972). The sedimentary sequence on the island strikes c.E-W, with dips towards the NNW to NNE at angles of 5°-15°. The steepest dips are found in the southern part of the island. In 1933, Bogdanov (Lyutkevich & Kharitonov 1958) reported a NW-dipping thrust-fault in the valley of Chorny creek, in the eastern part of the island.

As noted earlier, on Sredni sedimentary rocks of the Kildinskaya Group rest unconformably upon the Palaeoproterozoic granitoid basement. A K-Ar age determination on glauconite from sandstone of the Palvinskaya Formation on Sredni and the Korovinskaya Formation on Kildin yielded an age of 619±12 Ma (Bekker et al. 1970a). The Kildinskaya Group on Kildin contains diverse carbonate rocks and dolostone[1] beds with stromatolites *Gymnosolen ramsayi Steinm.*, *Pseudokussiella Kryl.* and *Tungussia Semikh.* (Krylov & Lyubtsov 1976, Raaben & Lyubtsov 1993, Raaben et al. 1995) and oncolites, and various sedimentary structures of probable biogenic origin. The sedimentary rocks of this group also contain a Late Riphean assemblage of microphitolites (Lyubtsov et al. 1989).

The age of the Volokovaya Group has been a subject of some controversy. It was considered by Keller & Sokolov (1960) to be Vendian, apparently solely on the basis of its stratigraphical position immediately above the Kildinskaya Group. This age was also suggested by Negrutsa (1971) on the basis of an erosional contact and a considerable pre-Volokovaya period of erosion between the Kildinskaya and Volokovaya Groups. As additional evidence for a Vendian age for the Volokovaya Group, Bekker et al. (1970a) reported a K-Ar whole-rock age of 600±20 Ma for a 1.5 m-thick olivine-diabase dyke that cuts the Pumanskaya Formation of the Volokovaya Group on the western coast of Sredni. A Vendian age for the Volokovaya Group rocks was also initially believed to be supported by the presence of phosphorite concretions (Negrutsa 1963, 1971). However, the Volokovaya Group, as well as the Kildinskaya, was later found to contain a rich assemblage of microphitolites of Late Riphean age (Lyubtsov 1980, Lyubtsov et al. 1989). In addition, a U-Pb isochron on phosphorite concretions from the Volokovaya Group yielded an age of 830±60 Ma (Negrutsa & Basalayev 1987). These data clearly suggest an Upper Riphean age for the Volokovaya Group, a conclusion also reached by Samuelsson (1995, 1998). Although the age [1] estimates of the Volokovaya Group thus seem to be contradictory, the group is evidently younger than the rocks of the Kildinskaya Group. There are also indirect reasons for its correlation with part of the Upper Riphean succession of East Finnmark (Siedlecka et al. 1995a). Whereas the nature of the lower contact of the Volokovaya Group is more or less clear, the upper limit of this youngest part of the Neoproterozoic succession is unknown since its former uppermost strata are not preserved.

2.2 Relationship between the Rybachi and Sredni successions

In the study region, one of the most difficult questions to resolve is the stratigraphic relationship between the rock successions of the Rybachi Peninsula (Einovskaya and Bargoutnaya Groups) and the Sredni Peninsula (Kildinskaya and Volokovaya Groups). At first glance it would seem that this problem could be solved within the area where the rock complexes of Sredni and Rybachi are juxtaposed, i.e. in the zone extending along the northeastern coast of Sredni from the extreme northwest and towards the southeast to Cape Motka and, further, from the mouth of the Rostoi creek to Eina Bay (Fig. 2). However, along this zone, which is basically a long-lived fault-zone between different blocks (the Sredni-Rybachi Fault Zone), the sedimentary complexes of Sredni and Rybachi are in tectonic contact and do not reveal any direct stratigraphic relationship. This was clearly demonstrated during the course of the recent joint fieldwork by Norwegian and Russian geologists. Previously described stratigraphic relationships between the rocks of the Kildinskaya, Volokovaya and Einovskaya Groups (e.g., Negrutsa 1971) were not supported by the recent investigations.

Within the Sredni-Rybachi Fault Zone, the sedimentary rocks are intensely folded into small-scale asymmetric folds with 10° to 85° limb dips, especially along the south coast of the Bolshaya Volokovaya Bay and south of the isthmus. Along the Sredni coast, fold axes and accompanying spaced cleavage commonly have a NW-SE trend. Small-scale folds post-dating the cleavage and trending approximately E-W (Roberts 1995) are also particularly common in clayey shale of the Poropelonskaya and Karuyarvinskaya Formations in the coastal cliffs of the northeastern part of the Sredni Peninsula. Within the fault-zone there are also minor NNW-SSE and NE-SW faults with small offsets.

A sequence comprising interlayered conglomerate, conglomerate-breccia and coarse quartzitic sandstone exposed on the isthmus between the two peninsulas was distinguished by Keller & Sokolov (1960) as the Motovskaya Formation. The rocks of this formation dip towards the northeast at angles of 20° to 30°. In the southern part of the isthmus, the rocks exhibit minor folds and faults. The precise contact between the rocks of the Motovskaya Formation and the sedimentary rocks of the Poropelonskaya and Zemlepakhtinskaya is unfortunately not exposed.

Negrutsa (1971) described a single exposure on Cape Motka and stated that the outcrop demonstrates that the conglomerate at the base of the Einovskaya Group (analogous to the rocks of the Motovskaya Formation) unconformably overlies an eroded surface of shale and

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[1] In many places throughout this report we use the term _dolomite_; in all cases, meaning _dolomite rock._ Here and there we also use the neutral term _dolostone_, for all types of dolomite rock.

sandstone of the Poropelonskaya Formation. However, this interpretation turned out to be incorrect (Siedlecka et al. 1995b). Besides, it should be pointed out that the exposures of the Motovskaya Formation located closest to outcrops of the Sredni Peninsula rock succession are strongly tectonised and cleaved. It would therefore seem that the detailed structure of the lowermost part of the Einovskaya Group can be elucidated only with the help of drilling in the area of Cape Vestnik.

Our observations in the area of Cape Vestnik, in the southeastern part of the isthmus, are in accord with those of Lyutkevich & Kharitonov (1958), Keller & Sokolov (1960) and Negrutsa (1971). There, in the lowermost exposed part of the Motovskaya Formation, the conglomerate is underlain by a unit of thin-bedded dark shale. The shale contains sandstone interbeds, irregular lenses and nests of breccia and conglomerate, and some very angular fragments of granite and gneiss. The thickness of the unit does not exceed 10 m. The shale displays evidence of quite intense tectonic deformation, which is stronger along the contacts of the lenses of breccia and conglomerate. This deformation was interpreted by Negrutsa (1971) as a result of subaqueous slumping. Polkanov (1925), on the other hand, considered the strong deformation in the shale to be a result of proximity to a major tectonic contact.

In the Bolshaya Motka Bay, at low tide one can observe exposures of deformed shale of the basal part of the Motovskaya Formation on the isthmus and the visually almost indistinguishable shale of the Poropelonskaya Formation along the northeastern part of the Sredni Peninsula. The assumption is, therefore, that a fault exists in the intervening unexposed ground between the two formations. On the northern side of the isthmus, in the Bolshaya Volokovaya Bay, there is a gradual lithological transition from the Motovskaya conglomerate to the overlying sedimentary rocks of the Lonskaya Formation of the Einovskaya Group.

On Cape Motka in the southwestern part of Rybachi Peninsula, the conglomerates of the Motovskaya Formation are exposed quite close to sedimentary rocks of the Zemlepakhtinskaya and Poropelonskaya Formations of the Kildinskaya Group. Negrutsa (1971) considered this to represent a normal stratigraphical relationship, i. e. with the Einovskaya Group being younger than the Kildinskaya, and unconformably overlying the latter, and with its conglomerate containing pebbles of the Kildinskaya Group rocks (glauconite sandstone, titaniferous sandstone, etc.). However, this interpretation of the structural and stratigraphic relationships in this area was not supported by the joint fieldwork carried out in 1991 with Norwegian colleagues, where we confirmed the presence of a tectonic contact between the successions (Siedlecka et al. 1995b, Roberts 1995).

2.3 Rybachi Peninsula, excluding the Cape Motka area

On Rybachi, the most complete section of the Neoproterozoic successions is observed in the eastern part of the peninsula (Fig. 2). The succession, subdivided into the Einovskaya and Bargoutnaya Groups, consists of interbedded sandstone, shale and conglomerate. It terminates with the shale-dominated Tsypnavolokskaya Formation. Detailed descriptions of the different formations and their lithofacies are contained in Siedlecka et al. (1995b). The rocks strike predominantly NW-SE and dip northeast at 10°-15°. Fold structures, based on the data of Tenner (1936), Vronko (in Lyutkevich & Kharitonov 1958) and the authors, are characterised by a 290°-315° axial trend with plunges of 0°-40° towards the southeast and northwest (see also Roberts 1995). The folds are SW-facing structures with an axial surface slaty cleavage dipping steeply to the northeast. Illite crystallinity data indicates a mainly anchizone grade of metamorphism (Roberts 1993, 1995, Rice & Roberts 1995).

In the northeastern part of Rybachi (in the area from Cape Ryumin southwards to Cape Bashenka), a sequence of clayey shale and sandstone of the Tsypnavolokskaya Formation is deformed into asymmetric folds varying in amplitude from 100 to 700 m; most of the folds are SW-facing. The shales are strongly cleaved, the cleavage dipping at 30°-70° to the northeast. To the south, the small-scale folding gradually disappears. Within this transition zone, Tenner (1936) and, later, Vronko (in Lyutkevich & Kharitonov 1958) reported several flexures and slickenside surfaces. Farther south, 30-40 m-thick zones of interbedded clayey shale and sandstone show structural evidence of horizontal strike-slip displacement.

On their geological map of the Sredni and Rybachi Peninsulas, Vronko and Agapjev (in Lyutkevich & Kharitonov 1958) outlined a northeastern Rybachi zone, comprising at least two units of clayey sedimentary rocks. Subsequently, Negrutsa (1971) separated a northwestern area in this same zone, characterised by graded-bedded sedimentary rocks of the Skarbeevskaya Formation, which has a S-dipping, thrust-fault contact against sandstones and shales of the Zubovskaya and Tsypnavolokskaya Formations (Fig. 2). The fault-bounded northwestern area, which is clearly distinguishable on Landsat-TM satellite imagery (Fig. 3) (Roberts & Karpuz 1995), was interpreted by Negrutsa as a separate tectonic or even palaeogeographic domain. The satellite photo, however, appears to show that the northwestern block has merely rotated anticlockwise by 20-25°, coeval with the fault movement, during a change in the stress regime (Roberts & Karpuz 1995).

2.4 Mafic dykes

Magmatic rocks occurring on the Sredni and Rybachi Peninsulas are represented by a few dolerite (diabase) dykes. The first observations of mafic dykes on the Sredni and Rybachi Peninsulas and Kildin island were reported in Fieandt (1912), who described about 20 E-W trending diabase dykes (Fig. 2). Polkanov (1925) subsequently found two diabase dykes on Cape Vestnik. The dykes generally have a NE-SW strike and are either vertical or dip steeply towards the northwest. Thicknesses vary from 8 to 10 m. Based on petrography, Polkanov distinguished three rock-types: (1) enstatite-augite diabase, (2) olivine-enstatite-augite diabase with a marginal facies which contains glassy basalt, and (3) chloritised glassy diabase. Since the work of Polkanov, there have been no further descriptions of the Sredni and Rybachi dykes in the Russian literature.

Polkanov (1935), for the first time, described dykes of glassy, uralitised, enstatite-augite basalt that intrude the sedimentary rocks of Sredni Peninsula and Cape Vestnik. Polkanov suggested that the dykes found on Cape Vestnik had been involved in tectonic movements. The other mafic dykes, reported by Fieandt (1912) and Polkanov (1936), had not been affected by tectonic deformation, and from this Polkanov argued for a long period of intrusive activity involving at least one major phase of tectonic movements. On Rybachi, dykes of gabbro-diabase have also been observed by the authors.

On Sredni (Kutovaya Bay) (Fig. 2), a 4-6 m-thick, c. N-S trending dolerite dyke, first found by Lyubtsov in 1964, can be followed over a distance of 110 m. According to Sinitsin (1967), the dyke is similar in composition to dolerites of the Neoproterozoic trap formation of the Ivanovskaya Bay on the northeastern coast of the Kola Peninsula. The dyke in Kutovaya Bay

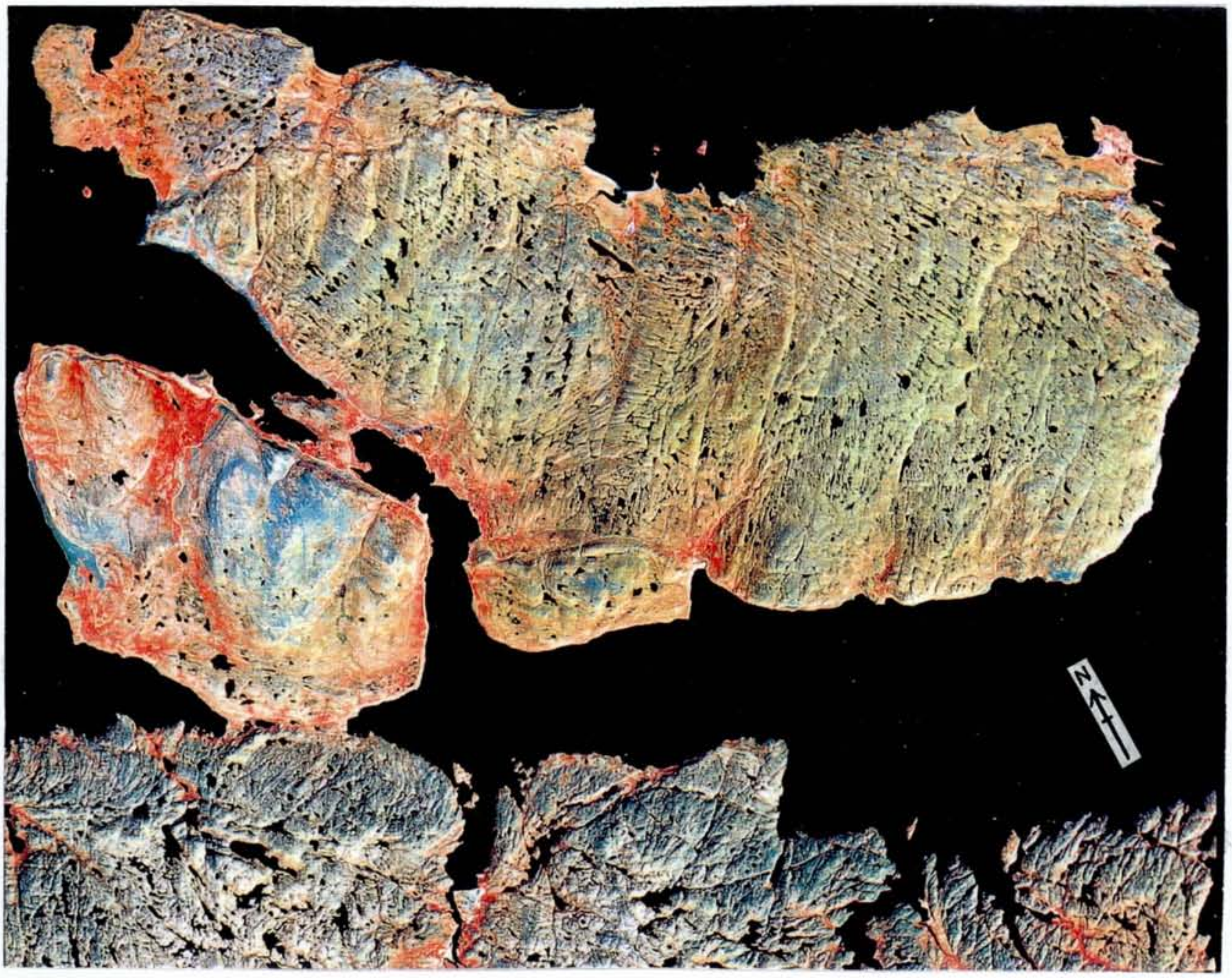

Fig. 3. Landsat 5-TM, colour composite satellite image of the Rybachi and Sredni Peninsulas, and part of the mainland of Kola Peninsula. In this reproduction, the image is reduced to approximately 1: 350,000 scale. Bluish colours represent exposed bedrock; orange-red colours indicate vegetation, mostly heather and some dwarf birch. For technical details, and an explanation of the structural features, see Roberts & Karpuz (1995). For geology and geographical names, see Fig. 2. The c. E-W Mainavolok fault in the northwestern part of Rybachi is easy to trace on the satellite image (cf. Fig. 2).

was dated by the K-Ar method (at the Laboratory for Geochronology of the Geological Institute, Kola Science Centre of the former USSR Academy of Sciences) and yielded an age of 525±20 Ma (Sinitsin 1967). This same dyke has recently been dated by the ^{40}Ar-^{39}Ar laser microprobe method (on pyroxene and plagioclase) and gave a minimum age of 546±4 Ma (Roberts & Onstott 1995). A palaeomagnetic study on this dyke has indicated a probable Vendian age (Torsvik et al. 1995). Another dolerite dyke has been reported from the northwestern part of Sredni and K-Ar dated to c. 600±20 Ma (Bekker et al. 1970a).

In NW Rybachi, several NE-SW-trending dolerite dykes intrude the Skarbeevskaya Formation. The near-vertical dykes are up to 6.5 m thick and clearly transect the NW-SE-trending folds and cleavage. Isotopic dating and palaeomagnetic work on three of these dykes have been reported by Roberts & Onstott (1995) and Torsvik et al. (1995). ^{40}Ar-^{39}Ar laser microprobe mineral analyses were not definitive, indicating only that the dykes are older than Ordovician model ages. A Late Devonian-Carboniferous thermal overprint was also recorded in the data, interpreted by Roberts & Onstott (1995) as relating to the effects of a regional crustal extension, rifting and sedimentation at this time. The palaeomagnetic study, on the other hand, pointed to a probable Late Vendian to Cambrian age for these same dykes (Torsvik et al. 1995).

Finally, it can be noted that Negrutsa (1971) reported the occurrence of two 0.5 m-thick beds of basic tuff within the sedimentary succession of the Kildinskaya Group on Sredni. These tuff layers were not located during the recent Russian-Norwegian collaborative fieldwork.

2.5 Correlations

The true stratigraphic relationships between the Kildinskaya, Volokovaya and Einovskaya Groups of the Sredni and Rybachi Peninsulas can be established on the basis of a comparison with successions on the Varanger Peninsula in Norway. There, mapping carried out by geologists from NGU has shown that a stratigraphic analogue of the Rybachi complex – the Kongsfjord Formation – is exposed in the cores of anticlines and is surrounded and overlain by successions that can be correlated with the sedimentary rocks of the Kildinskaya and Volokovaya Groups. Specifically, this is true for the Persfjord district in the northeastern part of Varanger Peninsula. The following succession of groups can thus be suggested for the Neoproterozoic in the northwestern part of the Kola Peninsula; in ascending order, Einovskaya – Bargoutnaya – Kildinskaya – Volokovaya.

Formations of the Kildinskaya Group also occur on Maly Aynov (Kheinya Sari) Island as well as on Kildin (Fig. 2). The sedimentary successions developed in other parts of Kola along the coasts of the Barents and White Seas are considered to have a similar Riphean age. In the section along the river Chapoma (Fig. l), there are red sedimentary rocks with pseudomorphs of salt and gypsum. These rocks are analogous to those in the Karuyarvinskaya Formation at the top of the Kildinskaya Group, and are rich in Riphean-Vendian microphitolites (Konoplyova & Fanderflit 1979).

The Tersky Formation along the White Sea coast and sedimentary rocks on Cape Tury (altered at the contact with an alkaline massif) can also be correlated with the Kildinskaya Group (Sergeeva et al. 1971). However, in this case the assumption of a late-Middle Riphean (Tersky Formation) and early-Middle Riphean (Cape Tury) age seems to be more acceptable (Negrutsa 1971, Lyubtsov et al. 1989). These sequences are lithologically similar to the

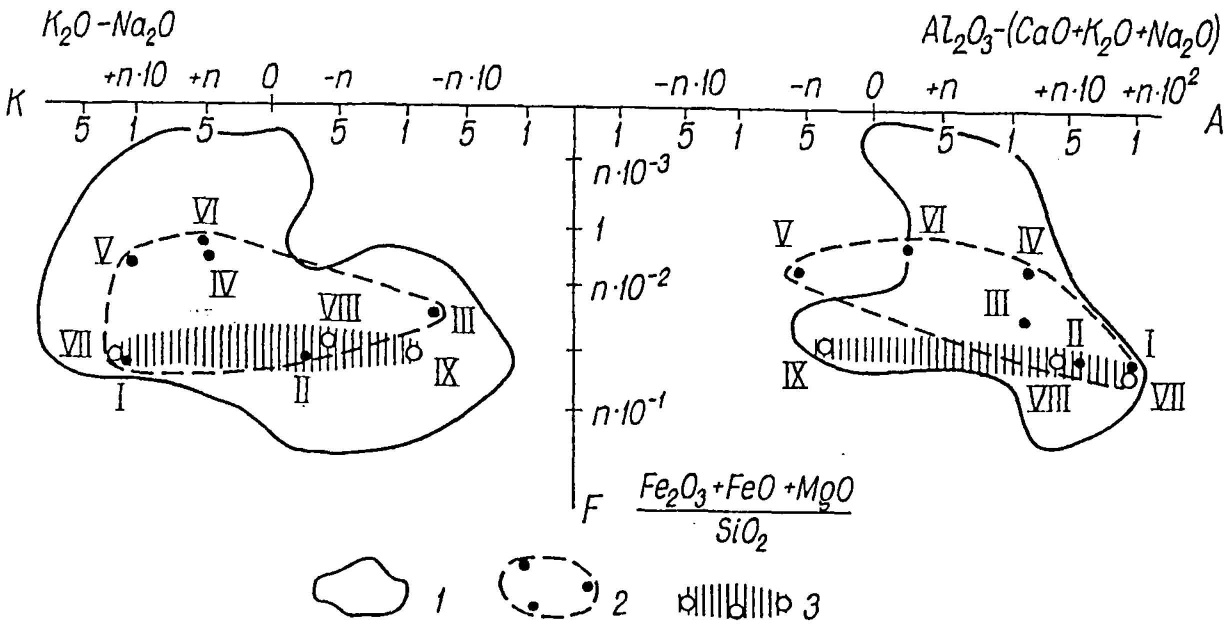

Fig. 4. Composition fields for the aluminosilicate sedimentary rocks of the Bargoutnaya (Upper Riphean ?) Group, the rocks of the Kildinskaya and Volokovaya (Upper Riphean) Groups, and the rocks of the Palaeoproterozoic Karelian Complex of the Kola region on the 'basicity (F) - relative aluminiferousness (A) - alkali ratio (K)' diagram (Predovsky 1980), calculated on the basis of formula coefficients, according to the mean compositions of typical rock groups.

1 – compositional field of the Palaeoproterozoic metasedimentary rocks of the Karelian Complex;

2 -- composition fields and points for the rocks of the Kildinskaya and Volokovaya Groups: I – mudstone, II – greywacke, III – subgreywacke, IV – arkose, V - feldspar-quartz sandstone, VI – quartzite.

3 -- composition fields and points for the rocks of the Bargoutnaya Group: VII – mudstone, VIII – greywacke, IX – subgreywacke.

Salminskaya Formation in southern Karelia and to the Jotnian in Finland, which formed in the interval between 1650 and 1200 Ma. Features common to all these sedimentary rocks are their continental character and occurrence in isolated grabens, and the weak chemical weathering of the parental rocks. The Upper Riphean rocks of the Kildinskaya Group are distinguished by their higher degree of sedimentary maturity which included the accumulation of oligomictic and quartz-cemented sandstone.

In summary, we can conclude that the Neoproterozoic sedimentary successions in the coastal areas of the Kola Peninsula are of Late Riphean (1050±50 - 680±20 Ma) age. The possibility of a Vendian (650±20 - 540 Ma) or Middle Riphean (older than 1050±50 Ma) age for some of the younger or older formations requires further investigation.

2.6 Sedimentary geochemical parameters

In the present report the authors use the translated terms 'stability' (stabilisation) and 'activity' (activisation) in referring to tectonic regimes of sedimentation. This means that an increase of tectonic activity in the provenance and accumulation areas results in increased rates of sedimentation, an increase in the processes of admixture of different materials, and an increase in the relative proportion of immature, mostly terrigenous, siliciclastic sediments. Alternatively, when the regime is stabilised, sedimentation rates decrease, the degree of maturity of sediments increases, and highly differentiated products, i.e. clay, quartzites and chemical precipitates, are more important. The sedimentary rocks from both regimes have specific petrogeochemical characteristics. It is therefore possible to interpret the stability, or activity of tectonic environments by studying the average maturity of sediments and quantifying the relative proportions of major elements. This approach has been attempted earlier (Predovsky 1970, 1980), and in this report we make use of these concepts and parameters.

The classification of sedimentary rocks used here is that of Predovsky (1970, 1980). The nomenclature has parallels with other classifications of sedimentary rocks. It involves, however, quantitative geochemical criteria in addition to texture and mineralogy.

The geochemical parameters of sedimentary rock composition adopted in our classification are:

$$F = \frac{Fe_2O_3 + FeO + MgO}{SiO_2}$$

$$A = Al_2O_3 - (K_2O + Na_2O + CaO)$$

$$K = K_2O - Na_2O$$

Parameter F represents the basicity (or femicity) of rocks of aluminosilicate-rich type. Among clastogenic sedimentary rocks, high F values are found in some mixed, immature sediments, polymictic sediments and in those associated with basic volcanism, and lowest values in quartz-rich varieties (quartzites, quartz-andesites). Sedimentary rocks with high contents of heavy clastic minerals (e.g., magnetite, ilmenite, haematite) and diagenetic iron sulphides

Table 1. A general classification of sedimentary rocks as used in this report.

Procedure	Examples and explanation
1. Subdivision on the basis of the medium in which the rock originated, and the determining energy source at the major stage of formation	Sedimentary rocks are considered to be exogenic and are subdivided into eluvial and sedimentary
2. Types of sedimentary rocks are distinguished on the basis of the main features of their chemical composition	Aluminosilicate, carbonate, phosphate, sulphide, sulphate, ferruginous, etc. rock types
3. Subtypes are distinguished on the basis of the mechanism of transport and accumulation, that determines their rock texture.	Clastogenic, clayey, chemogenic, etc.
4. Classes are distinguished on the basis of major compositional properties and the ratio of major chemical components	For clastic sedimentary rocks, for example, these are quartz monomict, arkose, subgreywacke, greywacke
5. Subclasses are distinguished on the basis of textural properties	E.g., coarse grained (conglomerate, etc.), sandstone, siltstone
6-8. Groups, subgroups, varieties and subvarieties are subsequently distinguished on the basis of textural and compositional characteristics	

Note: In addition, series can be distinguished as a separate element of classification of sedimentary rocks. Series are distinguished by evaluating the influence of synchronous and preceding processes of weathering, redeposition and volcanism upon the sedimentation. There are purely *terrigenous series*, where rock assemblages are generated after the weathering and redeposition of eluvium; and *volcanogenic-sedimentary series*, where the rock association is derived from volcanic material (including explosive material).

cannot be classified using this F parameter. In the case of parameter *A*, CaO is the molecular amount of lime minus molecular amount of CO_2 in cases where a carbonate admixture is present. Parameter *K* is calculated also in molecular amounts.

Conceptually, other parameters can also be used. In our classification we calculate the 'component ratio' in molecular values, which seems to provide the most reproducible illustrative diagrams plotted on the basis of the calculated parameters.

Application of geochemical parameters in the classification of sedimentary rocks (as is common when classifying magmatic rock types) is important, since it makes it possible to achieve at least four objectives:

- to develop quantitative boundary criteria in the general systematic classification (i.e. to obtain compatible and reproducible results);
- to describe and compare not only certain sedimentary rock types, but also their associations;
- to develop quantitative criteria for processes of sedimentary rock formation, and the evolution of these processes in time and space;
- to develop a quantitative basis for a comparative analysis of the compositions of diverse associations of volcano-sedimentary rocks.

The described approach is illustrated in Table 1. The table shows that one of the most significant points in the classification of the sedimentary rocks is to distinguish and describe rock classes. This is made by calculating either their mineralogical or their geochemical parameters. In this case, rock basicity is a fundamental parameter for aluminosilicate-bearing lithologies.

The three parameters can be used to plot a ternary diagram, along the margins of which it is possible to indicate the ratio of certain rock associations of arenaceous and clayey rocks. In addition, the compositional parameters can be used for the quantitative estimation of sedimentary maturity and for the assessment of some other sedimentary characteristics (Fig. 4).

The above geochemical parameters, as well as some others, can be applied in the classification of both arenaceous and clayey rocks, which can also be subdivided into classes based on basicity. An increasing basicity is represented by the following series: kaolinite clay – hydromicaceous and montmorillonite clay – chlorite-bearing clay enriched with femic components.

2.7 Hydrocarbon potential

It should be mentioned that parts of the Neoproterozoic sedimentary successions of the northwestern Kola Region are not without interest in terms of hydrocarbon potential. A separate chapter in this report is reserved for a discussion of all the available data. The sedimentary rocks of the Kildinskaya Group are characterised by a low metamorphic grade of organic matter (low ratio of methane to heavy hydrocarbons) and an epigenetic type of hydrocarbon distribution. Alternation of sandstone with shale and carbonate rocks, and a sufficiently high effective porosity of the sandstones make the diagenesis-grade Kildinskaya Group an interesting target, particularly because of its probable subsurface continuation into the Barents Sea trough (Fig. 1) beneath Phanerozoic accumulations. Dorogan-Sushcheva et al.

(1997) emphasized that a study involving a combination of DSS (deep seismic section) and an integrated refraction survey showed the presence of 0.7 to 13 km-thick Riphean successions in depressions and troughs of the Barents-Kara shelf. A detailed geophysical interpretation of this data is presented in Verba et al. (1998, see Fig. 8.1 – p. 42, Fig. 8.13 – p.68).

3. DESCRIPTION OF SECTIONS

3.1 Sredni Peninsula

KILDINSKAYA GROUP

The most complete section of the Kildinskaya Group (Mattivuono, according to Lupander (1934)) occurs on the Sredni Peninsula (Figs. 2 & 5). It rests unconformably on the basement granitoids and is overlain sharply by the Volokovaya Group (Pumanka according to Lupander (1934)). Negrutsa (1971) subdivided the Kildinskaya Group into five mappable formations (in ascending order): Pyarayarvinskaya (Kutovaya and Iernovskaya, according to Lyubtsov (1975)), Palvinskaya, Poropelonskaya, Zemlepakhtinskaya and Karuyarvinskaya.

3.1.1 Kutovaya Bay

In the westernmost part of Kutovaya Bay (Fig. 2), 200 m north of elevation point 22.1, west of the road, the basal sedimentary rocks of the Kildinskaya group are lying unconformably upon the granitoid basement. The first descriptions of this contact were presented by Boetlingk (1830), who considered the contact to be stratigraphic and at the same time reported fragments of red granite in the basal sandstone. Ramsay (1897-1899), while generally supporting the conclusions of Boetlingk, pointed out that the sandstone of this basal succession on Sredni is adjacent to the basement granite and thus suggested the presence of a possible fault between the Sredni and Kola Peninsulas. The same point of view was shared by Fieandt (1912) and Polkanov (1934a). An argument forwarded by Polkanov in favour of a fault contact between the basement granite and the Neoproterozoic sedimentary succession was that the sedimentary rocks of Sredni are stratigraphically higher than the rocks of Rybachi.

Geological mapping of Sredni and Rybachi conducted in 1948 by Agapjev and Vronko (Lyutkevich & Kharitonov 1958) allowed Agapjev to reach a different conclusion about the nature of this important contact. He found erosional pockets filled with 'Sredni sandstone' in the crystalline rocks of the contact zone, thus confirming the unconformity interpretation. Later, Lyutkevich & Kharitonov (1958) examined the contact and reported that the sedimentary rocks of the Sredni Peninsula rest unconformably and transgressively upon weathered rocks of the deformed pre-Neoproterozoic basement. The area was surveyed by Vladimir Negrutsa in 1960, and the actual contact at this important locality was subsequently stripped and exposed. Unsorted, coarse-grained, quartz-feldspar sandstones of the Kutovaya Formation occur in small depressions in the granitoid basement. The thick-bedded sandstones, which contain small, and some large (up to 30 cm), angular fragments of granitoid and gneissic rocks, exhibit cross-bedding. They are interlayered with current-rippled siltstones containing rare granite pebbles. In later years, additional information about the contact was

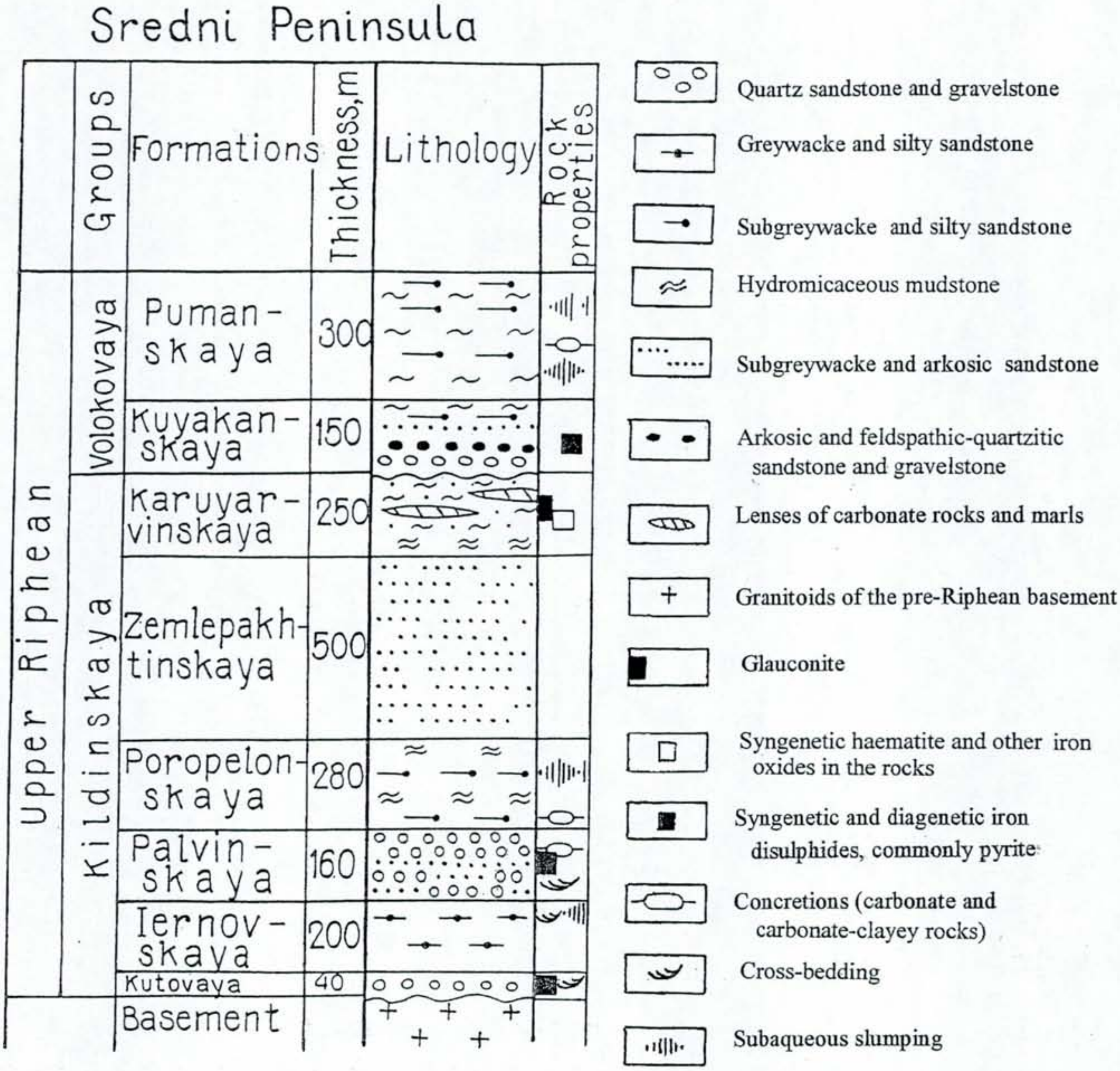

Fig. 5. Stratigraphy of the Neoproterozoic rocks of Sredni Peninsula.

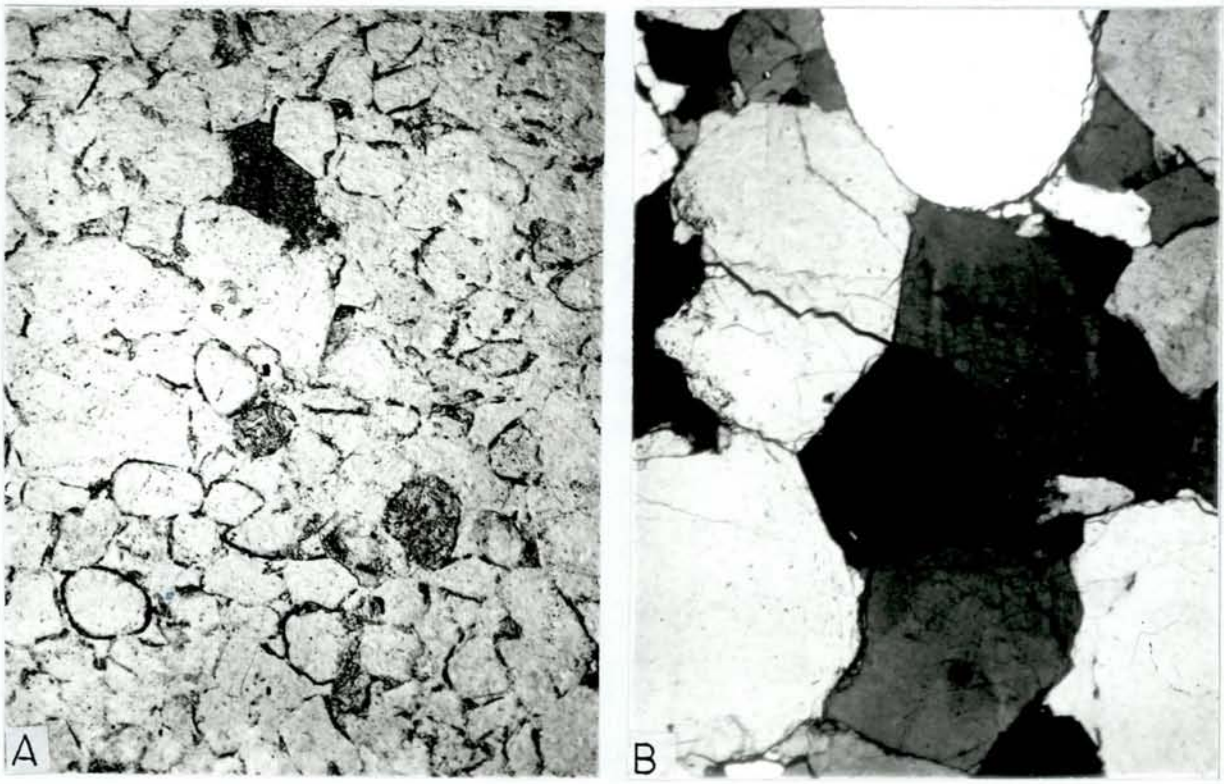

Fig. 6. (A) Coarse-grained, feldspathic, quartzitic sandstone from the basal part of the Kutovaya Formation; poorly rounded and angular grains, with hydromicaceous material along the contacts between the grains and in the porous cement (Sample 731-3). (B) Typical texture of coarse-grained, quartz-rich sandstone (Sample 731-9). The heights of the photomicrographs are -- in (A) 2.6 mm, in (B) 1.3 mm. Crossed nicols.

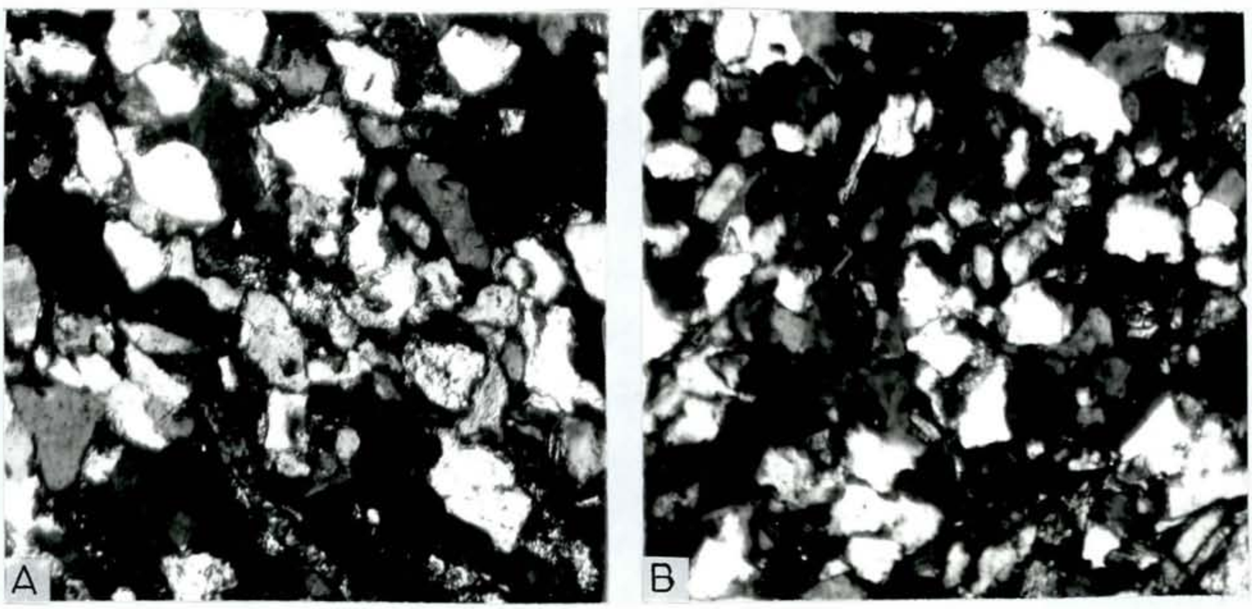

Fig. 7. (A) Typical fine-grained greywacke from the basal part of the Iernovskaya Formation showing angular grains, rock fragments and hydromicaceous cement (Sample 731-14). (B) Fine-grained greywacke from the middle part of the Iernovskaya Formation, with fragments of muscovite and ferromagnesian mica (Sample 731-18). The width of each photomicrograph is equivalent to 2.0 mm. Crossed nicols.

Table 2. Typical examples of chemical compositions (wt.%) of Neoproterozoic sedimentary rocks from the Sredni Peninsula and Kildin Island (in ascending stratigraphic order, from left to right).

Sample	731-15	731-5	731-27	262-32	8/4	102-1	761-5	106-7	732-19
SiO_2	69.31	87.92	98.12	55.00	4.80	54.80	6.51	81.00	86.65
TiO_2	0.67	0.11	-	0.92	0.06	0.60	0.32	0.75	n.d.
Al_2O_3	11.90	3.05	0.24	20.80	1.00	17.00	1.51	8.20	3.90
Fe_2O_3	0.97	0.22	-	2.72	0.62	8.25	0.24	1.75	1.48
FeO	4.67	2.12	0.81	5.18	3.49	1.68	0.39	1.47	n.d.
MnO	0.02	0.09	0.01	0.03	0.40	0.01	0.01	0.03	n.d.
MgO	2.27	1.23	0.13	2.47	18.35	4.11	1.85	0.71	0.18
CaO	0.74	1.31	0.16	0.22	28.27	1.98	48.08	0.22	2.55
Na_2O	2.54	0.09	0.02	1.11	0.16	1.70	0.10	1.13	n.d.
K_2O	3.46	1.38	0.04	4.68	0.21	3.32	0.29	3.32	n.d.
H_2O^+	0.05	0.01	0.04	0.09	-	0.09	0.10	0.08	n.d.
H_2O^-	2.29	0.98	0.20	4.30	0.60	4.14	0.95	0.66	n.d.
P_2O_5	0.16	0.06	0.06	n.d.	0.02	n.d.	0.01	n.d.	n.d.
CO_2	0.39	1.70	-	n.d.		n.d.	38.69	n.d.	n.d.
L.o.i.	n.d.	n.d.	n.d.	1.28		2.30	-	n.d.	n.d.
Total	99.47	100.29	99.84	99.79		100.19	99.60	99.32	n.d.
F	0.111	0.042	0.008	0.192		0.194		0.036	n.d
A	+31	+12	-2.7	+132		+69		+23	n.d.
K	-3	+13	+0.3	+32		+8		+17	n.d.

Notes: n.d. – not determined
731-15 - greywacke; Iernovskaya Fm., Sredni Peninsula, eastern coast of Malaya Volokovaya Bay.
731-5 - quartz sandstone with carbonate-hydromicaceous material in the cement; Kutovaya Fm., Sredni Peninsula, east coast of Malaya Volokovaya Bay.
731-27 – typical pure quartz sandstone of the Palvinskaya Fm., southwestern Sredni Peninsula.
262-32 - claystone which originally represented hydromicaceous clay, Korovinskaya Fm., Kildin Island.
8/4 - dolomite; Korovinskaya Fm., Koroviy Cape, Kildin Island.
102-1 - red-coloured, haematite-bearing claystone which originally represented a hydromicaceous clay with minor carbonate admixtures; from the upper part of the Bezymyannaya Fm., Kildin Island.
761-5 - limestone, Chernorechenskaya Fm., (lower member), Kildin Island.
106-7 - arkosic sandstone, upper beds of the Pridorozhnaya Fm., Kildin Island.
732-19 - quartz gravelstone, lower part of the Volokovaya Group, Sredni Peninsula, Bolshaya Volokovaya Bay.

All the compositional parameters are given according to the techniques proposed by Predovsky (1970, 1980).

reported by Negrutsa (1971) and Lyubtsov et al. (1978, 1990), which generally supported the conclusions of Agapjev and Vronko (in Lyutkevich & Kharitonov 1958).

The morphology of the pre-Kildinskaya erosional surface and the layering of the sediments filling the depressions indicate an uneven relief of this basement surface at the time of sedimentation. In the area from Kutovaya Bay, along the contact, to Malaya Volokovaya Bay, exposures of basal layers of the Kildinskaya Group and the basement granite are observed in many places. In one area, the basal units of the Kutovaya formation are transected by a c. N-S-trending gabbro-diabase dyke, which was traced by Lyubtsov on the northeast side of Kutovaya Bay in a small river valley, 1 km east of elevation point 128.6 and 900 m upstream from the mouth of the stream. As mentioned in chapter 2.4, this particular dyke has yielded a whole-rock K-Ar age of 525±20 Ma (Sinitsin 1967) and a ^{40}Ar-^{39}Ar minimum age of 546±4 Ma (Roberts & Onstott 1995).

3.1.2 Malaya Volokovaya Bay

This profile is along the southwestern coast of the Sredni Peninsula. In the tidal zone north of the mouth of an unnamed creek running from the east to the Malaya Volokovaya Bay, and on hill slopes, the sedimentary rocks of the Kutovaya, Iernovskaya and Palvinskaya Formations dip gently (5°-12°) northwards.

Kutovaya Formation. This is the first exposed formation in the Kildinskaya Group section, and was named after its geographical location (Figs. 2 & 5). Lithologies of this formation can be examined in the southern part of Sredni Peninsula, in the area of Kutovaya Bay. Here, the microcline-plagioclase granite of the pre-Riphean basement shows evidence of moderate pre-Kildinskaya weathering: feldspars are partially decayed and mafic minerals are oxidised. Previous researchers distinguished this part of the section as a member of a larger formation. The lithologies reflect an initial stage of sedimentation which was considerably different from the subsequent stages; the differences are ascribed to a stabilisation of the tectonic regime, manifested in a gradually higher maturity of the original sediments. The thickness of the formation is 40 m.

The formation consists predominantly of quartz- and feldspar-rich rocks. The most typical lithologies are poorly sorted and texturally immature, fine- to medium-grained, quartz and feldspathic sandstones (Fig. 6). Most of the sandstones are pale grey, greenish-grey or bluish-grey in colour. The lowermost part of the formation contains fine-grained hydromicaceous material in the porous cement, which is replaced by carbonate (commonly dolomite) and glauconite higher up the section. Resedimented quartz grains bear relict evidence of original roundness, marked by fine ferric oxides. Accessory minerals include well-rounded grains of zircon, tourmaline and apatite. Some interbeds contain minor amounts of gravel and fine-pebble quartz material. In rare cases, the cement of the sandstones is enriched in pyrite, which is generally oxidised. The oxidation of the pyrite causes an irregular, spotted, brown and red coloration of such interbeds. A typical example of the composition of a quartz-rich Kutovaya sandstone is given in Table 2 (Sample 731-5).

The formation also contains subordinate quartz-rich siltstone with glauconite. In the literature, the Kutovaya glauconites are reported to fall into two age groups, as indicated by K-Ar age determinations: 1059-1040 Ma (Keller et al. 1963) and 865-762 Ma (Bekker et al. 1970a). The Kutovaya fluvial sandstones commonly have horizontal bedding or uni-directional cross-

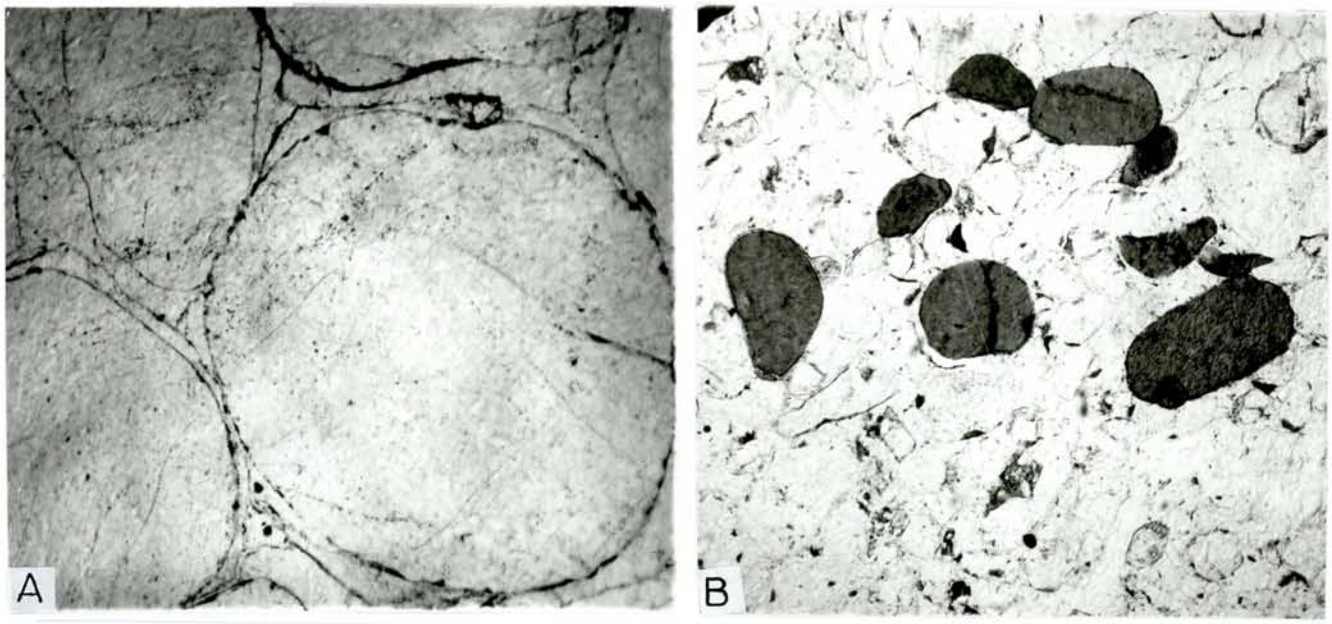

Fig. 8. (A) Regenerated, rounded grains of quartz and coarse-grained quartzitic sandstone from the middle part of the Palvinskaya Formation of the Sredni Peninsula (Sample 731-30). (B) Glauconite in medium- to fine-grained quartzitic sandstone (Sample 731-40). The widths of the photomicrographs are – in (A) 1.1 mm, in (b) 1.4 mm. Plane polarised light.

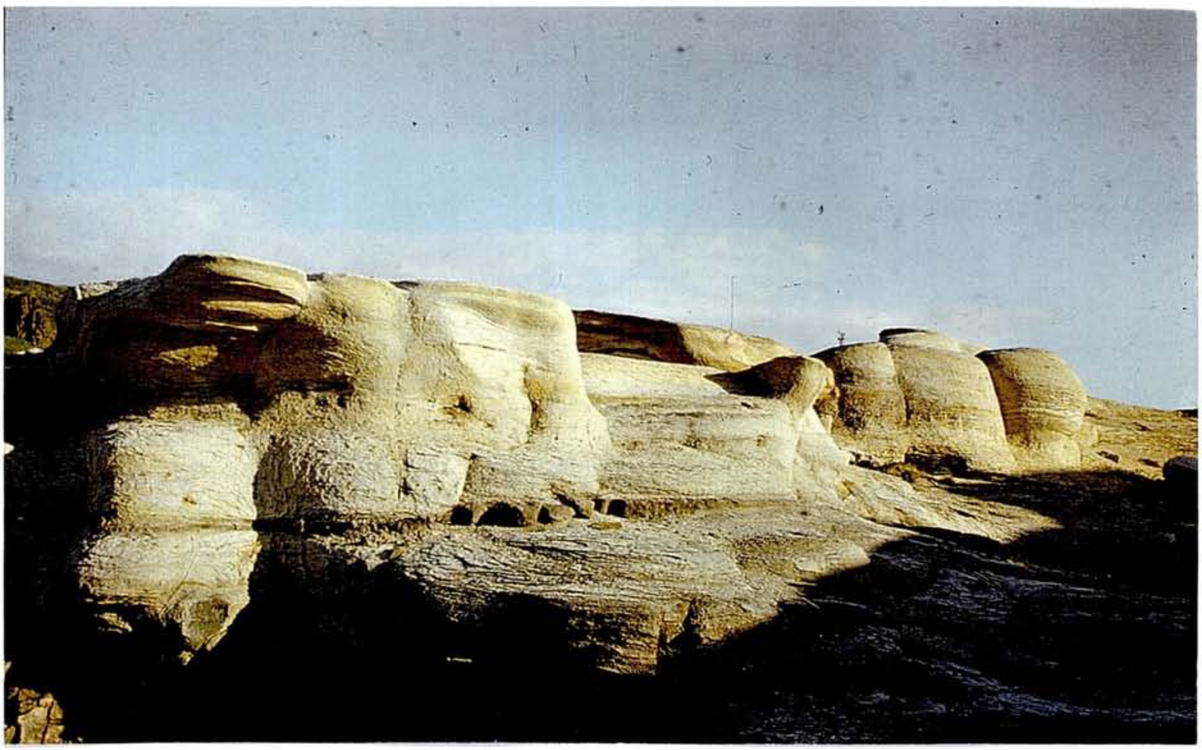

Fig. 9. Smoothly rounded, weathering forms in sandstones of the Zemlepakhtinskaya Formation, Kildinskaya Group; northwestern coast of Sredni Peninsula. The prominent dark layer represents a placer rich in leucoxene, with a high content of TiO_2. Similar titanium-rich interbeds are locally quite common in this formation. Photo: V.V.Lyubtsov.

Table 3. Typical examples of chemical compositions of mudstones from the Kildinskaya Group (wt.%).

Sample no.	731-22	262-32	102-1b	262-85	731-53a
SiO_2	57.22	55.0	54.80	51.80	56.87
TiO_2	0.76	0.92	0.60	0.79	0.61
Al_2O_3	16.00	20.80	17.00	17.70	17.98
FeO	2.87	2.72	8.25	8.67	5.25
FeO	7.83	5.18	1.68	1.21	1.99
MnO	0.02	0.03	0.01	0.18	0.26
MgO	3.17	3.47	4.11	3.71	2.66
CaO	0.29	0.22	1.98	2.75	0.21
Na_2O	2.10	1.11	1.70	1.89	1.00
K_2O	3.76	4.68	3.32	3.41	3.56
P_2O_5	0.04	0.09	0.09	0.12	0.08
H_2O+	4.64	4.30	4.14	2.74	6.39
H_2O-	0.68	n.d.	n.d.	n.d.	2.33
CO_2	0.03	n.d.	n.d.	2.20	n.d.
L.o.i.	n.d.	1.28	2.30	2.04	n.d.
Total	99.43	99.79	100.19	99.27	99.23
F	0.216	0.192	0.194	0.189	0.135
A	+78	+132	+69	+84	+119
K	+6	+32	+8	+5	+22

Sample characteristics and formation name:-
731-22 - mudstone which originally represented hydromicaceous clay with siltstone, Iernovskaya Formation, Sredni Peninsula.
262-32 - mudstone which originally represented hydromicaceous clay, Korovinskaya Formation, Kildin Island.
102-1b - red haematite-bearing mudstone which originally represented hydromicaceous clay with minor carbonate admixtures, top part of the Bezymyannaya Fm, Kildin Island.
262-85 - red haematite-bearing mudstone which originally represented hydromicaceous clay with carbonate, bottom part of the Pestsovozerskaya Fm, Kildin Island.
731-53a - red mudstone which originally represented hydromicaceous clay, top part of the Pestsovozerskaya Fm, Kildin Island.
n.d. -- not determined

bedding and ripple marks, with fining-up cycles developed (Siedlecka et al. 1995a), and also show evidence of subaqueous erosion.

Iernovskaya Formation. This next formation rests on the Kutovaya Formation with a concordant, transitional contact, and is exposed in map plan as a c. E-W strip in the southwestern part of Sredni. The total thickness of the formation is 200 m.

Accumulation of the deposits of this formation is related to a stage of activation of the tectonic regime, as evidenced by the rock composition. The formation consists mostly of dark grey, green-grey and pale grey sandstones. Medium- and fine-grained greywacke and glauconitic sandstones predominate (Fig. 7, Table 2, Sample 731-15), and arkoses are subordinate. In the series from arkose to greywacke, the number and volume of rounded, sand-sized, micro-quartzitic and chlorite-bearing rock fragments, and fragments of biotite, muscovite and chloritised femic minerals, increases. The bulk of the detrital grains comprise quartz, K-feldspar and plagioclase. Glauconite is also common. The cement consists of altered clayey material, and its amount and basicity (biotite and chlorite contents) is markedly increased in the greywackes. Typical accessory minerals are fine clastic magnetite, leucoxene, zircon, tourmaline and apatite. Locally, a spotted carbonate cement is present.

The uppermost part of the Iernovskaya Formation contains dark grey and brownish-grey mudstones (which were primarily hydromicaceous) and weakly metamorphosed silty pelites (Table 3, Sample 731-22). The greywackes of the Kildinskaya Group are generally distinguishable in several respects, described below, a feature which was evidently caused by the mixing of relatively mature sediments of varied composition. The rock characteristics indicate that the sedimentation rate was quite high.

Sandstones of the Iernovskaya Formation are characterised by cross-bedding, various types of ripple marks (including oscillation ripples with the distance between ridges up to several tens of centimetres) and slumping. Some sandstone beds show spectacular ball-and-pillow structures. From bottom to top, the proportion of horizontally bedded and thin-bedded sandstones increases. This may indicate that the sedimentation rate diminished towards the end of the period of accumulation of the Iernovskaya Formation.

The section through the formation is terminated by alternating, black, thin-bedded siltstone, pale grey to bluish, cross-bedded sandstone and dark grey, thin-bedded, rippled sandstone with desiccation cracks. Carbonate concretions are present in the sandstones.

In terms of sedimentary facies and depositional environment, the lower part of the Iernovskaya Formation is of transgressive character and is interpreted as fluvial to coastal marine, accumulated in a high-energy environment (Siedlecka et al. 1995a). The upper part is interpreted as a prograding deltaic succession.

Palvinskaya Formation. This formation, which is 260 m thick, occurs in the southwestern and southern parts of the Sredni Peninsula in the area of Lake Palvi. The formation rests with a sharp but concordant contact on the Iernovskaya sandstones.

The Palvinskaya Formation consists of beds of massive, dense, weathered, white to pale grey and yellowish-grey, coarse-grained, cemented quartzites and quartz sandstones (Fig. 8, Tables 4 & 5, Sample 731-27), which are characterised by high silica contents, a high degree of roundness of the quartz grains, and carbonate and glauconite in the cement (Fig. 8). In this context, the quartzites are notable for being the purest among the quartz-rich rocks of the

Table 4. Chemical compositions of samples of typical sedimentary rocks from the upper part of the Kildinskaya Group, and a sandstone from the Pechenga region.

Sample no.	3075	731-27	731-15	7-4	Pg-1
SiO	62.78	98.12	69.31	51.20	64.96
TiO_2	0.78	-	0.67	0.60	1.04
Al_2O_3	16.00	0.24	11.90	16.50	11.46
Fe_2O_3	2.42	-	0.97	7.89	1.97
FeO	4.14	0.81	4.67	1.00	7.71
MnO	0.04	0.01	0.02	0.35	0.05
MgO	1.94	0.13	2.27	4.65	2.84
CaO	0.63	0.16	0.74	4.73	1.52
Na_2O	2.51	0.02	2.54	1.48	3.20
K_2O	3.45	0.04	3.46	2.88	2.30
H_2O+	0.26	0.04	2.29	0.09	n.d.
H_2O-	3.77	0.20	0.16	4.54	1.42
P_2O_5	0.48	0.06	0.05	n.d.	0.23
CO_2	-	-	0.39	2.00	0.40
L.o.i.	0.07	n.d.	n.d.	1.64	2.73
Total	99.27	99.84	99.47	99.55	99.78
F	0.114	0.008	0.111	0.180	0.170
A	+70	-2.7	+31	+46	+14
K	-4	+0.3	-3	+7	-27

3075 - silty pelite, originally hydromicaceous, from the variegated rocks at the top of the Slantsevozerskaya Formation, Sredni Peninsula.
731-27 - typical pure quartz sandstone of the Palvinskaya Formation, SW Sredni Peninsula.
731-15 - greywacke sandstone, Iernovskaya Formation, Sredni Peninsula.
7-4 - unusual greywacke sandstone, middle part of the variegated Chernorechenskaya Formation, Kildin Island.
Pg-1 - greywacke metasandstone from the fourth sedimentary unit of the northern part of the Pechenga synclinorium; from the rock collection of Predovsky and Akhmedova.
n.d. – not determined.

Table 5. Chemical compositions of representative quartz-rich clastic rocks of the Kutovaya and Palvinskaya Formations of the Kildinskaya Group, and the Kuyakanskaya Formation of the Volokovaya Group.

Sample no.	731-5	731-27	731-28a	732-19
SiO_2	87.92	98.12	83.09	86.65
TiO_2	0.11	-	0.24	n.d.
Al_2O_3	3.05	0.24	5.07	3.90
Fe_2O_3	0.22	-	2.52	1.48
FeO	2.12	0.81	3.35	n.d.
MnO	0.09	0.01	0.01	n.d.
MgO	1.23	0.13	1.45	0.18
CaO	1.31	0.16	0.18	2.55
Na_2O	0.09	0.02	0.09	n.d.
K_2O	1.38	0.04	1.08	n.d.
H_2O+	0.01	0.04	0.42	n.d.
H_2O-	0.98	0.20	2.46	n.d.
P_2O_5	0.06	0.06	0.004	n.d.
CO_2	1.70	-	0.003	n.d.
L.o.i.	n.d.	n.d.	0.01	n.d..
Total	100.29	99.84	99.98	n.d.
F	0.042	0.008	0.00	n.d.
A	+12	-2.7	0.00	n.d.
K	+13	+0.3	0.01	n.d.

731-5 - quartzitic sandstone with carbonate-hydromicaceous cement, Kutovaya Formation, Sredni Peninsula., eastern coast of Malaya Volokovaya Bay.
731-27 - pure quartzite, Palvinskaya Formation, southwestern part of Sredni Peninsula.
731-28a - quartzitic sandstone, Palvinskaya Fm, southwestern part of Sredni Peninsula.
732-19 - quartzitic gravelstone, bottom part of the Volokovaya Group, Sredni Peninsula, Bolshaya Volokovaya Bay.
n.d. – not determined.

Kildinskaya and Volokovaya Groups on the Sredni Peninsula (Table 5). The uppermost part of the formation, where it was not eroded prior to deposition of the next formation, consists of variegated oolitic beds, layers of dolostone and some clayey shales (Siedlecka et al. 1995a).

The texturally mature quartzite beds form conspicuous benches in the topography, and can easily be traced along strike over long distances. The bedding surfaces are uneven and have gigantic ripples. In the lower part of the lowermost quartzitic bed, fragments of a subjacent sandstone are present. Many of the sandstone beds display herring-bone cross-bedding. In the upper part of the formation, quartzitic beds contain sericite and pyrite in the cement, and the content of glauconite is higher than in the lower part. K-Ar dating of glauconite from the lower, middle and upper parts of the Palvinskaya Formation has yielded ages of 730±14, 670±12 and 619±12 Ma, respectively (Bekker et al. 1970a).

Within this coastal section, twelve beds of quartzite varying in thickness from 1.0 to 6.0 m are alternating with thin interbeds of greenish-grey, thin-bedded, cross-bedded sandstones which contain lenses of phyllitic shale, quartz-rich, coarse-grained, cross-bedded sandstone, siltstone with interbeds of gravelstone, fine-pebble conglomerate, and layers with carbonate-ferruginous concretions. Weathered quartzite from the third and sixth beds from the bottom is dark grey on fresh surfaces, whereas the beds are red-brown in colour; this can be accounted for by a higher content of hydrous ferric oxides generated due to pyrite oxidation and the presence of carbonate. The section (30 m) through the formation terminates with an interbanded dark grey, thin-bedded, silty pelite and subordinate pale grey, wavy, thin-bedded sandstone.

A tentative interpretation of this formation is that it represents coastal beaches and, possibly, aeolian dunes which may have formed a series of prograding barrier ridges with interridge mud-sand flats (Siedlecka et al. 1995a).

We have correlated the Palvinskaya Formation of Sredni with the Korovinskaya, Bezymyannaya and Chernorechenskaya Formations of Kildin Island (Lyubtsov et al. 1978). The lithostratigraphic correlation was based on the following features:
(1) Stratigraphically, the Palvinskaya Formation and the correlated formations occur beneath the Poropelonskaya Formation of Sredni and the Pestsovozerskaya Formation of Kildin. The Poropelonskaya and Pestsovozerskaya Formations have lithologically much in common, and have been correlated by several workers (Negrutsa 1971, Lyubtsov et al. 1989).
(2) The Palvinskaya Formation, as well as the correlative formations of Kildin Island, contains products of sedimentary differentiation: quartz-rich sandstone, carbonate-bearing sediments and carbonate rocks. Carbonate-bearing rocks are present mostly in the Palvinskaya Formation on Sredni, whereas on Kildin both dolomite and limestone occur mostly in the Korovinskaya and Chernorechenskaya Formations.
(3) The correlated sedimentary sequences are inhomogeneous, i.e. they contain alternating beds of diverse composition.
(4) The twelve prominent beds of quartz-rich sandstone (quartzite) in the Palvinskaya Formation can be correlated with about the same number of carbonate beds in the Korovinskaya-Chernorechenskaya Formations. Despite this marked lithological difference, the correlated formations seem to have formed under quite stable tectonic conditions with lower rates of supply of terrigenous material from the provenance area, and this resulted in a higher degree of differentiation of the sediment. At the same time, sedimentation conditions in areas where the Palvinskaya and Korovinskaya-Chernorechenskaya Formations accumulated were different.

Negrutsa (1971) distinguished an upper member, 45 m thick, within the Palvinskaya Formation, which consists of red and variegated mudstone and sandstone. Negrutsa pointed out that the rocks of this upper member are not widely exposed. Taking this observation (Negrutsa 1971) into account, the proposed correlation between the sedimentary successions of the Sredni Peninsula and Kildin Island gains support, for the rocks of the upper parts of the Palvinskaya Formation on Sredni contain variegated and red rocks analogous to those in the Bezymyannaya and Chernorechenskaya Formations of Kildin. We would like to add here that the abundant, silica-rich, quartzitic sandstones of the Kildinskaya Group (Palvinskaya Formation) and Volokovaya Group (Kuyakanskaya Formation) on Sredni represent promising targets as a flux and industrial raw material (Lyubtsov & Predovsky 1983).

Poropelonskaya Formation. This formation rests with an erosional, unconformable contact upon different parts of the Palvinskaya Formation (Siedlecka et al. 1995a). A transgressive sandstone-conglomerate unit at the base is succeeded by dark-grey, muddy-clayey and sandy shales with glauconite and phosphorites (Fig. 2). Subordinate sandstone, which is thin, lenticular and ripple cross-laminated, becomes thicker and more common higher up and typically contains ball-and-pillow structures. This development is not unlike the upper parts of the Pyarayarvinskaya Formation.

There seem to be two phases of coarsening-upward development in the Poropelonskaya Formation, the second being towards the bottom of the overlying Zemlepakhtinskaya Formation. The latter consists of grey feldspathic sandstones with large-scale, tabular cross-bedding, and there are subordinate beds of silty shales and channels filled with up to 3.5 m-thick intraformational conglomerates. The Poropelonskaya and Zemlepakhtinskaya Formations together are interpreted as a prodelta-delta front, essentially a progradational succession. The repeated coarsening-upwards motif in the Poropelonskaya Formation may reflect separate flooding episodes. Negrutsa (1971) reported a sharp and even erosional contact between the Poropelonskaya and Zemlepakhtinskaya Formations. This contact, in our view, may be one of several effects of channelling observed by us in the prograding delta-front channels. However, the interpretation of these two formations and their relationship as proposed here is preliminary and more observations are clearly required, in particular in the thick sandy succession of the Zemlepakhtinskaya Formation (Siedlecka et al. 1995 a). The total thickness of the Poropelonskaya Formation is 280 m.

Zemlepakhtinskaya Formation. This formation is exposed along the western coast of Sredni, 4.5 km northwest of Matala-Niemi Cape and along the profile from elevation point 343 towards the northeast (Fig. 2). The total thickness of the formation is 500 m.

Sandstones of the Zemlepakhtinskaya Formation rest on rocks of the Poropelonskaya Formation with a sharp and locally erosional contact. The Zemlepakhtinskaya Formation consists of thick- and cross-bedded, medium- and fine-grained sandstone with a characteristic yellow and yellow-grey coloration (Fig. 9). Among the other rock-types present there are thick (up to 1.5 m) interbeds of dark grey and black sandstones with a high content of leucoxene and rutile (2.5% TiO_2). In the basal part of the formation, thin interbeds and lenses of gravelstone are present.

Within the lowermost part of the Zemlepakhtinskaya Formation, a 2.5-3 m-thick bed of gravelly conglomerate occurs within a yellow sandstone at 10-15 m above the base. This unit is traceable along strike both on the Sredni Peninsula and on Cape Motka. The gravelly conglomerate or gravelstone consists of flat (5-10 mm), rounded fragments (2-3 cm in diameter) of weathered silty sandstone. Some flattened pebbles of black pelitic shale and small phosphorite nodules are also present. Within the gravelly conglomerate bed, there are cross-bedded interbeds of sandstone; and towards the base of the conglomerate there is a 10-15 cm-thick layer of greenish-grey, thin-bedded, silty sandstone.

Karuyarvinskaya Formation. This formation occurs along the northeastern and western coasts of the Sredni Peninsula, and in the western slopes of the middle reaches of the river Vykat. The most complete sections of the Karuyarvinskaya Formation are exposed in the northeastern coastal areas of Sredni northwest of the mouth of the river Vykat (Fig. 2).

The Karuyarvinskaya Formation consists of alternating red sandstone of subgreywacke composition, siltstone, carbonate-cemented mudstone and subordinate grey and variegated dolomite. A notable feature of the formation, established for the first time by the authors along the coast of Bolshaya Volokovaya Bay, is the following. In alternating beds of oxidised red and reduced grey-green sediments, up to several metres thick, there are deep, vertical, tectonic joints that formed after the accumulation of several sedimentary layers. The joints are from tens of centimetres to a few metres in length and up to several centimetres wide. Along the joints the sediments from each overlying bed have penetrated as small neptunian (sedimentary) dykes into the underlying bed. At the contacts of the dykes the reduced interbeds are oxidised where the underlying bed has also been oxidised, and the oxidised beds are reduced where the underlying bed is reduced. These joints are considered to represent forerunners of a major collapse of the upper part of the Karuyarvinskaya Formation, that took place just before and at the time of accumulation of the basal layers of the Volokovaya Group. The contact between the Karuyarvinskaya Formation and the underlying Zemlepakhtinskaya Formation is generally not exposed. However, in one locality on the east bank of the river Vykat, a tectonic contact between the formations can be observed.

Variegated rocks of the upper part of the Karuyarvinskaya Formation (Figs.10 & 11) exposed along the western coast of the Sredni Peninsula (Fig. 2), comprise alternating red subgreywacke sandstone, siltstone and mudstone that may be carbonate-cemented. There are also subordinate beds of grey and variegated dolostone which, in places, show crinkled microbial lamination and tepee structures (Fig. 12). Desiccation cracks are abundant in this formation, and salt-pseudomorphs have been reported (Negrutsa 1971). The apparent thickness of the upper part of the Karuyarvinskaya Formation is about 30 m. The rocks are traceable northwards along the coast over a distance of 2.5-3 km.

Along the western coast of Sredni, the contact between the Karuyarvinskaya Formation and the overlying Kuyakanskaya Formation of the Volokovaya Group is quite well exposed (Figs. 10 & 11). The fact that variegated rocks forming the upper part of the Karuyarvinskaya Formation of the Kildinskaya Group are present here (Lyubtsov et al. 1978) is important for a clearer understanding of the stratigraphic relationships between the Kildinskaya and Volokovaya Groups on Sredni. The sedimentary features of the Karuyarvinskaya Formation are indicative of a shallow-water, low-energy, delta-plain environment with local hypersaline conditions, possibly representative of intertidal-supratidal sabkha-type flats.

VOLOKOVAYA GROUP

The Volokovaya Group overlies the Karuyarvinskaya Formation of the Kildinskaya Group (Figs. 2 & 5). In all the localities examined, the lower Kuyakanskaya Formation rests on variegated rocks of the upper part of the Karuyarvinskaya Formation. Volokovaya Group rocks are exposed along the western coast of Sredni, in the area of elevation point 129.9 m,

Fig. 10. Sharp erosional contact between variegated clayey rocks of the Karuyarvinskaya Formation of the Kildinskaya Group (below) and the sandstones of the Kuyakanskaya Formation of the Volokovaya Group. Sredni Peninsula, southwestern side of the Bolshaya Volokovaya Bay. Photo: A. Siedlecka.

Fig. 11. The erosional contact of Fig.10 in close-up showing the unsorted and chaotic basal conglomerate present at the bottom of the sandstones of the Kuyakanskaya Formation resting on the clayey, variegated rocks of the Karuyarvinskaya Formation. Photo: A. Siedlecka.

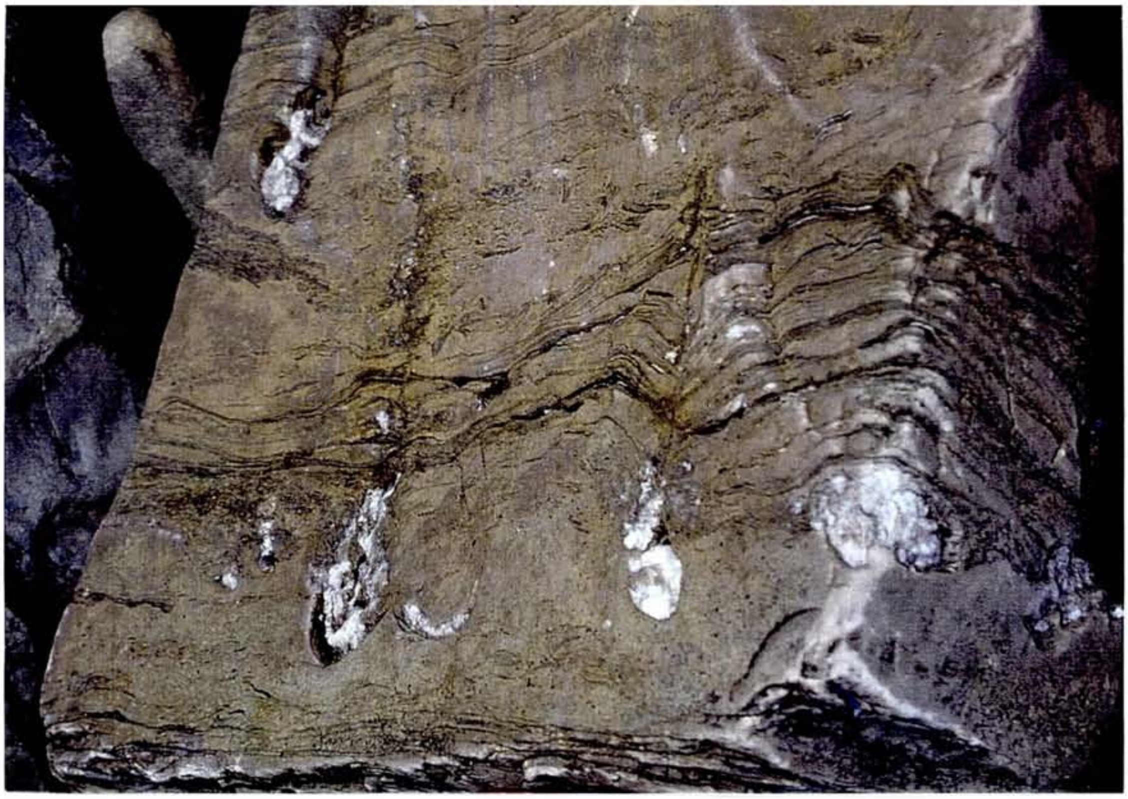

Fig. 12. Algal-laminated dolomite of the Karuyarvinskaya Formation with development of 'tepee structures' and calcite segregations (white), probably replacing evaporites. Sredni Peninsula, coastal section. Photo: A. Siedlecka.

Fig. 13. Sculptured weathering in sandstones of the Kuyakanskaya Formation, northwest Sredni; in the background, cliffs in rocks of the Pumanskaya Formation. Photo: V.V. Lyubtsov.

and farther to the northeast; and also on the northeastern coast of Sredni (2 km northwest of the mouth of the river Vykat) where, in coastal cliffs, a contact is observed between the Kildinskaya and Volokovaya Groups. The contact is also exposed along the coast 3.5 km northwest of the river Vykat. The Volokovaya Group, which has a total thickness of around 470 m, is subdivided into two formations: Kuyakanskaya (lower) and Pumanskaya (upper) (Negrutsa 1971).

Kuyakanskaya Formation. This formation is about 170 m thick and consists of coarse-grained, cross-bedded arkose and feldspathic sandstone (Figs.13 & 14), quartz gravel sandstone with interbeds of phosphorite-bearing conglomerates and breccias at the bottom (Fig. 15), and horizontally bedded subgreywacke sandstone with interbeds of silty pelite in the upper part. Channelling is common in the lower parts of the formation, and spectacular ball-and-pillow structures are present in some mixtite layers. Important features of the Volokovaya Group include evidence of submarine slumping and periodic increased rates of sedimentation.

Representative exposures of the bottom part of the Kuyakanskaya Formation are located in the northeastern coastal section of Sredni. Here, in the lowermost part of the formation, there is a sharp contact between variegated rocks of the uppermost part of the Kildinskaya Group and quartz-rich gravelly sandstone of the Volokovaya Group. The latter contains lenses and interbeds of conglomerate with fragments of variegated Karuyarvinskaya rocks, small pebbles of quartz, phosphorite concretions and granite fragments. The gravelly sandstone of the Kuyakanskaya Formation (Table 5, Sample 732-19) penetrates into fractures between pulled-apart and displaced blocks and boulders of variegated shale of the Kildinskaya Group. In the overlying layers, large clasts form interbeds and lenses which have features typical of olistostromes; first described from this area by Lyubtsov et al. (1978). Olistostromes are also present in northwestern parts of Sredni (Fig. 16). These relationships, although being indicative of a hiatus, can be understood as a result of a sudden activation of the tectonic regime and partial erosion of the accumulated sedimentary succession.

It is significant that the relationships observed between the Kildinskaya and Volokovaya Groups are different at different localities along the northeastern coast of Sredni. The contact between the groups exposed in coastal cliffs 2.5 km northwest of the mouth of the river Vykat is similar to that described above. Large, separated blocks of variegated silty pelite are present at the contact. Fractures between the blocks are filled with gravel and small pebbles of quartz from the bottom part of the Kuyakanskaya Formations. Blocks of siltstone from the Karuyarvinskaya Formation, tens of metres in length and up to 1 m thick, occur in the lowermost part of the Kuyakanskaya Formation.

At a locality 3.5 km northwest of the mouth of the river Vykat there is no evidence of erosion, and the contact between the Karuyarvinskaya and the Kuyakanskaya Formation is sharp. The Karuyarvinskaya variegated shale is overlain by pale grey, coarse-grained, quartzitic sandstone with small (0.5-1 cm) pebbles and fragments of quartz from the Kuyakanskaya Formation of the Volokovaya Group. The same kind of contact between the Volokovaya and Kildinskaya Groups is observed on Maly Aynov Island (p. 16).

In another interpretation, Siedlecka et al. (1995a) considered the coarse conglomerate and breccia at the base of the Kuyakanskaya Formation to represent an alluvial fan deposit. In general, fluvial conditions in the lower parts of the formation give way to mainly coastal-marine deposition higher up, with mixtites representing exceptionally high-energy, earthquake- or fault-related sedimentation.

Fig. 14. Deformed cross-bedding in sandstones of the Kuyakanskaya Formation, northwest Sredni Peninsula. Photo: V.V.Lyubtsov.

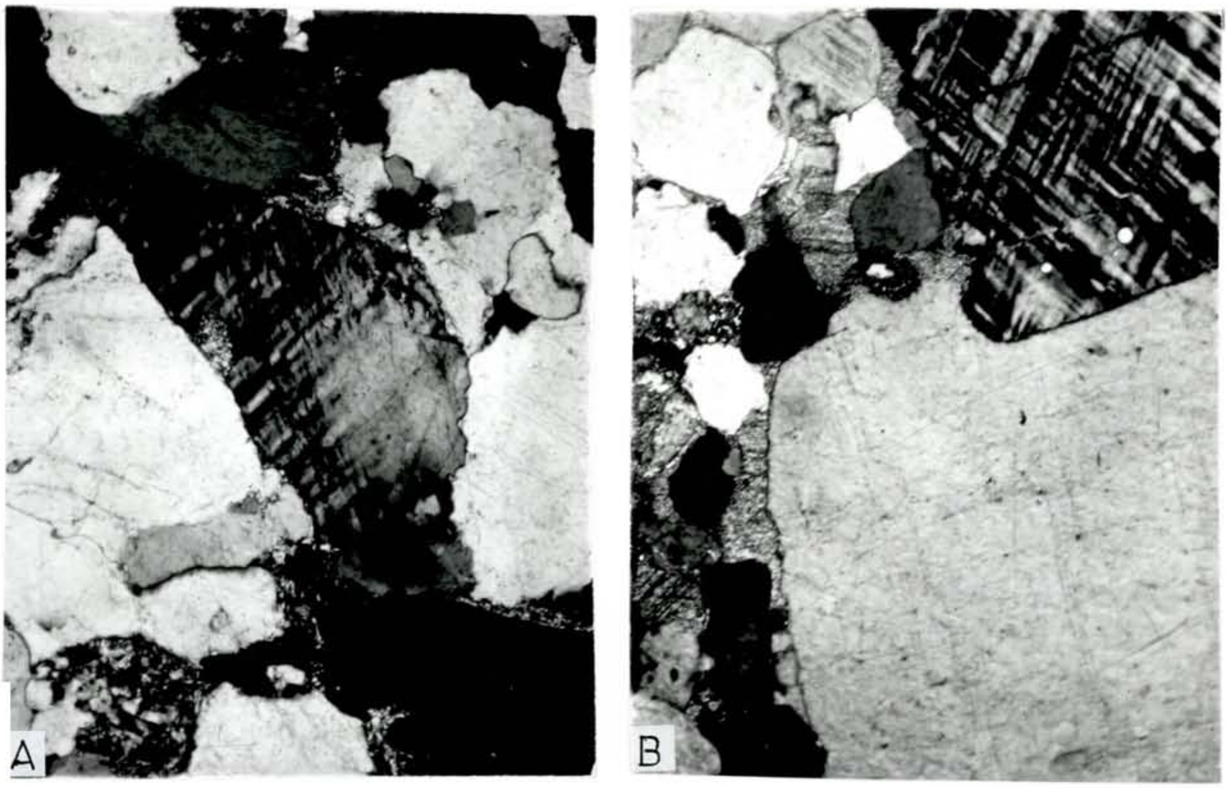

Fig. 15. (A) Coarse-grained, feldspathic, quartzitic sandstone from the lower part of the Kuyakanskaya Formation of the Volokovaya Group (Sample 7711-11). (B) Gravelly, feldspathic, quartzitic sandstone from the basal part of the Kuyakanskaya Formation (Sample 7711-10). Sredni Peninsula. The height of each photomicrograph is equivalent to 1.7 mm. Crossed nicols.

Pumanskaya Formation. This c. 350 m-thick formation, which forms prominent cliffs in the northernmost part of Sredni (Fig. 17), consists mainly of alternating dark grey to black muddy shale and subgreywacke sandstone. These lithologies display coarsening-upward cycles.

A hiatus between the Kildinskaya and Volokovaya Groups is confirmed by an examination of Soyuz satellite images and by new findings of variegated rocks of the Karuyarvinskaya Formation along the northern and western coasts of the Sredni Peninsula. A Late Riphean age for the Kildinskaya and Volokovaya Groups is indicated by the study of microphitolite assemblages (Timofeev 1969), and data obtained by Pyatiletov from an investigation of a collection made by Lyubtsov (Lyubtsov 1980, Lyubtsov et al. 1989, Samuelsson 1993, 1997, 1998).

Pyatiletov (Lyubtsov 1980) suggested that microfossils found in the described successions of the Sredni Peninsula and Cape Motka of the Rybachi Peninsula (Iernovskaya, Poropelonskaya, Zemlepakhtinskaya and Karuyarvinskaya Formations of the Kildinskaya Group, and Pumanskaya Formation of the Volokovaya Group) and Kildin Island (Korovinskaya and Bezymyannaya Formations of the Kildinskaya Group) belong to one and the same Upper Riphean assemblage. The differences lie in the number of certain forms present in various samples, in some taxa diversity, and in the state of preservation of the microfossils.

3.2 Maly (Kheinya Sari) and Bolshoy Aynov Islands

3.2.1 Maly Aynov (Kheinya Sari) Island

In the southern part of Maly Aynov (Kheinya Sari) Island (Fig. 2), variegated rocks of the uppermost part (30 m) of the Karuyarvinskaya Formation of the Kildinskaya Group dip gently (7°-10°) towards the northeast. In the northern part of the island, rocks of the Kuyakanskaya Formation (35-40 m) of the Volokovaya Group are present. Rock characteristics are similar to those in the northwestern part of the Sredni Peninsula. The contact between the Karuyarvinskaya and Kuyakanskaya Formations is sharp and shows evidence of slight erosion, but there are no visible signs of an angular unconformity. Bekker et al. (1970b) reported the occurrence of Zemlepakhtinskaya Formation lithologies on the southernmost tip of the island but his view has not been confirmed by our investigations. For the record, it should be noted here that on maps accompanying articles by Siedlecka et al. (1995a) and Roberts (1995) in NGU Special Publication No. 7, the bedrock of the Aynov Islands has been incorrectly marked as Zemlepakhtinskaya Formation.

Fig. 16. Olistostrome near the top of the Kuyakanskaya Formation, Volokovaya Group, northwestern coast of Sredni Peninsula. Photo: V.V.Lyubtsov.

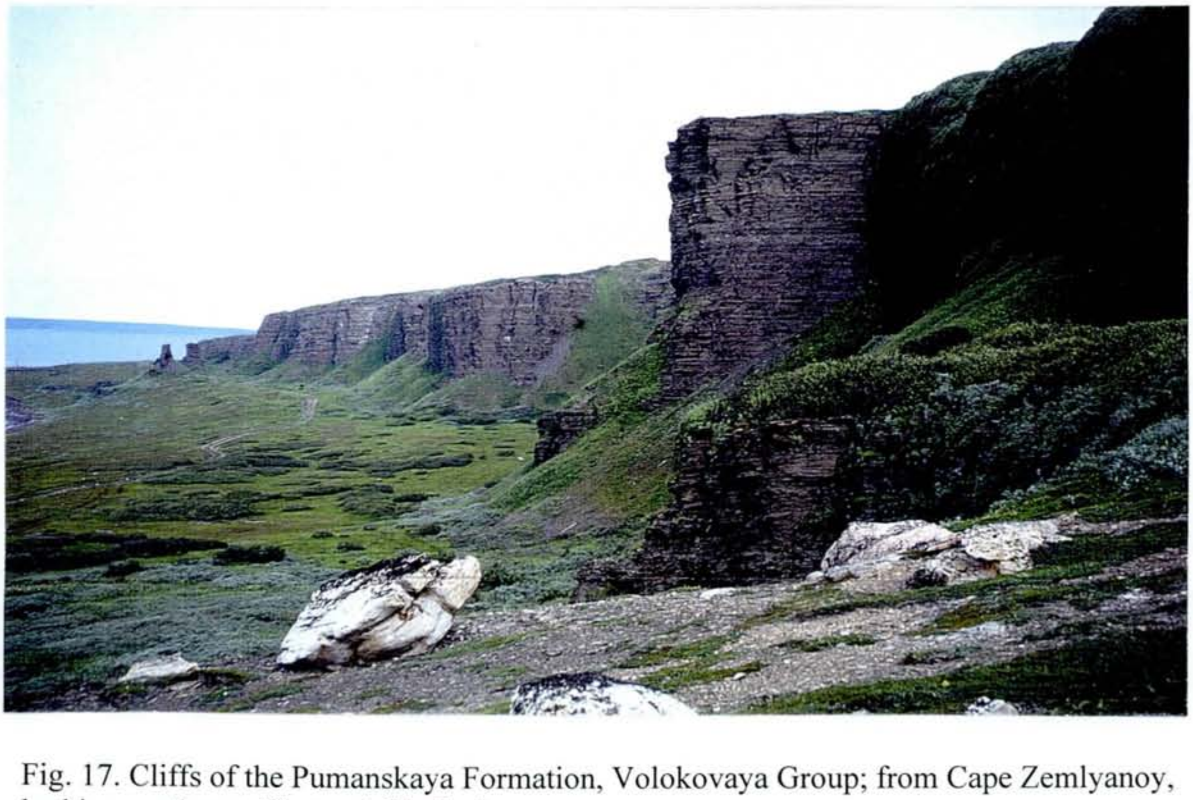

Fig. 17. Cliffs of the Pumanskaya Formation, Volokovaya Group; from Cape Zemlyanoy, looking northeast. Photo: A.Siedlecka.

3.2.2 Bolshoy Aynov Island

Rocks of the lower part (45-50 m) of the Kuyakanskaya Formation are exposed on the Bolshoy Aynov Island (Fig. 2). The lithologies are similar to those on the Sredni Peninsula – gravelly sandstone with lenses and interbeds of small-pebble conglomerate, grading into coarse-grained sandstone without gravel.

3.3 Kildin Island

KILDINSKAYA GROUP

The lower parts of the Kildinskaya Group may be observed in continuous sections in the tidal zone, in coastal cliffs, and along numerous fissures and stream sections on the southern side of the island (Figs. 18 & 19). The lowermost parts of the succession were partly revealed by a borehole drilled in 1933-1934 by Bogdanov and Gurevich in the area of Lake Slantsevoe (in Lyutkevich & Kharitonov 1958). From the drillcore data, eight lithological units were distinguished (from top to bottom):

1. Yellow sandstone with beds of sandy-clay sediments – 125 m;
2. Green sandstone with beds of clay and sandy-clay shale – 325-350 m;
3. Interbedded sandy-clay shale with beds of grey and glauconitic sandstone with ripple marks – 325 m;
4. Red clay shale with beds of red flaggy limestone with *Gymnosolen;* in the upper part, sandstone beds – 184 m (the Chernorechenskaya Formation in our subdivision);
5. (Bezymyannaya Formation);
6. Sandy-clay shale, locally micaceous, with interbeds and layers of glauconitic sandstone, layers of variegated conglomerate, limestone and dolomite, and grey limestone and dolomite with *Gymnosolen* – 92 m (Korovinskaya Formation). This is the lowermost exposed unit on Kildin. Further down, the borehole encountered rocks occurring below sea-level and corresponding to the Iernovskaya Formation of Sredni, according to our classification;
7. Grey sandstone alternating with dark grey and brown sandy-clay shale. The sandstone predominates in the upper parts of the section – 96 m;
8. Red-brown glauconitic sandstone with rare thin interlayers of black sandstone and clay shale – 46 m. Drilling was terminated at this level.

The exposed lithologies of the Kildinskaya Group are represented by rhythmically alternating sandstones and glauconitic shales of black, dark grey, grey-green and grey to brick-red and brownish colours, with thin beds of carbonate rocks containing stromatolites and oncolites. Lyubtsov & Predovsky (1975b) subdivided the sedimentary rocks exposed on Kildin Island into seven formations (from bottom to top): Iernovskaya (140 m), Korovinskaya (55 m), Bezymyannaya (45 m), Chernorechenskaya (55 m), Pestsovozerskaya (180 m), Pridorozhnaya (600 m) and Slantsevozerskaya (250 m).

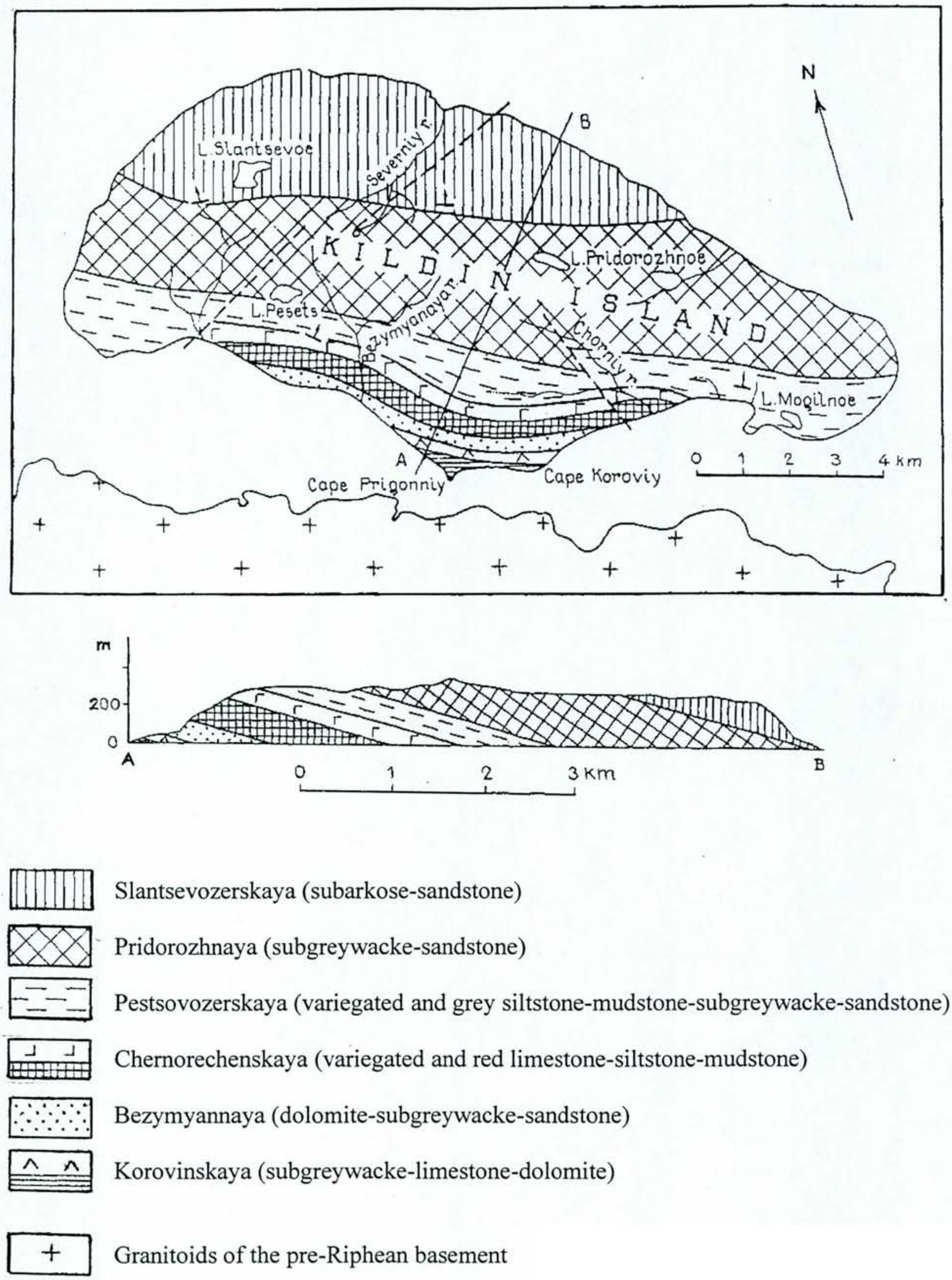

Fig. 18. Simplified geological map of Kildin Island, with cross-section A-B; compiled by Lyubtsov (1975), based partly on the work of Negrutsa (1971). The legend shows the six main formations of the Kildinskaya Group (the basal Iernovskaya Formation cannot be shown at this scale); and the pre-Riphean granitoid rocks of the basement on the mainland.

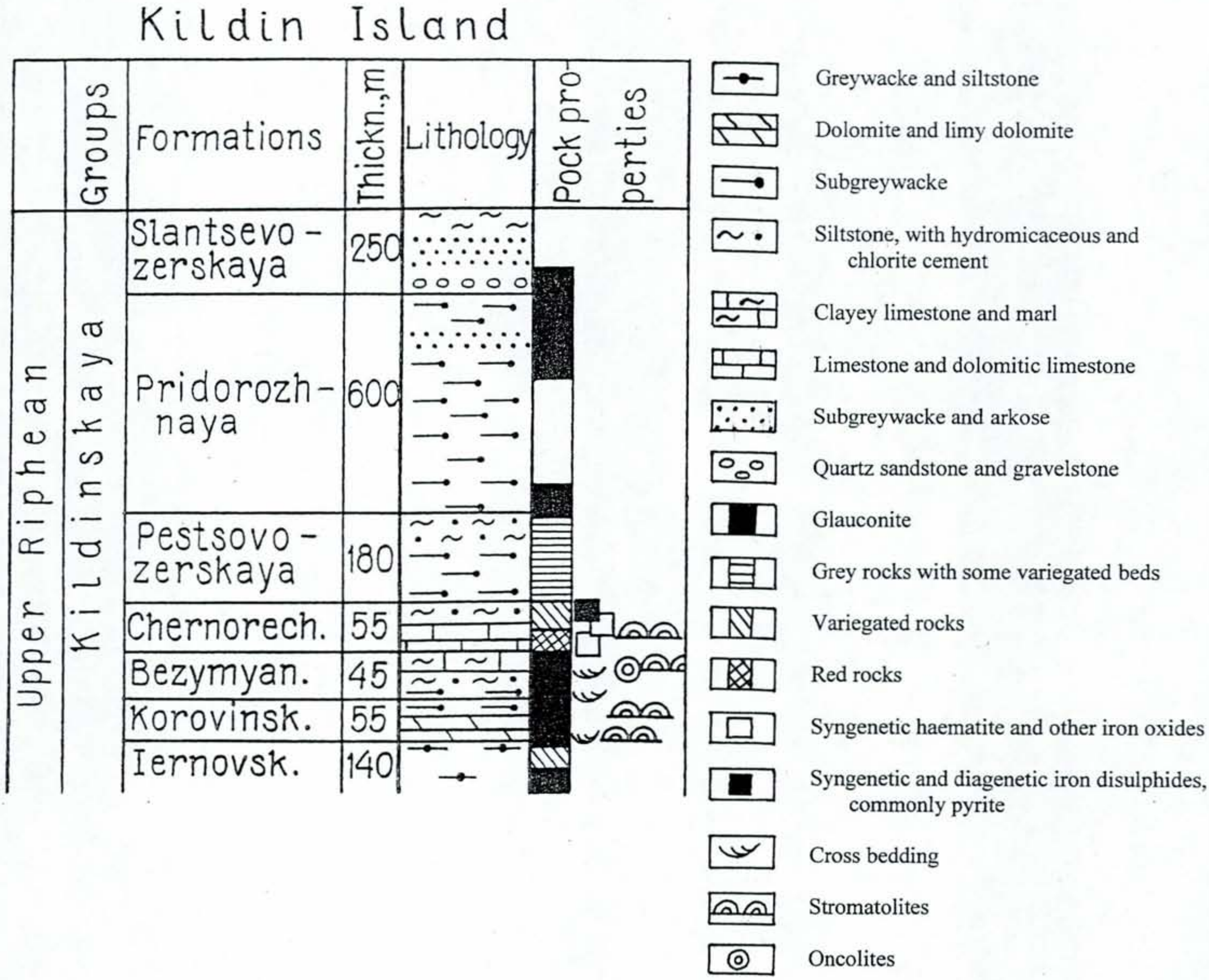

Fig. 19. Stratigraphy of the Neoproterozoic rocks of Kildin Island.

3.3.1 Cape Koroviy

Sedimentary rocks belonging to the four lowest units – the Iernovskaya, Korovinskaya, Bezymyannaya and Chernorechenskaya Formations – are exposed in the southernmost part of Cape Koroviy, on the southern coast of Kildin Island (Figs. 18 & 19).

Iernovskaya Formation. Only the uppermost part of the formation (1.5 m) is exposed at low tide. The bulk of the sequence was penetrated by the borehole. The Iernovskaya Formation section is represented by units 7 and 8 (see above), totalling 142 m. This is followed by 1 m of dark grey, thin-bedded, silty shale which is, in turn, sharply and conformably overlain by greenish-grey and yellow-grey stromatolitic carbonate rocks of the Korovinskaya Formation.

Korovinskaya Formation (Figs. 18 & 19). The name 'Korovinskaya' was first suggested by Negrutsa (1971). The rocks of the formation, with a total thickness of 55 m, are best developed at Koroviy Cape (Fig. 18) and are represented by alternating, parallel-laminated, greenish-grey, fine-grained clayey and medium-grained silty sandstone (of subgreywacke, greywacke or even arkose composition) with interbeds and lenses of glauconitic sandstone, and layers of grey stromatolitic limestone and dolomite. The formation shows widespread evidence of synsedimentary submarine erosion. The majority of the stromatolitic horizons of the Kildinskaya Group occur in this formation.

The lower member of the formation is 35 m thick and consists of alternating, greenish-grey, thin-bedded, fine-grained silty sandstone and clayey silty sandstone (subgreywacke and greywacke). This unit is succeeded by medium-grained subgreywacke and rarely by arkosic sandstones with interbeds of mudstone and eight beds of grey stromatolitic dolomite, calcareous dolomite and limestone. Stromatolites occurring in the formation have been determined as *Gymnosolen ramsayi Steinm, Pseudokussiella Kryl.* and *Tungussia Semikh.* (Krylov & Lyubtsov 1976, Raaben & Lyubtsov 1993). In general, subgreywackes generally prevail over greywackes; the rocks are better sorted and contain more clastic quartz than in the Iernovskaya Formation. Some interlayers and the bottom parts of some stromatolitic horizons show evidence of intraformational submarine erosion.

The upper member is 20 m thick. It consists of alternating, dark brown subgreywacke, clayey siltstone and silty sandstone, which contain thin interbeds and lenses of glauconitic quartz sandstone. The content of dolomite in the cement decreases from bottom to top. There are two beds of stromatolitic limestone and dolomite in the lower part of the member (Figs. 20 & 21). A chemical analysis of a sample of dolomite from this formation is presented in Table 2.

Bezymyannaya Formation. This rests conformably on the Korovinskaya Formation, and is exposed along the river Bezymyannaya (Figs. 18 & 19) and in coastal cliffs. The 45 m-thick formation is composed of dark brown and grey subgreywacke, siltstone and silty sandstone with interlayers of glauconitic sandstone and oncolitic dolomite. An eroded bed of stromatolitic dolomite overlain by oncolitic-stromatolitic sandy dolomite occurs in the upper part of the formation. Stromatolites are very small (2-3 cm).

The lower member (20 m) is composed of interlayered (1) dark brown and grey subgreywacke and clayey silty sandstones, fine to medium-grained, glauconite- and dolomite-cemented, and (2) medium- to coarse-grained, cross-bedded, arkosic sandstones with abundant glauconite. The upper part of the member contains layers of arkosic sandstone with

Fig. 20. Stromatolite bioherms growing on an uneven erosional surface of a dolomitic silty shale. Upper part of the Korovinskaya Formation. Southern coastal section of Kildin Island. Photo: A. Siedlecka.

Fig. 21. Weathered and eroded top surface of stromatolitic bioherms; dolomite of the Korovinskaya Formation, southern coastal section of Kildin Island. Hammer-head, 18 cm. Photo: D. Roberts.

Table 6. Typical examples of chemical compositions of carbonate rocks from the Korovinskaya (first four columns) and Chernorechenskaya Formations of the Kildinskaya Group (wt.%). Samples with the letter 'b' are taken from stromatolite columns; those with the letter 'c' are of material from between the stromatolite columns.

	Korovinskaya Formation, upper member				Chernorechenskaya Formation, lower member				
Sample	262/33c	262/33b	8/4b	8/4c	7615c	8/16b	262/82	8/17	8/17c
SiO_2	8.00	5.30	4.80	19.10	6.51	7.73	8.70	18.30	6.20
TiO_2	0.10	0.10	0.06	0.17	0.32	0.05	0.28	0.17	0.05
Al_2O_3	2.00	1.40	1.00	2.60	1.51	1.62	1.80	2.80	1.30
Fe_2O_3	0.54	0.06	0.62	0.46	0.24	0.82	1.05	0.35	0.63
FeO	1.68	1.05	3.49	3.57	0.39	0.41	0.29	0.49	0.35
MnO	0.25	0.11	0.40	0.36	0.01	0.08	0.05	0.24	0.14
MgO	5.01	2.02	18.35	14.85	1.85	1.02	0.07	3.92	2.40
CaO	43.37	46.40	28.27	22.77	48.08	47.75	49.06	37.95	48.40
Na_2O	0.23	2.07	0.16	0.40	0.10	0.16	0.39	0.35	0.19
K_2O	0.65	1.36	0.21	0.69	0.29	0.32	0.62	0.48	0.25
H_2O+	3.02	0.40	-	-	0.10	0.14	0.40	1.29	1.08
H_2O-	-	-	0.60	1.00	0.95	0.64	-	-	-
P_2O_5	0.12	0.02	0.02	0.11	0.01	0.01	0.24	0.01	0.02
CO_2	35.74	36.40			38.69	38.87	36.74	32.56	38.50
Total	100.70	100.33			99.60	99.62	100.31	99.25	99.55

Table 7. Average chemical compositions of major rock types of the Tsypnavolokskaya Formation of the Bargoutnaya Group, Rybachi Peninsula.

	Mudstone (2)	Siltstone and sandstone (13)	Sandstone (subgreywacke)(1)
SiO_2	55.0	61.0	71.14
TiO_2	1.00	0.74	0.33
Al_2O_3	20.42	14.90	10.50
Fe_2O_3	2.37	3.40	0.83
FeO	5.20	4.20	5.65
MnO	0.07	0.08	0.05
MgO	3.50	2.80	1.10
CaO	1.38	1.10	1.54
Na_2O	1.83	2.70	3.85
K_2O	4.75	2.58	1.62
P_2O_5	0.16	0.13	0.10
F	0.190	0.146	0.093
A	+96	+54	-4
K	+21	-16	-45

Note: The number of samples analysed is given in parentheses.
Column two -- Siltstone and sandstone of greywacke composition.

high contents of accessory minerals: apatite, zircon and tourmaline. Carbonate rocks are absent.

The upper member (25 m) is composed mainly of alternating, dark brown subgreywacke, silty sandstone and poorly sorted silty sandstone with interlayers of haematite-bearing brown and red mudstone. In addition, there are several interbeds of coarse-grained quartz sandstone with glauconite and dolomite in the cement. The upper member contains beds of oncolitic dolomite with small columnar stromatolites and with abundant, coarse-grained, rounded quartz and glauconite. A layer of eroded stromatolitic dolomite overlain by a bed of oncolitic dolomite is present at the top of the member. The lithologies of the formation reflect a shallowing of the basin, which is indicated by the predominance of oncolitic dolostones at the top.

Chernorechenskaya Formation. This unit is exposed in the valley of Chorny creek as well as in coastal cliffs (Figs. 18 & 19). The formation is characterised by widespread red pelite, siltstone and limestone underlying variegated red-brown, greenish-grey and green silty sandstone, mudstone and dolomite. Several beds (the thickest, 1.5-2 m) of variegated stromatolitic dolomite occur in the middle part of the formation. The formation is subdivided into two members.

The lower member (35 m) is composed of red, haematite-bearing, clayey siltstone and silty mudstone (cf. sample N 102-1b and 262-85 from the top of the Bezymyannaya Formation and the bottom of the Pestsovozerskaya Formation, respectively; Tables 2 & 3) with thin layers of red, microcrystalline limestone (sample numbers 7615c, 8/16b, 262/82 and 8/17c in Tables 2 & 6, Fig. 22a) with stromatolitic and oncolitic varieties, and a few thin interbeds of red, haematite-bearing (and clayey), silty sandstone (subgreywacke and arkose) (Fig. 22b).

Apart from the presence of limestone interlayers, the lower member is characterised by a widespread red limy mudstone with a $CaCO_3$ content varying from 5 to 30%. Beds are 3 metres thick or more. This makes the member a rather promising source of raw material for cement production. The character of the lower member indicates that the basin floor was significantly lowered, the supply of terrigenous material being limited. Red carbonate-clay deposits provide evidence for stable tectonic conditions, and for oxidising conditions in the source and sedimentation areas.

The upper member (25 m) is composed of variegated red-brown and green-grey, fine-grained, silty sandstone and siltstone (ranging from arkose to greywacke) (Table 4, sample 7-4), with interlayers of red-brown and green mudstone and pink haematite-bearing dolomite. In the lower part of the member there is a thin bed of dolomite showing evidence of erosion, and in places enriched in fine-clastic quartz. On the erosional surface there is a 1.5-2 m-thick bed of variegated stromatolitic dolomite.

The upper part of the upper member is characterised by red mudstone with numerous small carbonate concretions and rare thin interbeds of subgreywacke. Near the top of the section, in a 3-4 m-thick interval, there are several stromatolitic beds with thicknesses ranging from 0.3 to 0.5 metres. The character of the lithologies suggests that the supply of terrigenous material was low.

3.3.2 Pesets Lake

Bedrock exposures north of Cape Koroviy represent rocks of the Pestsovozerskaya Formation that reflect the maximum downwarping of the Kildinskaya basin; and the Pridorozhnaya and Slantsevozerskaya Formations that characterise the regressive stage of sedimentation of the Kildinskaya Group.

Pestsovozerskaya Formation. This 180 m-thick formation occurs in the area of Lake Pesets and in adjacent parts of Kildin. The formation comprises variegated and grey, alternating subgreywacke and greywacke, clayey silty sandstone, poorly sorted sandstone, siltstone and mudstone of red-brown and green-grey colours (Table 3, Samples 262-85 and 731-53a). Varieties with abundant sericite in the cement are common (Fig. 23).

In addition, there are interbeds of fine- and medium-grained subgreywacke and arkosic sandstone with a spotted dolomitic cement, and rare interbeds of quartz glauconitic sandstone and red sandy dolomite with a clayey admixture. Greywacke, and some subgreywacke, contains fine-clastic magnetite, aggregates of sphene (leucoxene), rounded grains of zircon, tourmaline and apatite, fragments of micas (biotite and muscovite) and abundant hydromicaceous cement. Lithic grains are represented by fine-grained felsic and chloritised basic rocks. The sandstones show cross-bedding. Mudstone, which originally was hydromicaceous, is commonly confined to the middle part of the formation.

Pridorozhnaya Formation. This 600 m-thick unit extends from Lake Pesets towards the coast, north of the exposures of the Pestsovozerskaya Formation, and in the area of Lake Pridorozhnoye (Fig. 18). The formation consists of dark grey and pale grey subgreywacke, greywacke and arkosic sandstones (Table 2, Sample 106-7) of varying grain size. The sandstone commonly contains grains of altered glauconite and small amounts of spotted dolomitic cement, which is generally ferruginous in weathered varieties. Accessory constituents are zircon, rutile, apatite, sphene and ore minerals. The rocks in the upper part of the formation commonly show evidence of shallowing and periodical draining of the basin. In general, the rocks of the formation reflect an active accumulation of terrigenous material.

Slantsevozerskaya Formation. This occurs mainly in the area of Slantsevoye Lake (Figs. 18 & 19). The 250 m-thick formation starts with lithologies that bear evidence of redeposition and placer accumulation of ore minerals. The formation consists mostly of grey and pale grey, fine- to medium-grained and poorly sorted subgreywacke, arkosic, feldspar-quartz and quartz sandstones. At some intervals in the section, there are sandstones that show a marked accumulation of heavy minerals in the basal parts of cross-bedded layers. Deformed, originally clayey pebbles of small size (1-1.5 cm in diameter) are found in the same interval. The nature of the rocks suggests that the influx of terrigenous material was less intensive. The section terminates with a bed of variegated mudstone, and sandy and silty mudstone.

The Pridorozhnaya Formation and part of the Slantsevozerskaya Formation of Kildin Island can be tentatively correlated with the Zemlepakhtinskaya Formation of Sredni Peninsula; and the top of the Slantsevozerskaya Formation (red rocks) with the Karuyarvinskaya Formation (Siedlecka et al. 1995a), which terminates the Kildinskaya Group section on the Sredni Peninsula.

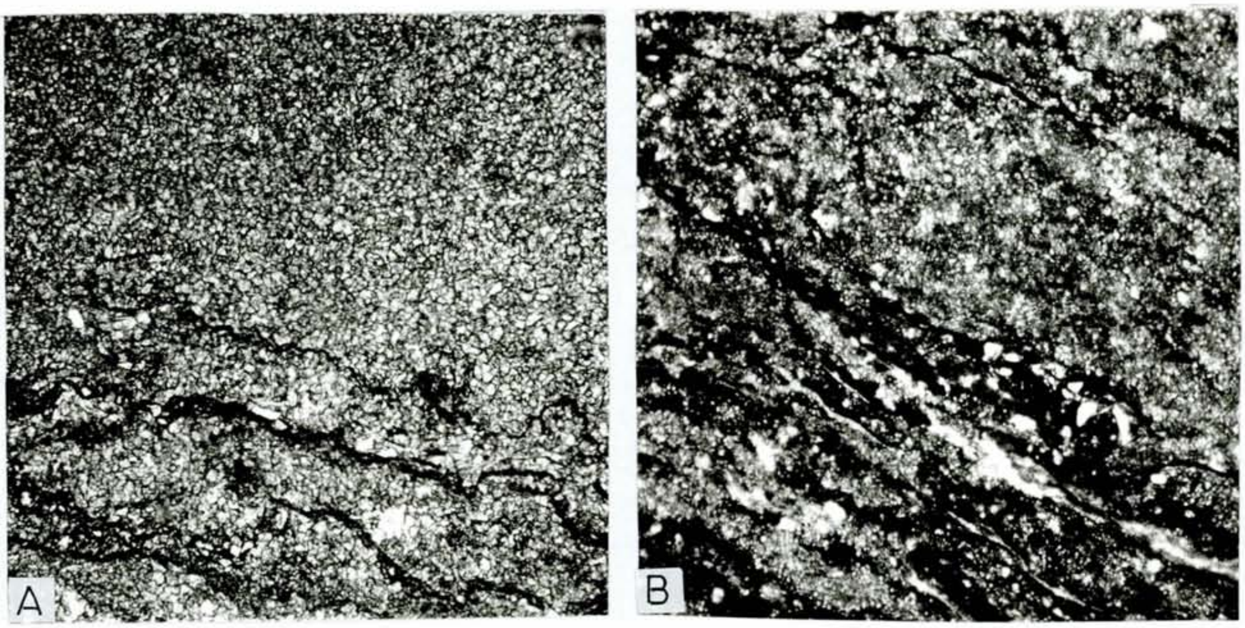

Fig. 22. (A) Red, fine-grained, crystalline limestone from the basal part of the Chernorechenskaya Formation, with admixture of clastic clay and haematite (Sample 7/1). (B) Red, haematite-bearing, silty-pelitic carbonate from the top part of the Chernorechenskaya Formation (Sample 102/1). The width of each photomicrograph is equivalent to 2.0 mm. Plane polarised light.

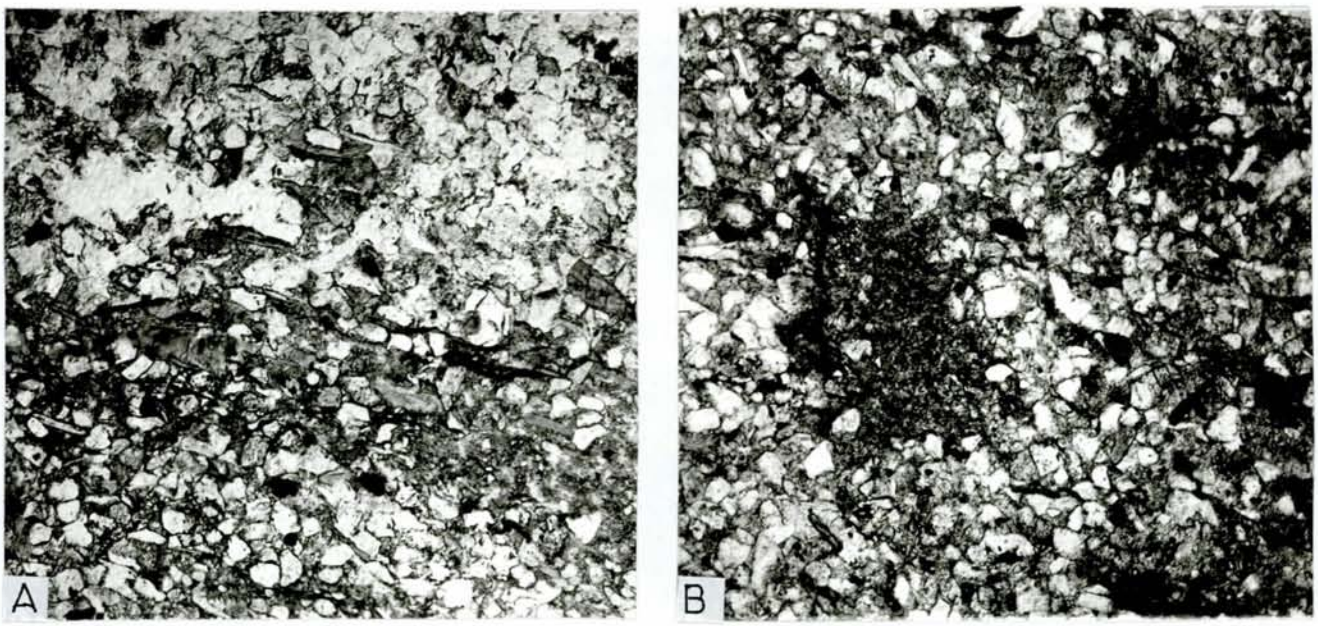

Fig. 23. Typical, lenticular (A – Sample 101-2) and nest-like (B – Sample 103-7) inclusions of hydromicaceous clay in subgreywacke and fine- to medium-grained sandstone of the Pestsovozerskaya Formation, Kildin Island. The width of each photomicrograph is equivalent to 2.1 mm. Plane polarised light.

3.4 Isthmus between the Sredni and Rybachi Peninsulas

EINOVSKAYA GROUP

Sedimentary sequences occurring on the isthmus between the Sredni and Rybachi Peninsulas and on the Rybachi Peninsula (Fig. 2) have been subdivided by Negrutsa (1971) into two groups: *Einovskaya*, which consists of the Motovskaya, Lonskaya and Perevalnaya Formations; and *Bargoutnaya*, which comprises the Maiskaya, Zubovskaya and Tsypnavolokskaya Formations. In the northwestern part of the Rybachi Peninsula, one more formation is distinguished: the Skarbeevskaya Formation.

Negrutsa (1971) considered that the area of the Rybachi Peninsula can be subdivided into two blocks, northwestern and southeastern, that are separated by a major ENE-WSW trending fault (Fig. 2). The most complete section through the very low-grade metasedimentary rocks and the rocks exposed on the isthmus between the peninsulas, is represented in the southeastern block.

Motovskaya Formation. This lowermost formation of the Einovskaya Group (Fig. 24), which is about 350 m thick, is best exposed on the isthmus between the Sredni and Rybachi Peninsulas (Fig. 2). In the zone from the isthmus to Eina Bay, the rocks of the Motovskaya Formation occur juxtaposed against formations of the Kildinskaya and Volokovaya Groups along a major tectonic line – the Sredni-Rybachi Fault Zone. It is significant that the rock successions of Rybachi are found only northeast of the fault zone, and the Kildinskaya and Volokovaya Groups only southwest of this line. The proposed unconformity and stratigraphic relationships between the Kildinskaya and Einovskaya Groups, as described by Negrutsa (1971), were not confirmed by our joint Norwegian-Russian field observations of 1990-1991.

Several exposures of the Motovskaya Formation are found along the southern coast of Bolshaya Volokovaya Bay, the northern coast of Bolshaya Motka Bay, and in the southeastern part of Rybachi. In the area of Bolshaya Volokovaya Bay, the exposed rocks of the formation are located close to the exposed sandstone of the Zemlepakhtinskaya Formation, whereas on the isthmus and at Cape Vestnik they are in proximity to black shale of the Poropelonskaya Formation of the Kildinskaya Group.

The Motovskaya Formation consists of interbedded, coarse-grained, quartzitic sandstone, breccia and polymictic, boulder-pebble conglomerate, dipping towards the northeast at angles of up to 45° (Figs. 25, 26, 27 & 28). The boulder conglomerate grades, from bottom to top, into fine-pebble conglomerate, gravelstone and sandstone. Boulders and smaller fragments are composed predominantly of granitoids (Fig.); clasts of highly mature rocks, such as quartzite, are absent. Negrutsa (1971) noted that the proportion of metasedimentary and metavolcanic pebbles and boulders increases markedly from west to east, reaching 40-50% in the area of Eina Bay (Fig. 26). The above features rule out the possibility of a correlation between the Volokovaya and the Einovskaya Groups.

The rock assemblage of Cape Vestnik has been interpreted as an olistostrome (Lyubtsov et al. 1990, Siedlecka et al. 1995b) formed along the steep, fault-controlled, unstable submarine margin of the developing basin. Associated deposits are akin to those accumulating from high-density turbidity flows. A detailed description of the various facies of the Motovskaya Formation can be found in Siedlecka et al. (1995b).

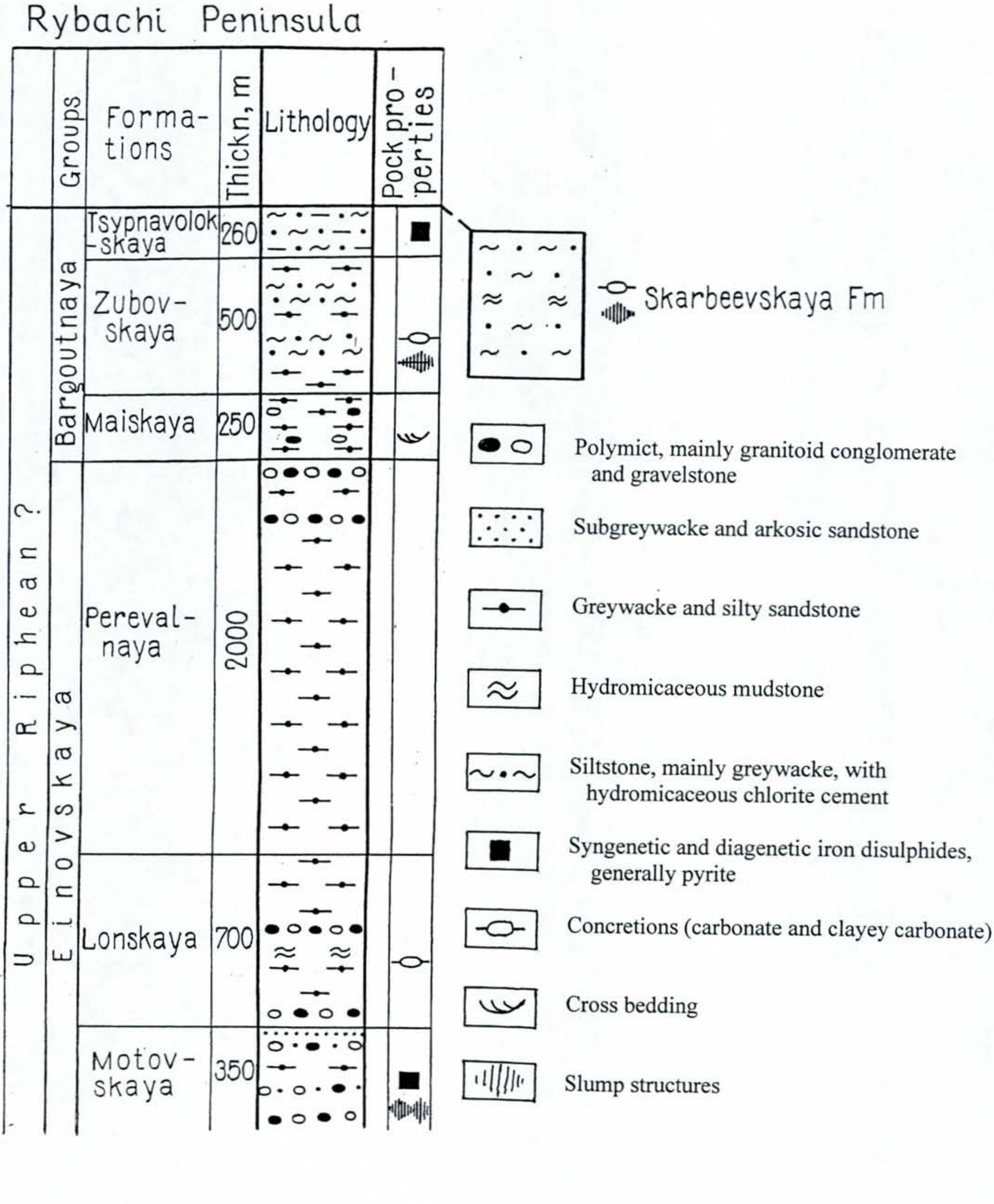

Fig. 24. Stratigraphy of the Neoproterozoic sedimentary rocks of the Rybachi Peninsula.

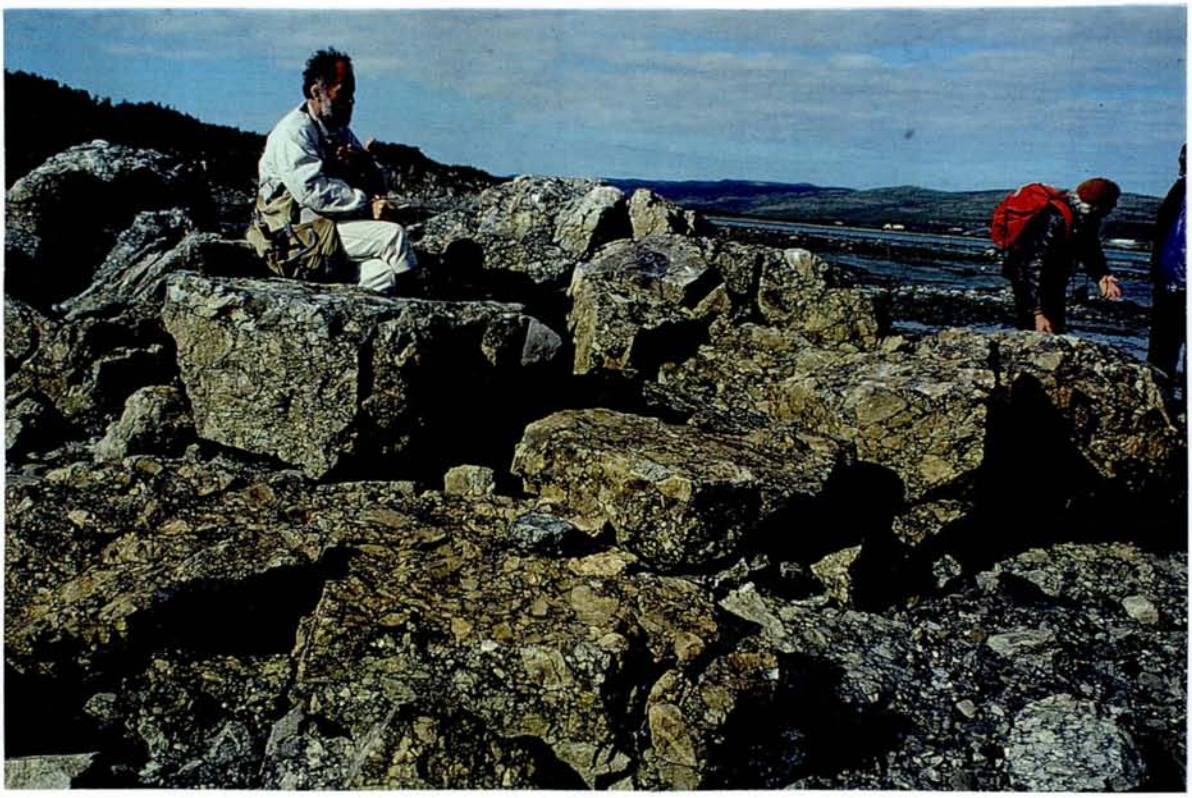

Fig. 25. Sedimentary breccia with chaotic texture (olistostrome). Motovskaya Formation of the Einovskaya Group. Cape Vestnik. Photo: A. Siedlecka.

Fig. 26. Coarse, unsorted conglomerate with angular and rounded extrabasinal clasts (Archaean intrusive rocks from Kola, Palaeoproterozoic volcanic and sedimentary rocks possibly from the Pechenga Greenstone Belt). Note the sharp contact between two turbidite beds. Motovskaya Formation of the Einovskaya Group. Coastal section east of Eina Bay, southern coast of Rybachi Peninsula. Photo: A. Siedlecka.

Fig. 27. Sedimentary breccia of the Motovskaya Formation, Cape Vestnik, showing the angularity of many of the clasts. The clasts are here composed mainly of Archaean granitoid and gneissic rocks. Pencil, c. 16 cm. Photo: D. Roberts.

Fig. 28. The same breccia as in Fig. 27, showing the typical chaotic texture of an olistostrome with a wide range of clast size, variable angularity/roundness, and a groundmass consisting of dark microbreccia to gritty sandstone. Cape Vestnik. Pencil, 16 cm. Photo: D. Roberts.

There is a gradual transition between the Motovskaya Formation and the overlying Lonskaya Formation. The contact is exposed in the northwestern part of the isthmus, in the tidal zone of Bolshaya Volokovaya Bay.

3.5 Rybachi Peninsula

The rocks of Rybachi Peninsula differ from those on Sredni Peninsula and the Kildin, Maly (Kheinya Sari) and Bolshoy Aynov Islands in that they are quite strongly folded (from relatively gentle folds in the south to open to tight, SW-facing, asymmetric folds in the north) and show clear evidence of low-grade metamorphism. The pelitic rocks, in particular, are quite strongly cleaved (Roberts 1995). The Rybachi rocks also show evidence of synsedimentary, soft-sediment deformation. Numerous quartz and carbonate-quartz veins were formed in the lithified sediments at the time of tectonic deformation; and there is evidence of minor thrusting and later, post-cleavage folding in some areas.

The summary section of the lithostratigraphic succession of Rybachi Peninsula (Fig. 24),with a total thickness of over 2500 m, is represented by polymictic sandstone, siltstone, mudstone and shale with interbeds of polymictic conglomerate.

EINOVSKAYA GROUP

Lonskaya Formation. This 700 m-thick formation occurs along the entire southwestern margin of Rybachi from Koroviy Cape to Eina Bay (Figs. 2 & 24). The Lonskaya Formation consists of conglomerate, gravelstone, subgreywacke and greywacke sandstone, siltstone, mudstone and rare thin interbeds of clayey limestone and marl (Negrutsa 1971). Many beds are erosively based and show graded bedding. The lithologies of this formation are considered to have been deposited mainly from high-density turbidity currents.

Perevalnaya Formation (Figs. 2 & 24). This formation, 1000 m thick, consists of homogeneous, ash-grey and yellow-grey, massive, unsorted, coarse-grained greywacke and subgreywacke sandstone and gravelstone, rocks which are somewhat similar to those in the Lonskaya and Motovskaya Formations (Negrutsa 1971). The sandstone contains rare lenses, up to 3 m-thick, of fine-pebble polymictic conglomerate, and the number of lenses increases towards the upper part of the formation (Fig. 29). The rocks are thick-bedded, with a bed thickness of 2-3 m or more. There is no evidence of graded bedding; and sedimentary structures on bedding planes are absent. Spherical cavities are common on the present-day surfaces of some of the sandstones and are believed to have formed by the weathering of carbonate concretions. Further details are contained in Siedlecka et al. (1995b).

Negrutsa (1971) pointed out the transgressive-regressive character of the Einovskaya Group. In his opinion, the group represents a complete sedimentation cycle comprising transgression and regression of a marine basin. The Lonskaya Formation, occurring in the middle part of the Einovskaya succession, reflects the deepest subsidence of the basin.

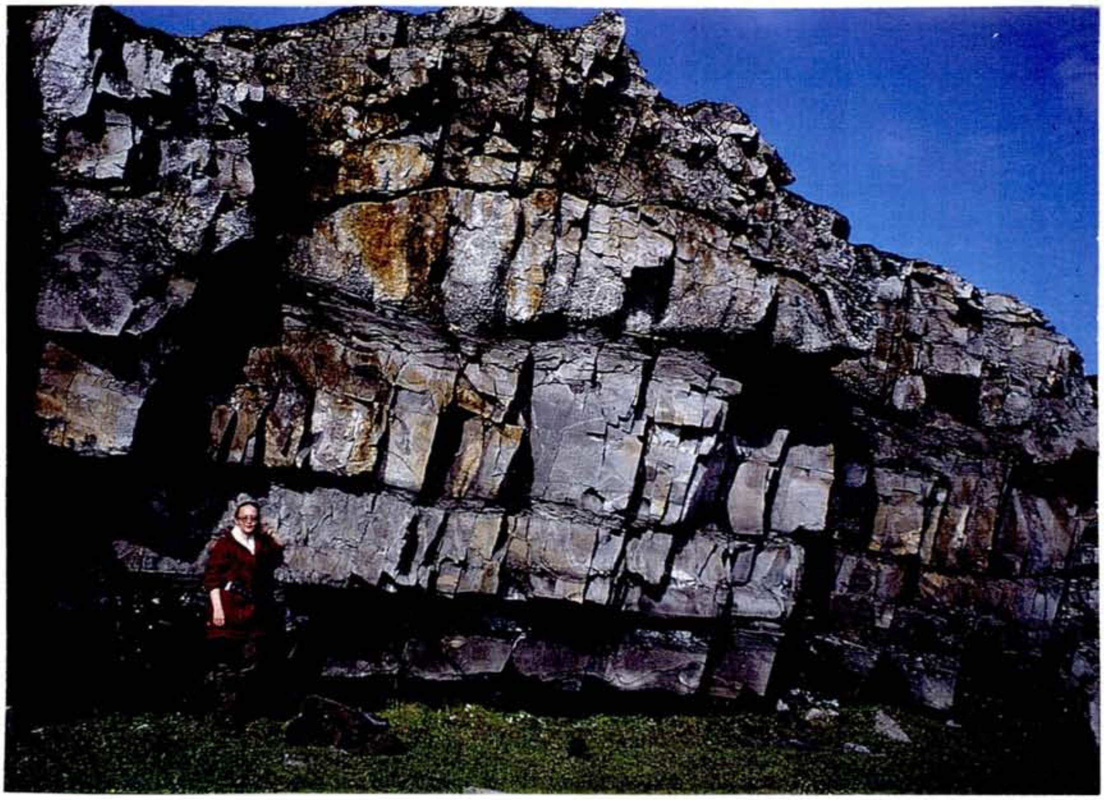

Fig. 29. Thick-bedded sandy and lenticular-conglomeratic turbidites, Perevalnaya Formation of the Einovskaya Group, Rybachi Peninsula, eastern coastal section, east of Cape Sharapov. Photo: A. Siedlecka.

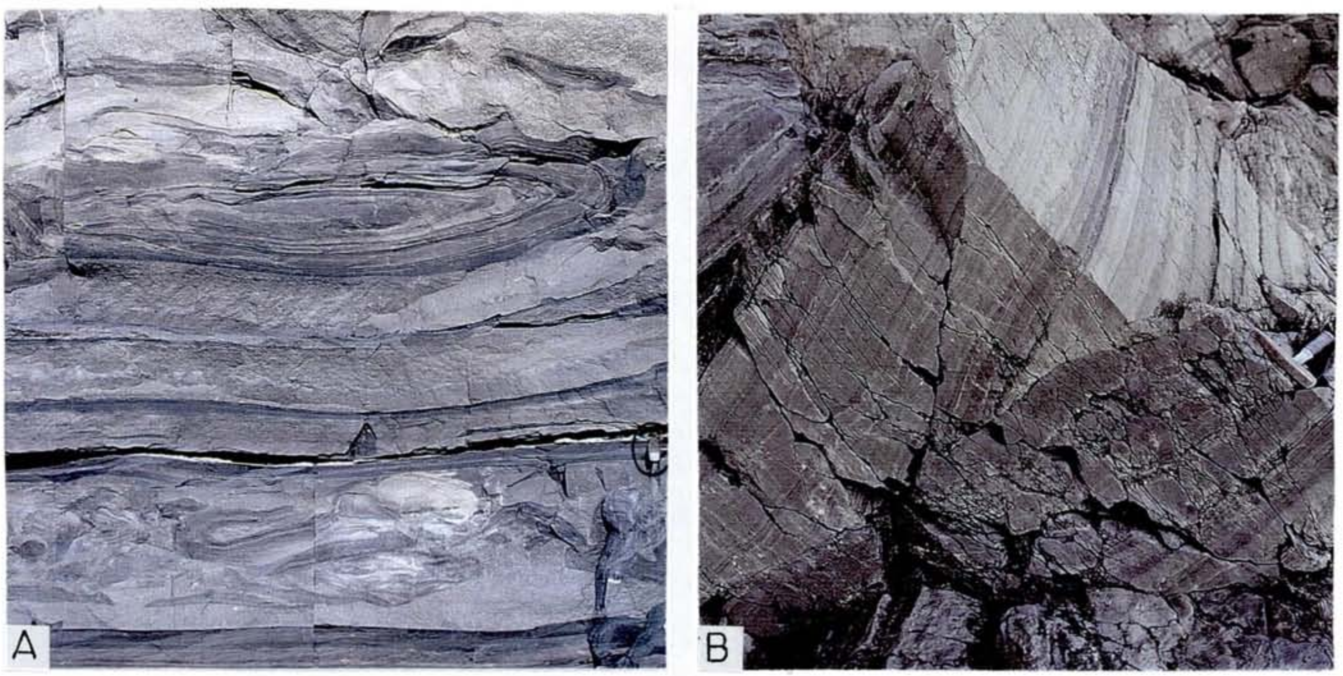

Fig. 30. (A) Synsedimentary, slump folds in turbiditic sandstones and shales of the Zubovskaya Formation, NE Rybachi. Hammer-head for scale (encircled), near bottom right. (B) Parallel-laminated, thinly bedded, silty sandstone and mudstone/shale (above) in synsedimentary slide-scar contact with slightly thicker-bedded turbidites; Tsypnavolokskaya Formation, NE Rybachi. In this coastal area, just SSW of Cape Tsypnavolok, there are abundant examples of soft-sediment deformation structures and small-scale synsedimentary faults (see also Siedlecka et al. 1995b). Photos: D. Roberts.

BARGOUTNAYA GROUP

Maiskaya Formation. The 250 m-thick Maiskaya Formation (Figs. 2 & 24) consists mainly of alternating greywacke-sandstone and gravelstone (Negrutsa 1971), sediments that are similar to those of the Perevalnaya Formation of the Einovskaya Group. Beds of boulder-pebble conglomerate are also present. The sandstones exhibit unidirectional cross-bedding, with current flow towards the north and northeast. Sedimentary siltstone-mudstone breccias are common. Erosion scars are also present within the sequence.

Polymict conglomerates (Negrutsa 1971) form thick (up to 30 m), elongated, lens-like bodies which are confined to the lower part of the formation. Boulders and pebbles of granitoids, specifically microcline granitoids, predominate. There are also a considerable number of boulders and pebbles of sedimentary rocks, commonly sandstones similar to those in the Kildinskaya Group. Pebbles of effusive rocks and quartzites similar to rock-types of the Karelian Pechenga complex are also present. The conglomerate is well sorted and boulders and pebbles are perfectly rounded and of isometric shape.

The relationship between the Maiskaya and Perevalnaya Formations is not clear, for the sandstones of both formations look similar and it is difficult to establish a clear boundary between them. Negrutsa (1971) suggested that there is a gradual transition between the formations. However, the presence of thick lenses of well-sorted boulder conglomerate with rounded granite boulders indicates that, in this time interval between the deposition of the two formations, there were major tectonic movements which led to a marine regression; and the Rybachi region was thus part of a long-lived, submarine coastal zone located near the tectonically active mountainous land mass.

Zubovskaya Formation. The 500 m-thick Zubovskaya Formation (Figs. 2 & 24) consists of alternating, mostly polymictic sandstones, gravelstone and shale (Negrutsa 1971). The thickness of sandstone units in the lower part of the formation reaches tens of metres, while in the upper parts it is 1 m or less. Shale beds and thicker units of shale increase in thickness from bottom to top from several tens of centimetres to 20 m or more. There are gradual transitions between the sandstones and shales, and the middle parts of sandstone beds are commonly more coarse-grained. Gravelstone, gravel conglomerate and siltstone breccias, for example, are generally confined to the middle parts of sandstone beds. The middle parts of shale beds are thin-bedded and they locally contain lensoid interbeds of dark grey and yellowish-grey limestone. Slump folds are common in parts of this formation (Fig. 30a).

Negrutsa (1971) considered these features to indicate a rhythmic development for the formation. The rhythms are complete transgressive-regressive sequences with transitions. The shales commonly exhibit slump deformation, spherulites and clay rolls, such that the Zubovskaya Formation is similar in several respects to the Lonskaya Formation of the Einovskaya Group. The similarity is further supported by the petrographic composition of rocks from both formations. The contact between the Zubovskaya and Maiskaya Formations is of a gradual transitional character.

Tsypnavolokskaya Formation. This formation, which has a minimum thickness of c. 200 m, occurs in the extreme northeast of Rybachi, and is the youngest lithostratigraphic unit exposed on the Peninsula (Figs. 2 & 24). The upper parts of the formation are concealed beneath the Barents Sea. The formation consists mainly of thin turbiditic sandstones, mudstones and shales (Fig. 31). A variety of sedimentary structures includes plastic, soft-sediment

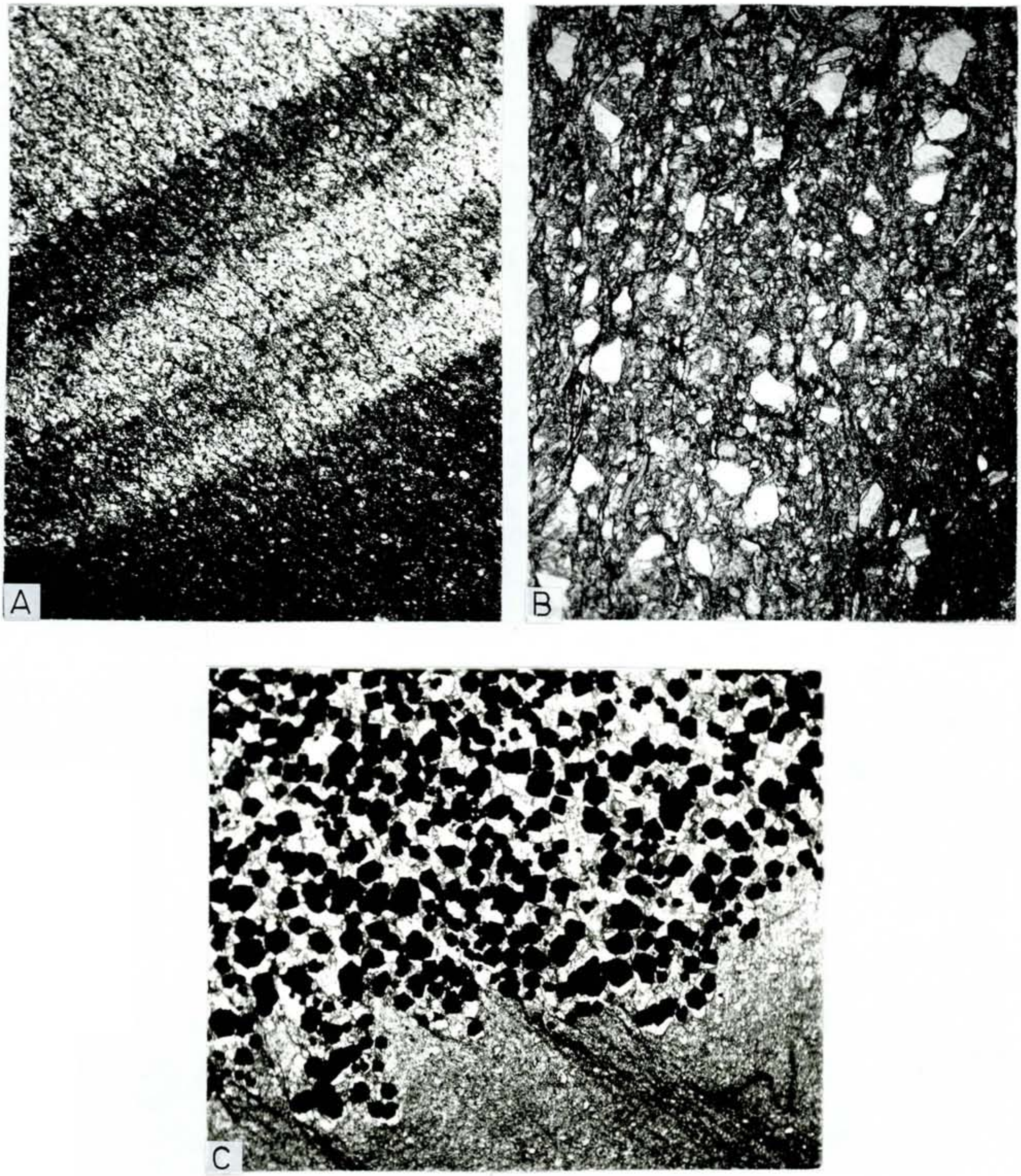

Fig. 31. Typical textures in polymict sedimentary rocks of the Tsypnavolokskaya Formation of the Bargoutnaya Group, Rybachi Peninsula. (A) Bedded greywacke and pelitic siltstone with hydromicaceous-chloritic cement (Sample 841). (B) Poorly sorted, pelitic greywacke and chlorite-bearing silty psammite (Sample 841-2). (C) A chlorite-pyrite interbed in chlorite-bearing greywacke and pelitic siltstone (Sample 841-4). The widths of (A) and (B) are equivalent to 2.0 mm; and (C), 2.6 mm. Plane polarised light.

Fig. 32. Turbiditic sandstones, siltstones and cleaved shales of the Skarbeevskaya Formation, Cape Kiyski, northwest Rybachi Peninsula; looking NW. The bedding dips gently to the northeast and is cut by a pervasive, steeply dipping, spaced cleavage. This NW-SE trending cleavage is common in pelitic formations and beds throughout the Rybachi Peninsula. It is axial planar to NW-SE trending folds and is considered to be of Baikalian (Late Vendian) age. Photo: D. Roberts.

Fig. 33. Thin-bedded, silty sandstones and cleaved shales of the Skarbeevskaya Formation, Cape Kiyski, with an erosively based, pale grey, silty sandstone layer in the middle of the picture. Photo: D.Roberts.

deformation structures, slide scars, and small synsedimentary faults (Fig. 30b). The lithological association is interpreted as having been deposited from low-density turbidity currents (Siedlecka et al. 1995b).

According to Negrutsa (1971) the formation differs from the Zubovskaya Formation in that it does not contain thick sandstone beds, whereas carbonate rocks and concretions are more abundant. The contact between the two formations is considered by us to be of transitional character. Lithologically, the shale of the Tsypnavolokskaya Formation is similar to that in the subjacent formation, but has a darker coloration and contains abundant pyrite mineralisation. Pyrite occurs as large crystals along bedding planes and in concretions. The shales exhibit thin horizontal bedding indicative of a calm marine environment.

We have examined and sampled the Tsypnavolokskaya Formation on the eastern coast of the Rybachi Peninsula for petrographic and chemical studies (Lyubtsov et al. 1989). In contrast to Negrutsa (1971), who considered sandstones to be absent, our observations showed that sandstone of greywacke composition and siltstone with clay admixtures are abundant in the Tsypnavolokskaya Formation, whereas mudstone is subordinate (Table 7). The sandstones, and especially the siltstones, commonly contain abundant chlorite in the cement; dark grey and black siltstones and rare mudstones containing disseminated pyrite do not have higher contents of organic carbon. Thus, even the most fine-grained shale, which is common in the Tsypnavolokskaya Formation, shows a low degree of sedimentary maturity.

Skarbeevskaya Formation. This 500 m-thick formation in northwestern Rybachi consists of grey, medium- to fine-grained, polymict sandstone, alternating dark grey siltstone, mudstone, marl and limestone, and beds of black and dark grey clayey shale (Negrutsa 1971) (Figs. 32 & 33). The basal parts of the 15-40 m-thick mesorhythms locally contain lenses of small- and medium-pebble conglomerates similar to those of the Motovskaya Formation. The pebbles are irregularly rounded, and angular fragments of granite are common in thin-bedded mudstone. Negrutsa (1971) reported phosphorite pebbles in conglomerates. The generally thin-bedded siltstones and mudstones commonly show evidence of slumping and display sole marks on their bedding planes. Further details of sedimentary facies and structures are given in Siedlecka et al. (1995b).

Negrutsa (1971) considered the Skarbeevskaya Formation to be similar to the Lonskaya Formation of the Einovskaya Group. However, these two formations show differences in their contents of sandstone and shale, and in the average grain size of fragments in sandstone and conglomerate. Negrutsa explained the differences by lateral facies changes. Siedlecka et al. (1995b), on the other hand, considered that parts of the Skarbeevskaya Formation are lithologically similar to the Zubovskaya Formation.

As noted earlier, the Skarbeevskaya Formation is juxtaposed against formations of the Bargoutnaya and Einovskaya Groups along a tectonic contact. This is a south-dipping reverse fault, informally termed the *Mainavolok fault* by Roberts & Karpuz (1995).

3.6 Neoproterozoic rocks of the Tersky Coast of the White Sea

The Neoproterozoic sedimentary rocks of the Tersky coast of the White Sea are exposed in three different areas of the southern Kola Peninsula and represent three stratigraphic levels (Fig. l). The oldest, based on microfossils, is the Early-Middle Riphean Turyinskaya

Formation (Sergeeva et al. 1971, 1974). The next unit, the Terskaya Formation, is considered to be of early-Late Riphean age (Sergeeva et al. 1971, 1974), while the Chapomskaya Formation is Latest Riphean (Timofeev 1969, Konoplyova & Fanderflit 1979, Lyubtsov et al. 1989).

3.6.1 Tury Cape, southernmost part

Sergeeva (1973) examined in detail the geology and stratigraphy of the Neoproterozoic successions along the southern coast of the Kola Peninsula, and presented a description of the 255 m-thick *Turyinskaya Formation*. According to this author, the Turyinskaya Formation is exposed in a narrow strip only on the southernmost part of Tury Cape.

The section through the formation (Fig. 34) starts with a basal, gravel-pebble, oligomictic conglomerate that transgressively overlies the granitoids of the Umba Complex. The conglomerate is 7.7 m thick. It is overlain by 6 sandstone units, in ascending order: 1 – quartzitic, mostly medium-grained, cross-bedded sandstone, 15 m thick; 2 – horizontally bedded, poorly sorted sandstone, 4.5 m; 3 – poorly sorted sandstone, 12 m; 4 – grey and greenish-grey, horizontally bedded, poorly sorted sandstone, 81 m; 5 – bluish-green and green, horizontally bedded, fine- and medium-grained sandstone, 35 m; 6 – bluish-grey, horizontally and cross-bedded, fine-grained sandstone, about 100 m. The sandstone units are cut by ultrabasic-alkaline intrusive rocks.

The sandstone units differ mostly in the character of the bedding; mineralogically, the rocks are similar. The proportion of fine-grained sandstone generally increases from bottom to top, and there are intercalations of quartzite and carbonate rock in some places. This is suggestive of a transgressive sedimentation cycle (Sergeeva et al. 1974). According to Sergeeva et al. (1974), the Turyinskaya rocks are shallow-marine, coastal-facies deposits. The orientations of cross-bedding foresets and current ripples in the sandstone indicate that the clastic sediments were transported mainly from the north and northwest.

Plant detritus has been reported from almost all samples collected from the Turyinskaya Formation. This is represented by black angular fragments of plant membranes and black rounded spheromorides, and by silhouette forms of spheromorides. The upper part of the formation is the richest in terms of diverse palaeontological material. Timofeev (in Sergeeva et al. 1971, 1974) reported well-preserved spheromorides and algae. Some samples yielded *Bodaibinia*, which are rounded and oval, dark grey, transparent flat forms, apparently of organic origin, and partly mineralised.

The plant remains in the rocks of the Turyinskaya Formation, according to Timofeev (1969), suggest an Early-Middle Riphean age (the presence of *Kildinella* rules out the possibility of a pre-Riphean age). In general, the microfossil assemblage is similar to that reported from the Upper Riphean Yurmatinskaya Formation in the South Urals. We were not able to confirm these data, and in our opinion, the question of the precise age of the Turyinskaya Formation remains open.

3.6.2 Yulitsa river, lower reaches

The sedimentary succession in the southern part of the Kola Peninsula, known as the *Terskaya Formation*, is part of the Neoproterozoic 'red beds' which occur mostly beneath the

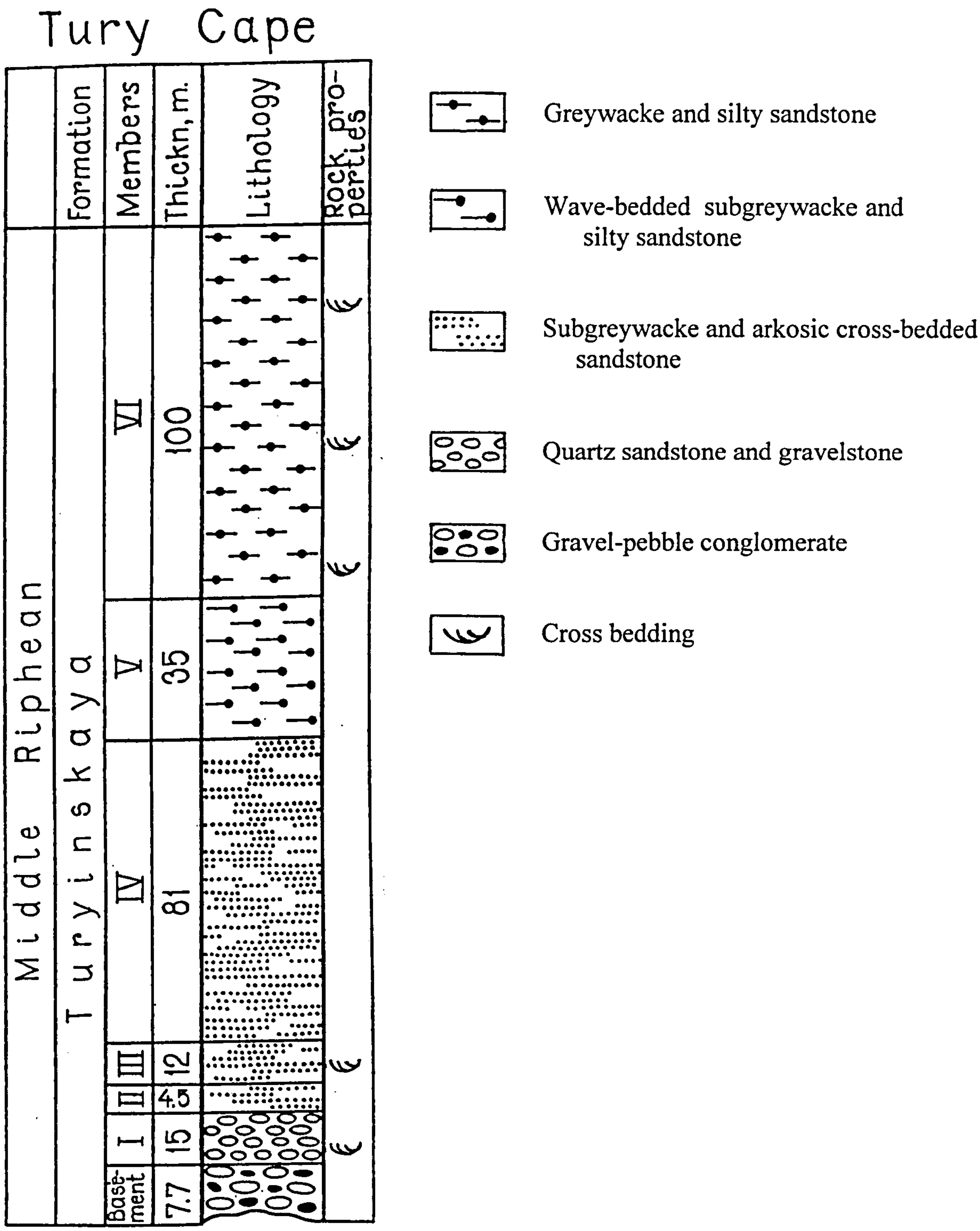

Fig. 34. Stratigraphy of the Neoproterozoic sedimentary rocks of Tury Cape; after Sergeeva et al. (1971).

present-day level of the White Sea. The 'red beds' are exposed in the area of the river Varzuga basin (Lake Kitsa - river Yulitsa), and in the coastal area from the mouth of the river Chavanga to Tury Cape (Fig. 1). The most representative section of the 330 m-thick Terskaya Formation is exposed in the area of the lower reaches of the river Yulitsa (Figs. 1 & 35).

In the summary section of Neoproterozoic sequences of the Kola Peninsula, the 'red beds' occupy the lower part of the Upper Riphean (Sergeeva et al. 1971, 1974). Sergeeva et al. subdivided the sediments into basinal and continental types, distinguished by the nature of the terrigenous rocks and their structural and lithological features. The red-coloured rocks exposed along the southern coast of Kola exhibit features indicative of a variety of facial environments of sedimentation. Alluvial fans facing a shallow-marine basin and possible lacustrine sediments are also present.

The lower part of the Terskaya Formation along the river Yulitsa consists of small-pebble conglomerate that rests with an angular unconformity upon eroded Archaean schists and gneisses. The conglomerate is interbedded with coarse-grained sandstone. The middle part of the section consists of medium-grained sandstone, while the upper part comprises fine-grained, brick-red sandstone containing intervals of bluish-grey siltstone.

The stratigraphic position of the Terskaya Formation and the correlated 'red beds' of the northern and eastern coasts of the Kola Peninsula was finally established when microfossils were found in these sediments. Detailed palaeontological analyses of samples from the Terskaya Formation 'red beds' in the area of the river Yulitsa, the Kashkaransky and Lodochny creeks, the villages Salnitsa and Kuzomen, Tolstik Cape, and the Varzuga and Kitsa rivers, enabled Timofeev (in Sergeeva et al. 1971, 1974) to describe numerous microphytofossils.

On the basis of its lithological composition and microfossil assemblage, the Terskaya Formation is correlated with the lower part of the Serdovskaya Formation and its stratigraphic analogues: the Nenokskaya, Orshanskaya and Pinskaya Formations of the Russian Platform (Sergeeva et al. 1974). The Terskaya Formation, in the opinion of the above investigators, is younger than the Jotnian in Karelia, and this view is supported by the presence of fragments of Jotnian rocks in the red-coloured sedimentary rocks on Kola. The Terskaya Formation has also been compared with the Muhos Formation (Finland) which has an isotopic age of 1300 Ma (Tynni & Silvova 1966). The microfossil assemblage from the Muhos Formation is similar to that of the Terskaya Formation (Tynni 1978). Two samples of silty pelite from the Terskaya Formation from the river Yulitsa have been dated by the K-Ar method at the Institute of Precambrian Geology and Geochronology of the Russian Academy of Sciences, St. Petersburg, at 1263±40 and 1080±40 Ma (N.S. Mikhailova, pers.comm. 1993).

3.6.3 Chapoma river, lower reaches

The base of the *Chapomskaya Formation* is exposed along the lower reaches of the Chapoma River (Fig. 1). The lower part of the 250 m-thick formation consists of red sandstone, siltstone and mudstone (Fig. 36). In the upper part of the formation, there is an alternation of grey sandstone, siltstone and dark grey, almost black mudstone. The rocks of the formation occur in a graben, and are exposed along the river over a distance of about 10 km upstream from the river mouth. Timofeev (in Sergeeva et al. 1971, 1974) examined microphytolites found in the formation and reported a Late Riphean age. In Timofeev's opinion, the Chapomskaya

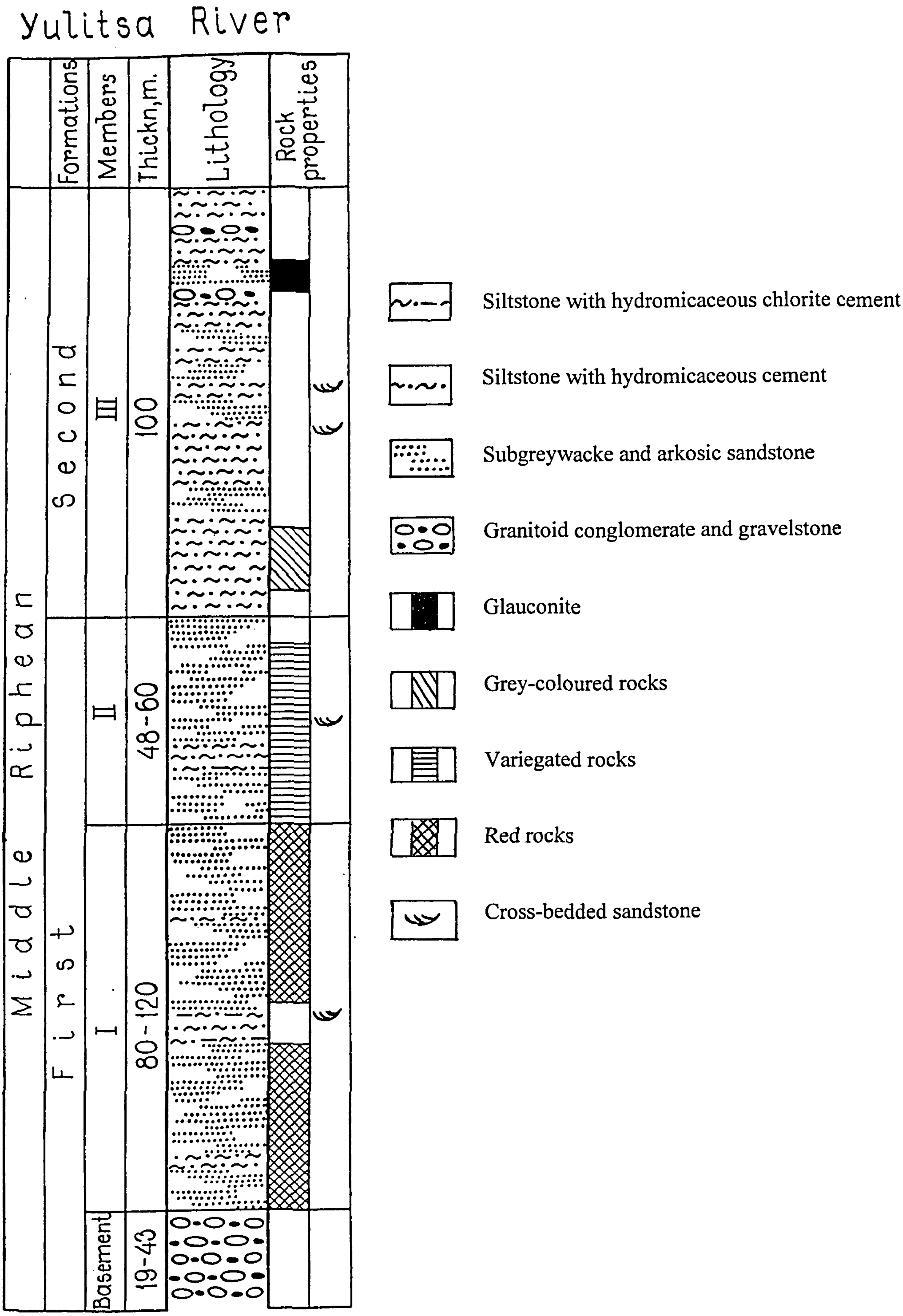

Fig. 35. Stratigraphy of the Neoproterozoic sedimentary rocks of the Terskaya Formation, Yulitsa River; after Sergeeva et al. (1971).

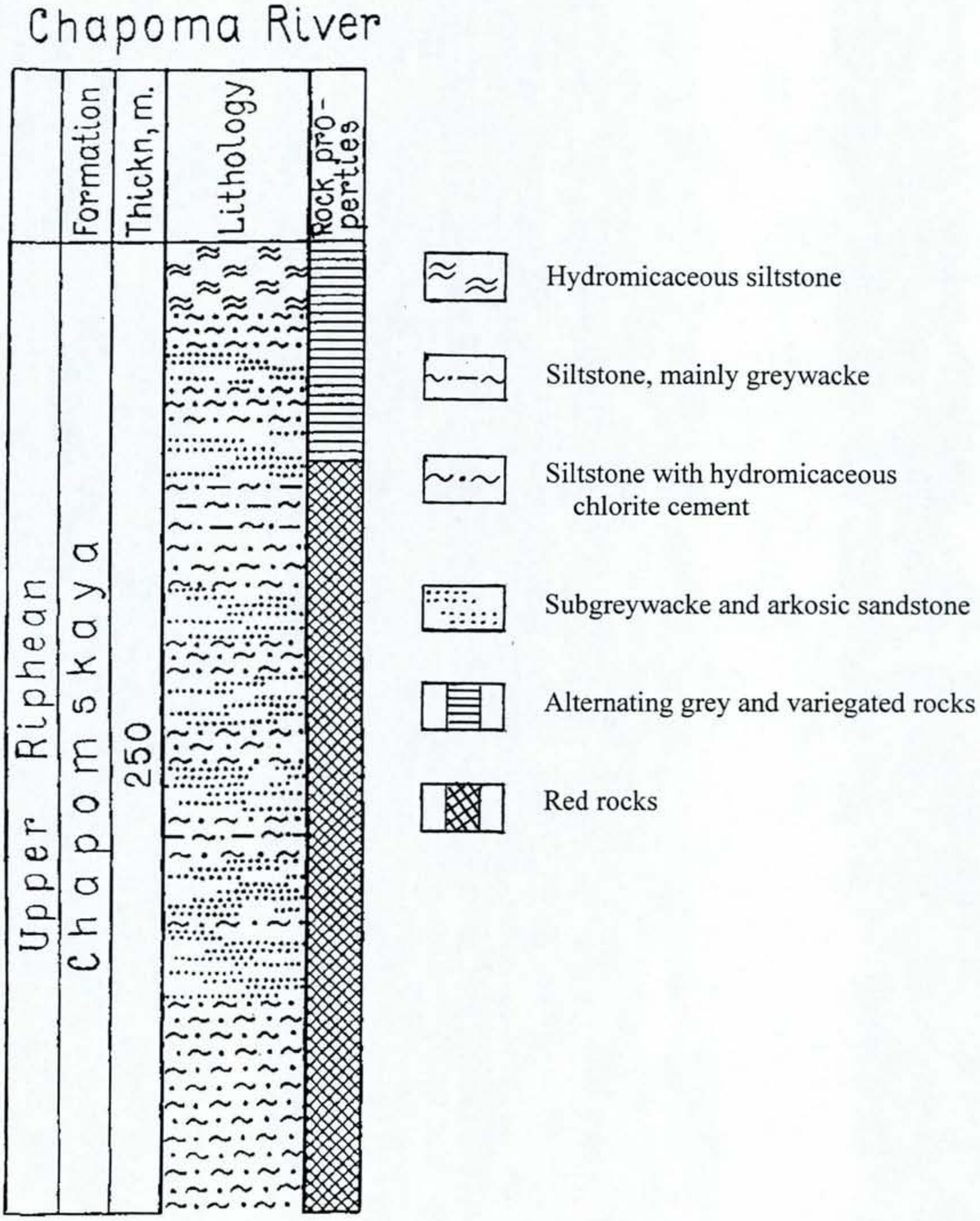

Fig. 36. Stratigraphy of the Neoproterozoic sedimentary rocks of the Chapomskaya Formation, Chapoma River (Lyubtsov et al. 1989).

Formation is a stratigraphic analogue of the upper part of the Kildinskaya Group and also possibly the lower part of the Volokovaya Group of the Sredni Peninsula.

Later, Konoplyova & Flanderflit (1979), Pyatiletov (in Lyubtsov 1980) and Mikhailova (in Lyubtsov et al. 1989) reported a typical Upper Riphean microfossil assemblage and some Vendian microfossils in the Chapomskaya Formation. As well as microphytolites, there are also acritarchs, filamentous algae and fungi (fungi and germinating forms ?), and most of them are diagnostic of the Upper Riphean.

4. MICROFOSSILS OF NEOPROTEROZOIC AGE ON THE KOLA PENINSULA

Microfossils from the Neoproterozoic sedimentary rocks on the Kola Peninsula have been studied by Timofeev (1969), Sergeeva et al. (1974), Ragozina (1971, 1976), Ragozina & Stepkin (1979), Konoplyova & Fanderflit (1979), Pyatiletov (in Lyubtsov 1980), Jankauskas (1989), Mikhailova (in Lyubtsov et al. 1989) and Samuelsson (1993, 1997). Three hundred samples selected by Lyubtsov from Kildin Island, Sredni and Rybachi Peninsulas, and the Turyinskaya and Chapomskaya Formations were examined by Mikhailova (in Lyubtsov et al. 1989), and 252 of the samples yielded microfossils. Samples were selected from a variety of rock-types including mudstone, siltstone, sandstone, carbonate rocks and gravelstone.

The collection of rocks from the Murmansk coast yielded a diverse microfossil assemblage from the Kildinskaya and Volokovaya Groups, and a poor assemblage from the Einovskaya and Bargoutnaya Groups. Results of micropalaeontological studies of the Kildinskaya Group of Kildin Island and the Sredni Peninsula are presented briefly below.

On Sredni, the Kutovaya Formation contained comparatively few taxa (Table 8). Sandstones yielded a poor microfossil assemblage; the microfossils are quite well preserved, brown coloured, and some specimens are corroded and partly pyritised. The relatively low taxonomic diversity is accounted for by deposition in a shallow-marine coastal facies with reworking in the surf zone.

The Iernovskaya Formation contains almost similar microfossil assemblages in both sandstone and siltstone (Table 8). The state of preservation is better than in the Kutovaya Formation. Lithostratigraphical characteristics indicate that there was a plentiful supply of organic material, and that redeposition was limited.

Sandstone and mudstone from the Palvinskaya Formation yielded well-preserved microfossils (Table 8). The specimens are brown and yellow in colour, and their walls are only slightly affected by pyritisation.

Sandstone, siltstone and mudstone of the Poropelonskaya Formation (Table 8) showed a varied microfossil assemblage in a good state of preservation. The microfossils are brown, dark yellow and yellow in colour; their walls are locally pyritised. In places, large acritarchs have been partly destroyed, mostly during diagenesis but also, in part, during the process of sedimentation. Median fracturing is common in these acritarchs.

Sandstone of the Zemlepakhtinskaya Formation (Table 8) yielded a rather varied microfossil assemblage which is, however, poorer than in the two formations mentioned above.

Table 8. Microfossils of the Kildinskaya and Volokovaya Groups (Sredni Peninsula)

Microfossils	Kildinskaya Group						Volokovaya Group	
	Kutovaya	Iernovskaya	Palvinskaya	Poropelon-skaya	Zemlepakh-tinskaya	Karuyarvin-skayr	Kuyakan-skaya	Pumanskaya
Leiosphaeridia crassa (Naum.)	◊	◊	◊	◊	◊	◊	◊	◊
L.holtedahlii (Tim.)	–	–	•	•	•	–	–	•
L.ternata (Tim.)	–	–	•	•	•	•	•	•
L.exculpta (Tim.)	–	–	•	•	•	•	•	•
L.jacutica (Tim.)	–	–	•	•	•	•	–	•
L.kulgunica Jank.	–	–	–	•	–	–	–	•
L.minutissima (Naum.)	–	–	–	•	•	•	•	•
Leiosphaeridia sp.	•	•	•	•	•	•	•	•
Stictosphaeridium sinapticuliferum (Tim.)	•	•	•	•	–	–	•	•
Pterospermopsimorpha pileiformis (Tim.)	–	•	–	•	•	•	–	•
Spumosina rubiginosa (Andr.)	–	–	–	•	•	•	•	•
Simia simica Jank.	–	–	•	–	–	–	•	–
Kirbia multipartita Mikh. Et Volk.	–	–	•	•	–	–	–	–
Satka sp.1	–	–	–	•	–	•	–	•
Trachyhystrichosphaera parva Mikh.	–	•	•	•	•	•	•	•
Valeria lophostriata Jank.	•	–	–	–	•	•	•	•
Leiofusidium dubium Jank.	•	–	–	–	–	–	–	–
Octoedryxium truncatum Rud.	–	–	•	–	–	–	–	–
Symplassosphaeridium sp.	–	–	•	•	•	•	•	•
Synsphaeridium sp.	–	•	•	•	–	•	•	•
Microconcentrica sp.1	–	–	–	–	–	–	–	•
Caudosphaera expansa Hermet Tim.	–	•	–	–	•	–	–	–
Caudosphaera sp.	–	–	–	–	–	–	–	•
Germinosphaera tadasii A.Weiss	–	–	–	–	–	–	–	–
G.unispinosa Mikh.	–	–	–	–	–	–	–	•
Tetrasphaera antiqua Tim. Et Herm.	–	–	–	–	–	–	•	–
Ostiana microcystis Herm.	–	–	•	•	–	–	–	–
Leiotrichoides typicus Herm.	–	–	–	•	•	•	•	•
Polysphaeroides sp.	–	–	–	•	–	–	•	•
Arctacellularia sp.	–	–	–	–	–	–	–	•
A.doliiformis Herm.	–	–	–	–	–	–	–	•
Halythrix sp.1	–	–	–	–	–	–	–	•
Brevitrichoides baahkiricus Jank.	–	–	–	–	–	–	–	•
Oscillatoriopsis sp.	–	–	–	–	–	–	–	•
Bodaibinia	–	–	–	–	–	–	•	–
Assemblages of forma	–	•	•	•	–	•	•	•
Filamentous algae	–	–	–	•	•	•	•	•
Algae sheaths	–	–	–	•	–	–	•	•
Fragments of organic membranes	•	•	•	•	•	–	•	•

• - some ◊ - few — - absent

Table 9. Microfossils of the Kildinskaya Group (Kildin Island)

Microfossils	Korovinskaya	Bezymyan-naya	Chernore-chenskaya	Pridorozhn-aya	Slantsevozer-skaya
Leiosphaeridia crassa (Naum.)	◊	◊	◊	◊	◊
L.exculpta (Tim.)	•	•	—	—	—
L.jacutica (Tim.)	•	•	—	•	—
L.ternata (Tim.)	•	•	•	•	—
L.holtedahlii (Tim.)	—	•	•	•	•
L.minutissima (Naum.)	—	•	—	—	—
L.kulgunica Jank.	—	•	—	—	—
Leiosphaeridia sp.	•	—	•	•	—
Chuaria circularis Wal.	—	•	—	—	—
Pterospermopsimorpha pileifomis (Tie.)	—	—	—	—	—
Spumosina rubiginosa (Andr.)	—	•	—	—	—
Trachyhystrichosphaera parva Mikh.	•	—	—	—	—
T.truncata Herm et Jank.	•	—	—	—	—
Satka sp.1	•	—	—	—	—
Symplassosphaeridium sp.	•	—	•	—	—
Synsphaeridium sp.	•	•	•	•	—
Ostiana microcystis Herm.	•	—	—	—	—
Germinosphaera sp.	•	—	—	—	—
Clavitrichoides rugosus Milkh.	•	—	—	—	—
Leio.trichoides typicus Herm.	•	—	—	—	—
Polysphaeroides sp.	•	—	—	—	—
Bodaibinia	—	—	—	—	•
Filamentous algae	•	•	—	—	—
Algae sheaths	•	•	—	—	—
Assemblages of forma	•	•		•	•

• - some ◊ - few — - absent

Microfossils are well preserved and dark yellow. Some specimens are corroded, pitted and display cracks around their margins.

Mudstone, siltstone and carbonate rocks of the Karuyarvinskaya Formation (Table 8) yielded varied microfossil assemblages in a good state of preservation. The microfossils are brown in colour, corroded, and some are fractured; filamentous algae are slightly pyritised.

The higher taxonomic diversity of microfossils in the Iernovskaya Formation than in the Kutovaya Formation can be accounted for by a decrease in redeposition in the coastal zone. A better preservation and a higher number of taxa in the Palvinskaya and Poropelonskaya Formations can be explained by deposition in a relatively stable basinal environment.

The shallow to moderately deep basinal environments of Poropelonskaya time were accompanied by the 'normal' tendency for microfossil distribution to be at a maximum in mudstone. A greater influx of terrigenous material (e.g. Zemlepakhtinskaya sandstone), on the other hand, resulted in fewer microfossil assemblages. When the sedimentation regime was stabilised again in Karuyarvinskaya time, and basin environments reappeared, the sediments show more profuse microfossil assemblages.

The Volokovaya Group, on the Sredni Peninsula, is lithologically a continuation of the sedimentation processes which characterised the deposition of the Kildinskaya Group. This is also reflected in the state of preservation and diversity of microfossils found in the Volokovaya Group.

The Kuyakanskaya Formation is characterised by the highest number of taxa in sandstone (Table 8). The state of preservation is even better than in the Kildinskaya Group. The specimens are brown and yellow in colour, and cracked walls are rare. Filamentous algae show little sign of corrosion.

Sandstone and mudstone of the Pumanskaya Formation yielded a varied microfossil assemblage (Table 8) with a good state of preservation. The microfossils are brown and yellow in colour, corroded, and display median fracturing and cracks around the margins. Filamentous algae are heavily pyritised.

On Kildin Island, microfossils have been reported from most formations. The distribution of microfossils is similar to that in the correlated part of the Upper Riphean Kildinskaya Group on Sredni, which supports the adopted correlation (see Section 6 and Fig. 41). The microfossil assemblages of Kildin are notable for being most diverse in sandstones.

In the Korovinskaya Formation (Table 9), microfossils are most abundant in sandstone, fewer in number in siltstone and limestone, and are almost absent in dolomite. The microfossils are in a good state of preservation, and brown and dark yellow in colour; cracking is rare and silhouette forms are absent.

The sandstones of the Bezymyannaya Formation (Table 9) yielded *Leiosphaeridia crassa (Naum.)* and well-preserved large species of *Chuaria circularis Wal.* A similar microfossil assemblage is reported from siltstone and dolostone.

The Chernorechenskaya Formation siltstone (Table 9) contains rather well-preserved microfossils, including a few specimens of fractured *Leiosphaeridia ternata (Tim.)* and pitted acritarchs of *L.holtedahlii (Tim.)*. The Pridorozhnaya and Slantsevozerskaya Formation

Table 10. Microfossils of the Chapomskaya Formation

Microfossils	Chapomskaya formation
Leiosphaeridia crassa (Naum.)	◊
L.ternata (Tim.)	◊
L.jacutica (Tim.)	◊
L.kulgunica Jank.	—
L.minutissima (Naum.)	•
L.exculpta (Tim.)	•
Leiosphaeridia sp.	•
Pterospermopsimorpha pileiformis (Tim.)	•
Stictosphaeridium sinapticuliferum (Tim.)	•
Spumosina rubiginosa (Andr.)	•
Octoedryxium truncatum Rud.	•
Satka sp.1	•
Valeria lophostriata Jank.	•
Symplassosphaeridium sp.	•
Synsphaeridium sp.	•
Trachyhystrichosphaera parva Mikh.	•
Trachyhystrichosphaera sp.1	•
Gloviferum deminatum Herm. et Tim.	•
Caudosphaera expansa Herm. et Tini.	•
Germinosphaera unispirosa Mikh.	•
Tetrasphaera antiqua Tim. et Herm.	•
Leiotrichoides typicus Herm.	•
Polysphaeroides sp.	•
Oscillatoriopsis sp.	•
Filamentous algae	—
Algae sheaths	—
Algae trichomes	•
Assemblages of forma	•
Fragments of organic membranes	•

• - some ◊ - few — - absent

Table 11. Microfossils of the Einovskaya Group (Rybachi Peninsula)

Microfossils	Motovskaya	Lonskaya	Perevalnaya	Skarbeev-skaya
Leiosphaeridia crassa (Naum.)	•	◊	•	•
L.Holtedahlii (Tim.)	•	•	•	•
L.ternata (Tim.)	—	•	•	•
L.Kulgunica Jank.	—	•	—	—
L.exculpa (Tim.)	—	•	•	•
Leiosphaeridia sp.	•	•	•	•
Pterospermopsimorpha pileiformis (Tim.)	•	—	—	—
Stictosphaeridium sinapticuliferum (Tim.)	•	—	—	—
Trachyhystrichosphaera parva Mikh.	—	•	—	•
Octoedryxium truncatum Rud.	—	—	—	•
Octoedryxium sp.	—	◊	—	•
Margominuscula rugosa (Naum.)	—	•	—	•
Spumosina rubiginosa (Andr.)	—	—	•	•
Satka undosa (Jank.)	—	—	—	•
Synsphaeridium sp.	•	—	—	•
Bodaibinia	—	•	•	•
Filamentous algae	—	—	—	•
Algae sheaths	—	—	•	—
Assemblages of forma	—	—	•	—
Fragments of organic membranes	•	•	•	•

• - some ◊ - few — - absent

sandstones also contain rather well-preserved microfossils although they are few in number (Table 9).

On Rybachi, the Einovskaya and Bargoutnaya Groups differ from the other sedimentary sequences both in lithofacies development and in fossil content. The low taxonomic diversity and poor state of preservation of microfossils from these groups are evidently caused partly by the high-energy environments of terrigenous sediment accumulation. We suggest that apart from processes which impeded differentiation of the sedimentary material, there were also other factors, for example, possibly temperature and physical-chemical regimes, which were unfavourable for organic development in the Late Neoproterozoic basin of the Einovskaya and Bargoutnaya stages.

In the Einovskaya Group, the Motovskaya sandstone and siltstone are palaeontologically the most profitable sedimentary rocks (Table 11). The microfossil assemblage in the siltstone is poorer in number of taxa, but richer in quantity of specimens than that in the sandstone. The state of preservation is poor. The microfossils are dark grey and black in colour, corroded and pitted. The Lonskaya Formation yielded more microfossils from the sandstone than the siltstone (Table 11). The state of preservation is poor. In the Perevalnaya Formation, microfossils are more abundant in sandstone and siltstone than in other rock-types (Table 11). The state of preservation is poor. In the Skarbeevskaya Formation, some samples of sandstone, siltstone and mudstone are found to contain abundant but poorly preserved microfossils.

Siltstones of the Maiskaya Formation (Table 12) were found to contain a comparatively more abundant microfossil assemblage than the fine-grained sandstones. The state of preservation of the microfossils is generally poor. In the Zubovskaya Formation, sandstone and siltstone, and in the Tsypnavolokskaya formation, silty sandstone contain rare, poorly preserved microfossils (Table 12).

Statistics of microfossil distribution in all the formations investigated on the Kola Peninsula show that the Chapomskaya and Poropelonskaya Formations are characterised by a normal distribution series (mudstone- siltstone- sandstone), whereas the Maiskaya and, in part, Zubovskaya Formations exhibit a siltstone-sandstone series. The most abundant microfossils are generally found in sandstones.

Some features of microfossil accumulation and preservation in the Neoproterozoic sequences of the Murmansk coast can be explained by the fact that this was a tectonically active area confined to the transition zone between the Early Precambrian Fennoscandian craton and a Late Riphean, fault-controlled, mobile, basinal area along its outer margin.

On the Tersky coast, palaeontological material has been acquired only from the Chapomskaya Formation (Table 10). The Turyinskaya and Terskaya Formations have not been studied so thoroughly for microfossils. The Turyinskaya Formation is generally poor in microfossils: only *Leiosphaeridia sp.* and *L.holtedahlii (Tim.)* were found. Re-examination of samples from Timofeev's collections from the Turyinskaya and Terskaya Formations have not confirmed Early-Middle Riphean or early-Upper Riphean ages. The stratigraphic position of these formations is therefore only tentatively established on the basis of Mikhailova's data (Lyubtsov et al. 1989). Further palaeontological analysis is evidently needed.

Microfossils from the Kildinskaya and Volokovaya Groups and the Chapomskaya Formation (Tables 8, 9 & 10) show considerable similarity, according to Pyatiletov (in Lyubtsov 1980)

Table 12. Microfossils of the Bargoutnaya Group (Rybachi Peninsula)

Microfossils	Maiskaya	Zubovskaya	Tsypnavolok-skaya
Leiosphaeridia crassa (Naum.)	•	•	•
L.holtedahlii (Tim.)	•	•	•
L.ternata (Tim.)	•	•	•
L.exculpta (Tim.)	•	•	•
L.minutissima (Naum.)	—	•	—
Leosphaeridia sp.	•	•	•
Spumosina rubiginosa (Andr.)	•	•	—
Stictosphaeridium sinapticuliferum (Tim.)	—	—	•
Trachyhystrichosphaera parva Mikh.	—	—	•
Bodaibinia	—	•	•
Filamentous algae	—	•	—
Fragments of organic membranes	•	•	•

• - some — - absent

Table 13. Microfossil assemblages in Neoproterozoic rocks of the Kola Peninsula

R_2?	R_3				$R_2 - R_3$?		Microfossils
Turyinskaya Fm	Kildinskaya Group		Volokovaya Group	Chapomskaya Fm	Einovskaya Group	Bargoutnaya Group	
Tury Cape	Kildin Island	Sredni Peninsula		Chapoma River	Rybachi Peninsula		
----------	----------	----------	----------	----------	----------	----------	Leiosphaeridia sp. = Protosphaeridium densum Tim.
----------	----------	----------	----------		----------	----------	L.holtedahlii Tim.
	----------	----------	----------	----------	----------	----------	L.crassa (Naum.)
	----------	----------	----------	----------	----------	----------	L.exculpta (Tim.)
	----------	----------	----------	----------	----------		L.ternata (Tim.)
	----------	----------	----------	----------			L.jacutica (Tim.)
	----------	----------	----------	----------	----------		L.kulgunica Jank.
	----------	----------	----------	----------		----------	L.minutissima (Naum.)
	----------						Chuaria circularis Wal.
	----------	----------	----------	----------	----------		Pterospermopsimorpha pileiformis (Tim.)
	----------	----------	----------	----------	----------	----------	Spumosina rubiginosa (Andr.)
	----------	----------	----------	----------	----------	----------	Trachyhystrichosphaera parva Mikh.
	----------						T.truncata Herm. et Jank.
	----------	----------	----------	----------			Satka sp.1
	----------	----------	----------	----------			Symplassosphaeridium sp.
	----------	----------	----------	----------	----------		Synsphaeridium sp.
	----------	----------					Ostiana microcystis Herm.
	----------						Germinosphaera sp.
	----------						Clavitrichoides rugosus Mikh.
	----------	----------	----------	----------			Leiotrichoides typicus Herm.
	----------	----------	----------	----------			Polysphaeroides sp.
		----------	----------	----------	----------	----------	Stictosphaeridium sinapticuliferum (Tim.)
		----------	----------				Simia simica Jank.
		----------					Kirbia multipartita Mikh.et Volk.
		----------	----------	----------			Valeria lophostriata Jank.
		----------					Leiofusidium dubium Jank.
		----------		----------	----------		Octoedryxium truncatum Rud.
		----------		----------			Microconcentrica sp.1
		----------	----------				Caudosphaera expansa Herm. et Tim.
		----------					Caudosphaera sp.
			----------	----------			Germinopphaera tadasii A.Weiss
			----------	----------			G.unisphinosa Mikh.
			----------				Tetrasphaera antiqua Tim. et Herm.
			----------				Arctacellularia sp.
			----------				A.doliiformis Herm.
			----------				Halythrix sp.1
			----------	----------			Brevitrichoides bashkiricus Jank.
				----------			Oscillatoriopsis sp.
				----------			Trachyhystrichosphaera .sp.1
					----------		Globiferum deminatum Herm. et Tim.
					----------		Octoedryxium sp.
					----------		Margominuscula rugosa (Naum.)
						----------	Satka undosa (Jank.)

and Mikhailova (in Lyubtsov et al. 1989). The samples yielded typical Upper Riphean microfossils, such as *Leiosphaeridia kulgunica Jank., Trachyhystrichosphaera parva Mikh., T.truncata Herm. et Jank., Valeria lophostriata Jank., Leiofusidium dubium Jank., Kirbia multipartita Mikh. et Volk., Globiferum deminatum Herm. et Tim., Caudosphaera expansa Herm. et Tim., Germinosphaera tadasii A.Weiss., G. unispinosa Mikh., Tetrasphaera antiqua Tim. et Herm.*, and *Brevitrichoides bashkirikus Jank.* The microfossil assemblage from these units correlates well with assemblages of the Karataevskaya Group in the Southern Urals, the Chernorechenskaya Formation of the Igara region, Dashkinskaya Formation of the Yenisei ridge, Bezymyannaya and Linok Formations of the Turukhan and the Tolparovskaya Formation of the Urals.

The Einovskaya and Bargoutnaya Groups of the Rybachi Peninsula contain a poor assemblage of microfossils (Tables 11, 12 & 13). The Båsnæring Formation of the Barents Sea Group of Varanger Peninsula is also characterised by a low number of taxa (Vidal & Siedlecka 1983). Two samples were examined by Vidal. One sample (FA-11/77) yielded poorly preserved, strongly corroded, dark grey to black fragments of *Kildinosphaera sp.* and *Trachysphaeridium sp.* The other sample (NMb/L) yielded dark brown, better preserved specimens of *Leiosphaeridia asperata (Naum.), Kildinosphaera chagrinata Vidal, K.granulata Vidal, Trachysphaeridium sp., cf. Stictosphaeridium sp.* and *Chuaria circularis Wal.* (up to 125 μm). Taking into account a revision of type microfossils of the Precambrian of the former USSR, the genera *Kildinosphaera* and *Trachysphaeridium* are junior synonyms of *Leiosphaeridia sp.* Therefore, sample FA-11/77 actually contains only *Leiosphaeridia sp,* and sample NMb/L - *Leiosphaeridia crassa (Naum.), L.exculpta (Tim.), L.jacutica (Tim.), L.atava (Naum.), L.sp., cf. Stictosphaeridium sp.* This microfossil assemblage, according to Mikhailova (in Lyubtsov et al. 1989), is similar to the assemblages found in the Einovskaya and Bargoutnaya Groups.

Diagnostic microfossils of Vendian age (*Bavlinella faveolata Sphep., Retiforma tolparica Mikh., Podoliella irregulare Tim.*) have not been found in the examined rocks.

5. HYDROCARBONS AND ORGANIC CARBON IN THE NEOPROTEROZOIC SEDIMENTARY ROCKS OF NORTHWESTERN KOLA PENINSULA

It is widely recognised that the shelf areas of offshore northern Russia have a considerable hydrocarbon potential. The prospects for oil and gas in the Phanerozoic sedimentary rocks of the shelf areas have been discussed in numerous publications (e.g. Sokolov 1978, Malyshev 1998).

New data obtained by some of the present authors (Lyubtsov et al. 1981, 1994) suggest that parts of the Neoproterozoic sedimentary sequences on the Barents Sea shelf may be promising targets for gas, and to a lesser extent, oil. Our views are in accord with the earlier suggestions concerning widespread biogenic organic material in the Late Precambrian sedimentary and metasedimentary rocks of this region (Sidorenko & Sidorenko 1975). These suggestions relate to the concept formulated by the cited authors about 'hydrocarbon respiration' of Precambrian sedimentary sequences as a source of 'fluid organic material' both in the Precambrian rocks and in overlying Phanerozoic cover sequences (Sidorenko & Sidorenko 1975, Sidorenko & Tenyakov 1978).

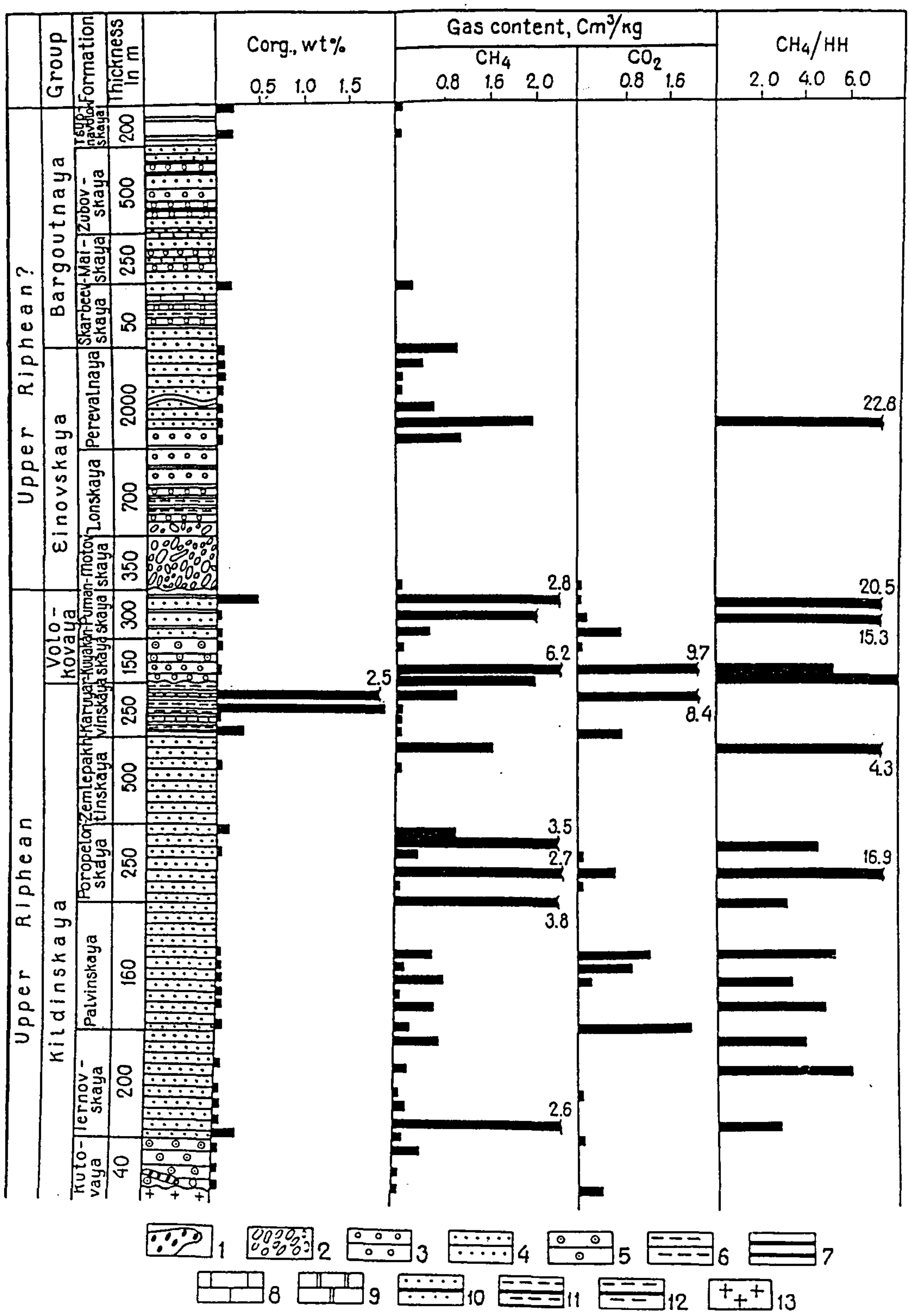

Fig. 37. Distribution of C_{org} and hydrocarbon gases in the Riphean sedimentary rock successions of the Sredni and Rybachi Peninsulas (Lyubtsov et al. 1981).

1 – polymict conglomerate, 2 – monomict conglomerate, 3 – gravelstone, 4 – sandstone, 5 – feldspathic-quartzitic and arkosic sandstone, 6 – siltstone, 7 – mudstone, 8 – limestone, 9 – dolomite, 10 – clayey sandstone, 11 – silty mudstone, 12 – clayey siltstone, 13 – granite and granite-gneiss of the crystalline basement.

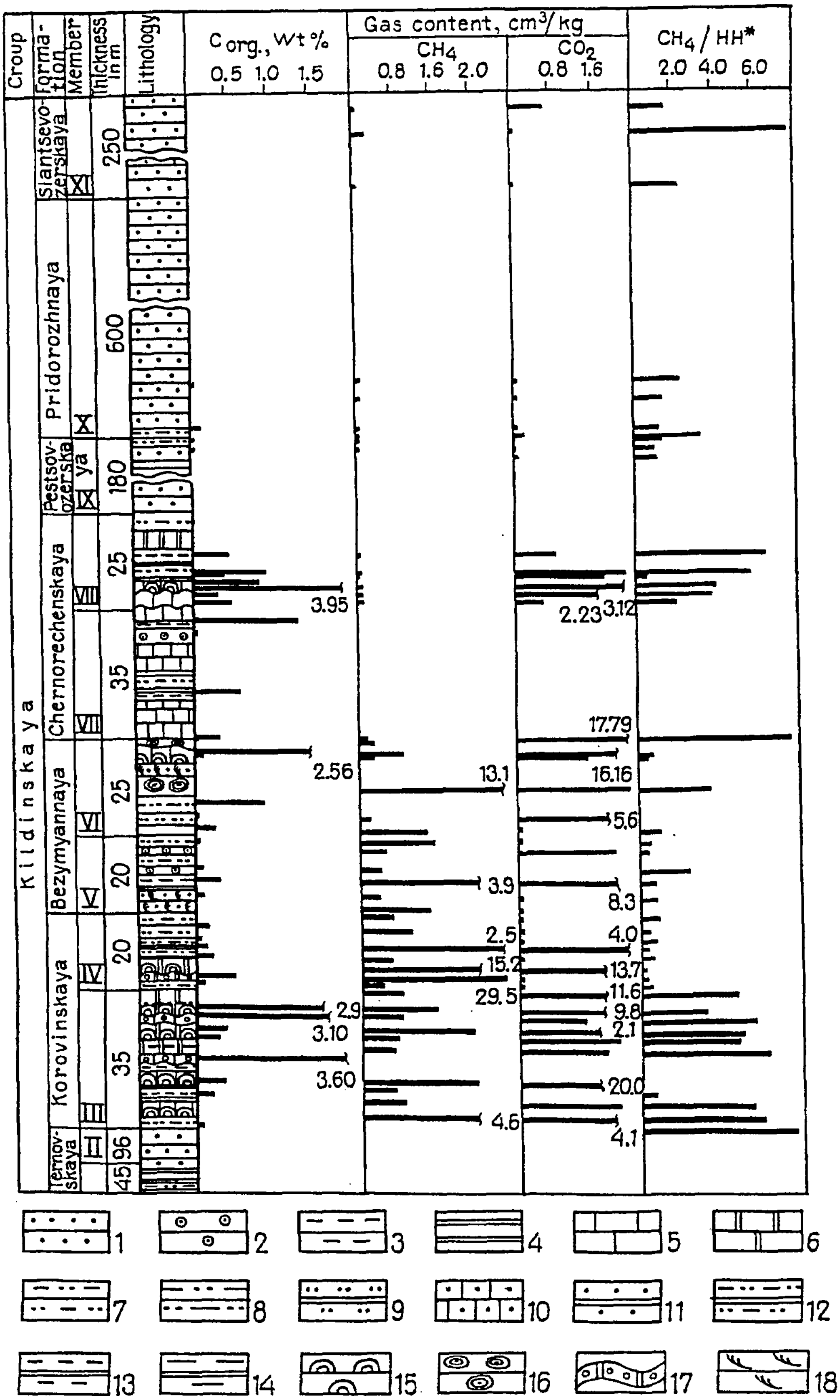

Fig. 38. Distribution of C_{org} and HHG along the section through the Kildinskaya Group, Kildin Island (Lyubtsov et al. 1981).

1 – Subgreywacke, partly arkosic sandstone; 2 – Feldspar-quartz and arkosic sandstone; 3 – Siltstone; 4 – Clayey shale; 5 – Limestone; 6 – Dolomite; 7 – Subgreywacke and greywacke sandstone and siltstone; 8 – Silty, feldspar-quartz sandstone; 9 – Sandy, clayey shale; 10 – Limy sandstone; 11 – Clayey sandstone; 12 – Clayey, silty sandstone; 13 – Silty, clayey shale; 14 – Clayey siltstone; 15 – Stromatolites; 16 – Oncolites; 17 – Synsedimentary breaks; 18 – Cross bedding; 19 – Granite and granite-gneiss of the crystalline basement.

This chapter is concerned with the possible role of Neoproterozoic sedimentary rocks in the hydrocarbon potential of the Barents Sea shelf in areas adjacent to the Kola Peninsula (Fig. 1). The data presented include information on contents of hydrocarbon gases, organic carbon and bitumens in the Upper Riphean rocks of the northwestern Kola Peninsula, that are similar to those of gas-condensate and petroleum-bearing Phanerozoic sequences. The study is based on sample collection and field observations made by the authors during lithological and geochemical examinations of the Neoproterozoic rocks on the Sredni and Rybachi Peninsulas, Kildin Island and the Kola coast carried out in the period 1974-1978. Hydrocarbon gases and bitumen in these rocks were investigated by Petersilje and Pavlova (in Lyubtsov et al. 1981) at the Laboratory of Gases and Bitumen at the Geological Institute of the Kola Science Centre of the USSR (now Russian) Academy of Sciences. The distribution of Neoproterozoic rocks in the southern parts of the Barents Sea was first described by Verba (in Belkov et al. 1979), and more recently by Verba et al. (1998). The early data were subsequently summarised and interpreted jointly by Lyubtsov et al. (1981) and Lyubtsov & Predovsky (1981). A more detailed summary and interpretations are contained in Mitrofanov & Sharov (1998).

Samples were collected along profiles on Kildin Island, from Cape Koroviy to the northern coast across the strike; on the Sredni Peninsula, from the northern coast of Malaya Volokovaya Bay to Poropelon Lake in the north, and from the southern coast of Bolshaya Volokovaya Bay to the south, through rocks of the Karuyarvinskaya Formation and Volokovaya Group; and on the Rybachi Peninsula, in the western and eastern parts of the peninsula (Fig. 2). In total, 152 samples were taken for this study.

Some samples of sedimentary rocks (Figs. 37 & 38) yielded high contents of hydrocarbon gases, reaching 53.4 cm^3/kg of rock. Compositionally, the gas of the Neoproterozoic sedimentary rocks differs considerably from gases in other Precambrian rocks of the Kola Peninsula. It is enriched in heavy hydrocarbon gases (HHG) (C_2-C_5) and, consequently, the $C_1/(C_2$-$C_5)$ ratio is low.

Hydrocarbon gases (HG) are distributed irregularly. The average content of HG in the samples with high CH_4 contents is as follows (vol. %):

CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_5H_{12}	CH_4/HHG
76.12	13.25	5.42	3.56	1.62	3.2

The CH_4/HHG ratio in the samples with increased contents of methane varies from 2.4 to 40, which is similar to that in gases of Phanerozoic sedimentary sequences (see below). The ratio of methane (which has a higher stability at high temperatures) to less stable HHG can serve as one of the indicators of metamorphism in biogenic hydrocarbon compounds. The methane to HHG ratio in hydrocarbon gases of selected Phanerozoic deposits is as follows:

Komi Republic	Gas deposits	from 11.3 to 57.28
Komi Republic	Gas-condensate	2.35
Canada	Gas	from 5.96 to 85.7
Canada	Gas-condensate	from 8.10 to 12.48
Orenburg Region, Russia	Gas-condensate	from 4.30 to 9.69
Perm Region	Gas-oil	from 2.90 to 3.45
Saratov Region	Gas-oil	from 5.96 to 23.66

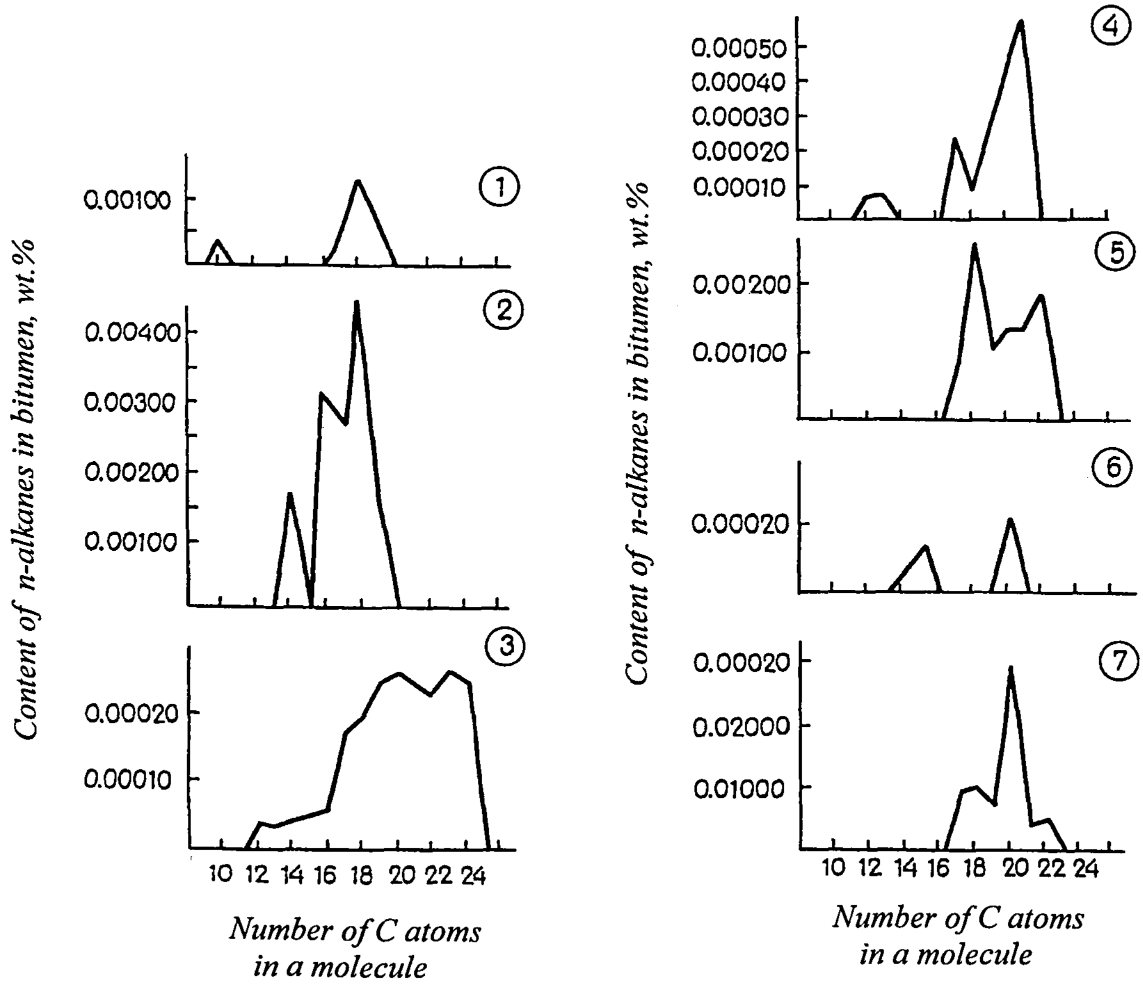

Fig. 39. Gas chromatograms from samples of sedimentary rocks from the Kildinskaya Group; content of n-alkanes versus molecular weight in bitumens. 1, 2, 3 – carbonate rocks; 4, 5, 6 – sandstones; 7 – siltstone.

The CH_4/HHG ratio in Riphean rocks of the southern part of the Kola Peninsula (Tury Cape) is 11.8, which thus broadens the area of oil potential of the Neoproterozoic successions.

High HG contents are found in samples of sandstone and carbonate rocks of the Korovinskaya and Bezymyannaya Formations of Kildin Island and the Poropelonskaya, Kuyakanskaya and Pumanskaya Formations on Sredni Peninsula (Figs. 38 & 39). In most of the samples, hydrocarbon gases are contained in the rocks where organic carbon is generally absent. This suggests that the HG are of epigenetic character and were migrating into the host rocks with high effective porosity. According to Tyuremnov & Galichanina (1976), the open porosity in the sandstones varies from 1.2 to 4.0 %.

High HG contents in the lower part of the Kildinskaya Group of Kildin Island (Korovinskaya and Bezymyannaya Formations) and in the Karuyarvinskaya Formation on Sredni Peninsula are found mostly in heterogeneous parts of the section, consisting of various carbonate rocks, marls, shales and sandstones. This fact, in conjunction with the suggested epigenetic nature of the HG and their similarity in composition to HG of Phanerozoic sedimentary sequences, can indicate that these hydrocarbon gases could migrate, and could have been derived from Phanerozoic sequences of the Barents Sea depression.

Some of the samples examined in this study contain high organic carbon contents (Figs. 37 & 38). Organic carbon is irregularly distributed in the rocks, and it is contained mostly in dolomite and siltstone (Figs. 37 & 38). The following table presents the average organic carbon content in various rocks of the Kildinskaya Group of Kildin Island:

Rock-type	Number of samples	Organic carbon content, wt.%		
		Average	minimum	maximum
Sandstone	30	0.10	0.01	0.92
Siltstone	20	0.21	0.01	1.47
Limestone	11	0.11	0.02	0.47
Carbonate rocks	4	0.17	0.00	0.64
Dolomite	17	0.86	0.01	3.95

The highest C_{org} contents are found in microgranular dolomite containing clayey and sandy carbonate beds. The clayey carbonate beds contain thin interbeds enriched in organic material.

The distribution of C_{org} in the formations and members of the Kildinskaya Group on Kildin Island is illustrated in the following table:

Formation	Member	Number of Samples	C_{org} content, wt.%		
			Average	min	max.
Slantsevozerskaya	XI	6	0.03	0.01	0.03
Pridorozhnaya	X	4	0.04	0.01	0.09
Pestsovozerskaya	XI	5	0.05	0.02	0.10
Chernorechenskaya	VIII	7	0.32	0.01	0.89
Chernorechenskaya	VII	6	1.02	0.00	3.95
Bezymyannaya	VI	11	0.43	0.01	2.56
Bezymyannaya	V	10	0.08	0.00	0.29
Korovinskaya	IV	16	0. 16	0.01	0.64
Korovinskaya	III	28	0.30	0.02	3.60

High C_{org} contents are commonly characteristic of the rocks of the Korovinskaya, and upper parts of the Bezymyannaya and Chernorechenskaya Formations.

From lithological and geochemical evidence, the high C_{org} contents in the Kildinskaya Group are confined to the sedimentary facies that are transitional from shallow- to intermediate-depth basinal environments. The overlying formations, consisting mostly of sandstone, do not have high C_{org} contents.

The following distribution of disseminated C_{org} is established in the Riphean sequences of the Sredni Peninsula:

Group	Formation	Number of samples	C_{org} content, wt/% average	min.	max.
Volokovaya	Pumanskaya	4	0.03	0.01	0.06
	Kuyakanskaya	9	0.02	0.01	0.03
Kildinskaya	Karuyarvinskaya	8	0.38	0.02	2.61
	Zemlepakhtinskaya	3	0.01	0.01	0.02
	Poropelonskaya	5	0.08	0.04	0.17
	Palvinskaya	8	0.02	0.01	0.04
	Iernovskaya	8	0.05	0.01	0.15
	Kutovaya	4	0.01	0.00	0.17

Dispersed bituminous material was extracted by means of chloroform from seven rock samples from the Kildinskaya Group on Kildin Island. The samples (sandstone, carbonate rocks and siltstone) were small and it was possible only to estimate the total amount of bitumen in the rocks, the content of paraffins and their compositions. The amount of bitumen extracted varied from 0.0011 wt.% in sandstone to 0.0086 wt.% in limestone. The bituminous material of different rocks and sequences was compositionally different, which testifies to its relationship with the host rocks.

The bitumens extracted from carbonate rocks of member IV were oily, brown in colour and have a somewhat pleasant smell. Gas chromatograms show that the paraffins from carbonate rocks are composed mainly of liquid normal alkanes (Fig. 39). The extracted hydrocarbons from all rock-types show a maximum of the n-alkane distribution at C_{18}. Bitumen from sandstone had similar physical properties to bitumen from carbonate rocks. However, the former contained a wider range of paraffin compounds: fluid and solid paraffins, and compounds of normal and isostructures. Bitumens from sandstones have one feature in common: compounds with an even number of carbon atoms are predominating in fluid paraffins, and those with an odd number are predominating in solid paraffins.

The distribution of Riphean rocks on and beneath the bottom of the Barents Sea has not been studied in detail. Seismic surveys conducted in the offshore areas near the coast of the Kola Peninsula indicate that the Neoproterozoic terrigenous formations, which are in general similar to those exposed on the Sredni and Rybachi Peninsulas, and Kildin Island, occur along the Murmansk coast in a relatively narrow belt, the width of which decreases from 70-80 km in the western part of the Kola shelf to 30-46 km in the eastern part. Beyond this belt, according to the seismic data the Neoproterozoic sequences, which are interpreted as the uppermost structural complex of the folded basement, thin out rather abruptly. This boundary, which is significant in a tectonic context, has been confidently traced by a seismic reflection survey down to a depth of 10-12 km, and in the more deep-seated areas of the South Barents depression down to a depth of 14-16 km. The upper surface of the Neoproterozoic

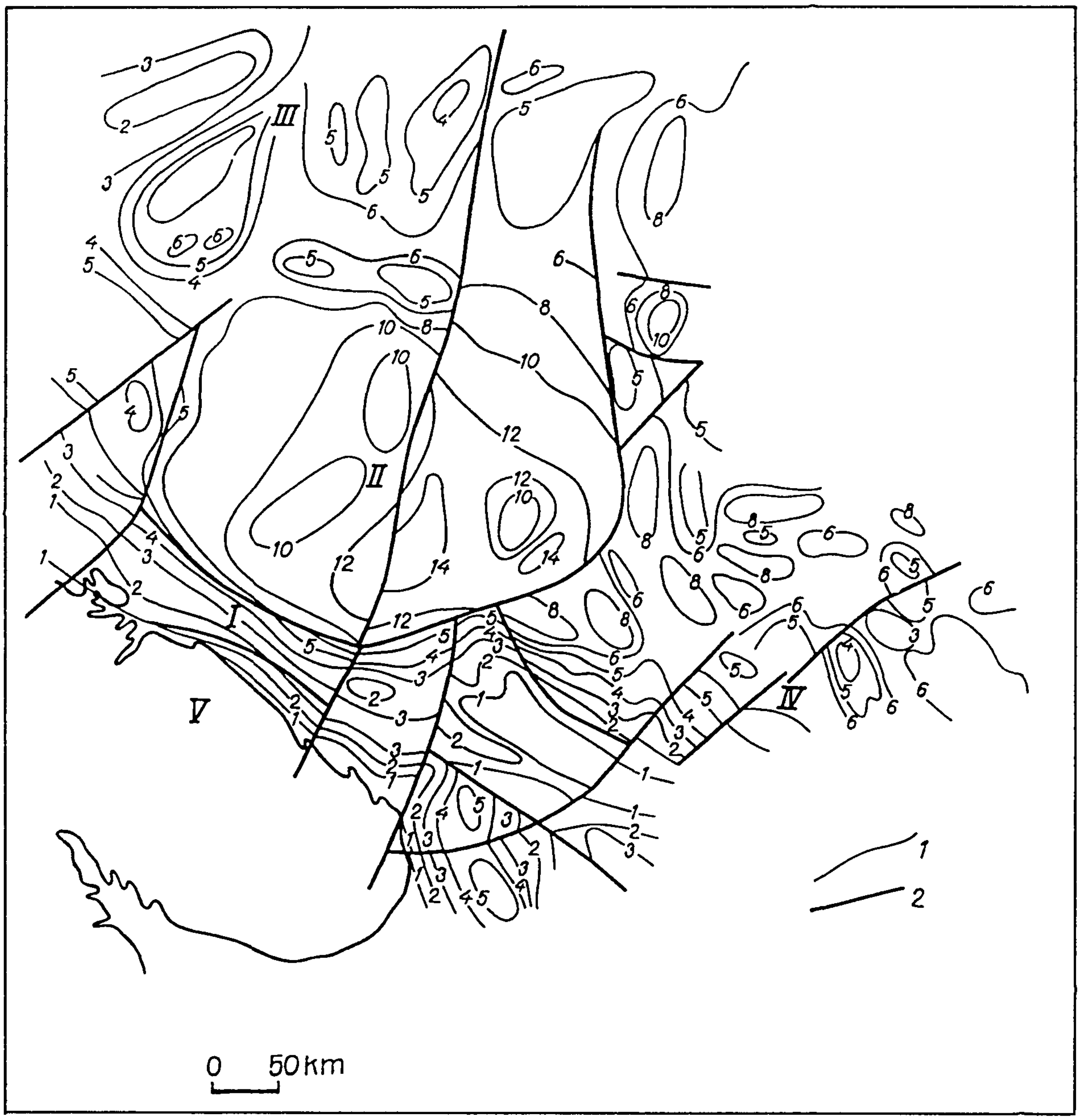

Fig. 40. Depth to the top of the Neoproterozoic sedimentary complexes in the southern part of the Barents Sea (from Verba, in Belkov et al. 1979). 1 -- Structural contours of the roof of the Neoproterozoic rock complexes (depths in km). 2 -- Major faults. I - NW-SE trending Kola-Kanin monocline. II - South Barents depression. III - Central Barents uplift (anticline). IV - Pechora syneclise. V - Kola Peninsula.

sedimentary rock complex is gently inclined (at an average angle of about 2°), and is locally step-faulted (Fig. 40) (Verba et al. 1997, 1998, Dorogan-Sushcheva et al. 1997).

Seismic data suggest that the degree of tectonic deformation in the Neoproterozoic sedimentary rocks offshore tends to decrease towards the north. Specifically, velocities of refracted waves recorded from the basement surface at various points on the profile from Cape Svyatoi Nos (Kola) to Mezhdusharsky Island are markedly higher in the coastal zone than in localities where the basement occurs at greater depths (5.8-6 km/s and 4.9-5.2 km/s, respectively). Farther to the north, in the Central Barents block area, the structure of ancient units is only poorly known. Aeromagnetic surveys and calculated depths to magnetically recorded structures, which are tentatively referred to magmatic complexes of Precambrian (possibly pre-Baikalian) age, indicate that here the basement is uplifted and the Neoproterozoic sedimentary successions can be anticipated at a depth of 4-6 km.

The tectonic setting of the Neoproterozoic rock complex in this region of the shelf is conjectural. On the basis of regional geological reconstructions, the Neoproterozoic successions can here be tentatively assumed as being in subplatform and platform facies as, for example, on Medvezhi Island, northeast of Svalbard, and on Franz Josef Land (Verba et al. 1997).

There are two aspects to consider when estimating the petroleum potential of the Neoproterozoic sedimentary rocks in the southern part of the Barents Sea shelf. Firstly, the occurrence of the Neoproterozoic rocks at moderate depths, a low to intermediate metamorphic grade, a lack of reliable evidence for the existence of structural or stratigraphic traps, and uncertainty about the presence of rocks with reservoir properties do not facilitate a reliable estimation of prospects for hydrocarbon resources. Secondly, these successions were originally represented by sedimentary terrigenous (sandy-clayey) rocks and rarely by carbonate platform formations which would presumably have contained considerable amounts of organic material. Eventually, the earlier terrigenous successions gradually subsided and their subsidence and burial were accompanied by the deposition of younger formations; and subsequently, these sequences went through a stage of thermodynamic alteration favourable for maturation of organic material to hydrocarbons of the petroleum series. This stage of development was called a 'major petroleum-forming stage' by Vassoevich et al. (1976). According to their reconstruction of the history of tectonic evolution of the South Barents depression, the Neoproterozoic lithostratigraphic successions should have passed through this stage at the end of the Palaeozoic. At that time, the volatile, easily migrating components of organic matter were probably moving both laterally and vertically and could have provided epigenetic hydrocarbons to the overlying Phanerozoic rocks, which have good reservoirs, impermeable caps and favourable conditions for fluid accumulation.

The geochemical data presented above indicate the presence of moderate amounts of remanent organic material in the Neoproterozoic sequences, and suggest that the processes of organic maturation and hydrocarbon migration could well have taken place. These rock units can therefore be considered as source rocks which have gone through the major petroleum-forming stage and have lost most of their hydrocarbon potential, in particular the anchizone (subgreenschist facies) rocks of the Einovskaya and Bargoutnaya Groups on Rybachi. This, however, does not rule out the possibility that in some uplifted blocks where the Neoproterozoic rocks occur at accessible depths, epigenetic hydrocarbons (mostly gas) of some commercial importance may still be present.

The main conclusions from the above discussion are as follows:

1. The Neoproterozoic sequences of Kildin Island and Sredni Peninsula contain hydrocarbon gases that, compositionally, do not differ from gases of gas-condensates and oil-gas pools of the Phanerozoic.

2. The diagenesis-grade Kildinskaya Group contains rocks with moderate contents of dispersed C_{org}, formed at the transition from shallow- to moderately deep-marine facies.

3. A low CH_4/HHG ratio in paraffins and the predominance of fluid compounds in dispersed bitumen indicate a low maturity of the organic material.

4. Differences in composition of dispersed bitumen from different rocks and stratigraphic intervals suggest a syngenetic origin for the bitumen.

5. Sandy sedimentary rocks of the Upper Riphean successions could have, and can still serve as reservoirs for hydrocarbons.

6. A summary of the results from the recent investigations suggests that there is a possible, but limited gas potential for the Neoproterozoic successions on the Barents Sea shelf, although this is more likely to favour gas accumulations rather than oil. These sedimentary rocks could have been one of the sources of hydrocarbons for the overlying Phanerozoic sedimentary sequences, and in some structurally favourable cases they could have been, and could still be, the host rocks for commercial gas accumulations.

6. DISCUSSION AND CONCLUSIONS

An important factor influencing our general understanding of the geology and stratigraphy of the Neoproterozoic sedimentary rocks in the northwestern Kola region is the presence of the long-lived, c.NW-SE trending fault zone that separates the greater part of the Rybachi Peninsula from the Sredni Peninsula and Aynov Islands. Structurally, the domain northeast of the fault zone (hereafter called the Rybachi Region) is notable for its higher degree of folding, faulting and low-grade metamorphism and cleavage development than the southwestern area (Kildin Region) which is characterised by insignificant deformation and only diagenesis-grade alteration. As the two regions consist of different Neoproterozoic sequences, it is therefore impossible to unambiguously determine the age relationships between the stratigraphic units exposed on either side of the fault zone. On the other hand, the stratigraphic relationships between the formations within each region seem to be fairly well understood.

In the Rybachi Region, the lithostratigraphic section starts with the Einovskaya Group, the basal part of which is not exposed. In the area of Cape Vestnik, the lowermost strata are dark shales which grade up into the breccias and conglomerates of the Motovskaya Formation. At the boundary between the Einovskaya and Bargoutnaya Groups there is evidence of tectonic movements at this time. As the Tsypnavolokskaya Formation, which terminates the Bargoutnaya Group, dips beneath the Barents Sea, the upper boundary of this group is not exposed. The precise stratigraphic relationship between the Skarbeevskaya Formation and the Einovskaya and Bargoutnaya Groups is not clear because of the presence of the fault contact between them.

In the Kildin Region, the lowermost formation of the Kildinskaya Group, the Kutovaya, rests transgressively upon the Archaean basement in the southernmost part of Sredni. As there is no weathering crust on the Archaean granite-gneiss (despite a long time gap), this indicates that a period of erosion predated the deposition of the Kutovava Formation. Older, as yet undiscovered members of the Kildinskaya Group may also be present beneath Sredni, something that can be revealed only by deep drilling.

Within the Kildinskaya Group, four major levels corresponding to stages of basin development can be tentatively distinguished. The first level, represented by the Kutovaya and Iernovskaya Formations, is evidently transgressive. The second level comprises the Palvinskaya Formation on Sredni and the correlated Korovinskaya, Bezymyannaya and Chernorechenskaya Formations on Kildin. This level is characterised by a gradual stabilisation of the tectonic regime of sedimentation. The third level is represented by the Poropelonskaya and Zemlepakhtinskaya Formations on Sredni and the correlative Pestsovozerskaya, Pridorozhnaya and Slantsevozerskaya Formations on Kildin. This is a transgressive-regressive level, with a rather more homogeneous composition than in the second level. The fourth level is known only on Sredni, represented by the Karuyarvinskaya Formation. The deposition of this formation ended with a hiatus and partial erosion.

The deposition of the Volokovaya Group, starting with the Kuyakanskaya Formation, marks a significant stage in the development of the Kildin Region. Our observations have shown that, during the deposition of the Kuyakanskaya Formation, tectonic activity increased sharply leading to submarine slumping and the formation of olistostromes. The preceding stabilisation of the regime and the hiatus led to the formation of high-silica rocks; the quartz-rich and feldspathic-quartzitic gravelstones and sandstones of the Kuyakanskaya Formation.

The precise stratigraphic age of the various units in the Rybachi and Kildin Regions is an open question. The microfossil assemblage from the Rybachi Region (Einovskaya and Bargoutnaya Groups) does not give a clear answer. However, the diversity and poor state of preservation of the palaeontological material can be indicative of a relatively old age (Early Upper Riphean) for the sedimentary rocks of the Rybachi Region.

The microfossil assemblage of the Kildinskaya Group suggests a Late Riphean age. The same age may be suggested for the Volokovaya Group, although the possibility that it may extend up into the Vendian is, in our view, still open to discussion.

The major structural contact separating the Rybachi and Kildin Regions evidently continues to the northwest as the Trollfjorden-Komagelva Fault Zone of the Varanger Peninsula, where the fault zone separates two structural-facial regions: the Barents Sea Region to the northeast and the Tanafjorden-Varangerfjorden Region to the southwest (Siedlecka & Roberts 1992). These regions of Varanger Peninsula show differences similar to those found between the Rybachi and Kildin Regions. To the southeast, the fault zone apparently continues to the north of Kildin Island and along the northeastern coastline of the Kola Peninsula. It then crosses the Kanin Peninsula south of Kanin Śtone Ridge (Pae) and extends to the Timans (Siedlecka 1975, Olovyanishnikov et al. 1997 and in press, Roberts & Siedlecka 1999). In the Kanin-Timan region, the fault also separates a northeastern zone, where the Neoproterozoic rocks are deformed and weakly metamorphosed, from a southwestern zone where the rocks are less deformed and less altered. In other words, the major fault zone represents a fundamental boundary between contrasting structural-facial zones along the periphery of the Neoproterozoic palaeocontinent. These two contrasting sedimentation regimes have been termed pericratonic and basinal, southwest and northeast of the fault, respectively.

Standard scale	Rybachi – Barents Sea zone: Barents Sea subzone: Group	Barents Sea subzone: Formation	Rybachi subzone: Group	Rybachi subzone: Formation	Tana - Kildin zone: Tana subzone: Group	Tana subzone: Formation	Sredni subzone: Group	Sredni subzone: Formation	Kildin subzone: Group	Kildin subzone: Formation	Terski zone: Formation
Vendian	Lokvikfjellet	Skidnefjellet Stordalselva Skjærgardsneset Styret Sandfjorden			Vestertana	Breivika Stappogiedde Mortensnes Nyborg Smalfjord	Volokovaya	Pumanskaya Kuyakanskaya			
Upper Riphean	Barents Sea	Tyvjofjellet Båtsfjord Båsnæringen			Vadsø,Tanafjorden	Grasdalen Hanglecaerro Vagge, Gam-asfjellet, Dakko-varre, Stangenes Grønneset, Ek-Kerøya, Golne-Selva, Paddeby, Andersby, Fu-Gleberget, Klubbnasen, Veinesbotn	Kildinskaya	Karuyarvin-skaya, Zemlepakhtin-skaya, Poropelonskaya Palvinskaya Iernovskaya Kutovaya		Slantsevozerskaya Pridorozhnaya Pestsovozerskaya Bezymyannaya Korovinskaya Iernovskaya	Chapom-skaya
		Kongsfjord	Bargoutnaya	Tsypnavolok-skaya and Skarbeevskaya Zubovskaya Maiskaya							Terskaya (conven-tionally) Turyinskaya (convention-ally)
			Einovskaya	Perevalnaya Lonskaya Motovskaya							

Fig. 41. Correlation scheme for the Neoproterozoic sedimentary successions in the Kola Peninsula coastal regions, Northwest Russia, and the Varanger Peninsula, Northeast Norway, based on structural-facial zoning. Note that in the Tana subzone, the Vendian-Cambrian boundary is placed close to the base of the Breivika Formation, Vestertana Group.

For a general stratigraphic correlation of the Neoproterozoic sedimentary rocks of the Finnmark (Varanger Peninsula) and Kola Regions, it is not only the similarities of the major structural-facial domains of these two regions that are important but also the differences in their lithostratigraphies. It is possible to suggest that the Barents Sea Region of Varanger differs from Rybachi in the fact that it contains not only analogues of the Bargoutnaya Group (Kongsfjord Formation in the Persfjord area (Siedlecka 1992)), but also possible analogues of the Kildinskaya Group (rocks of the Båsnæring, Båtsfjord and Tyvjofjell Formations), which in turn can be correlated with parts of the Tanafjorden and Vadsø Groups. The situation is further complicated, however, because the successions in the Barents Sea Region that are comparable to some units of the Kildinskaya Group occur in a structural setting which is similar to that in the Rybachi Region, i.e., the rocks are strongly deformed and weakly metamorphosed.

The relationships between the stratigraphic successions in the Rybachi and Kildin Regions are tentatively illustrated in Fig.2, profile A-B. It should be noted that the base of the Kildinskaya Group, and also of the Einovskaya Group, is nowhere exposed. Only by carrying out deep drilling along the Sredni-Rybachi profile will we be able to fill these gaps in our knowledge of the history of these tectonically juxtaposed regions.

We also present a tentative correlation scheme between the Neoproterozoic sequences of the Kola Region and the Varanger Peninsula (Fig. 41). This scheme favours a correlation of the upper part of the Rybachi Peninsula section with the Kongsfjord Formation (Siedlecka & Edwards 1980, Pickering 1979, Vidal & Siedlecka 1983).

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