CAMBRIAN AND ORDOVICIAN OF ST. PETERSBURG REGION

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CAMBRIAN AND ORDOVICIAN OF ST. PETERSBURG REGION

Guidebook of the pre-conference field trip

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INTRODUCTION TO THE GEOLOGY OF THE ST. PETERSBURG REGION

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The St. Petersburg region is located at the transition between the southern slope of the Baltic shield and the northern slope of the Moscow basin. Like northern Estonia, it belongs to the Baltic monocline where relatively undisturbed Vendian and Lower Palaeozoic strata are almost flat-lying with a slight dip (2.5-3.5 m per km) to the south. The thickness of the Lower Paleozoic sequence in the St Petersburg region ranges from 220 to 350 m (Cambrian: 120-150 m; Ordovician: 100-200 m).

Ordovician carbonate rocks in the vicinity of St. Petersburg occupy an elevated area called the "Ordovician (Silurian) plateau". The plateau, as can be seen on the geological map, consists of two parts (Fig. 1). The western part is called the "Izhorian plateau" and the eastern part the "Volkhovian plateau". The Ordovician plateau is bounded in the north by a prominent natural escarpment known as the Baltic-Ladoga Glint (Lamansky, 1905) or the Baltic Glint (Tammekann, 1940). The main natural outcrops of Middle Cambrian-Lower Ordovician rocks in the region follow the line of the Glint.

Cambrian and Tremadocian (Ordovician) rocks are represented in the St Petersburg region mainly by unconsolidated clays and quartz sands that contain low diversity faunas of organophosphatic brachiopods, conodonts, phosphatocopids and some problematic organisms. The rest of the Ordovician within the interval from the Arenig to Caradoc is characterized by carbonate sedimentation. A clear trend from temperate to tropical carbonates can be demonstrated. The carbonates are usually rich in bryozoans, brachiopods, trilobites, ostracodes, echinoderms and conodonts. Shells of gastropods, bivalves and cephalopods as well as sponge spicules are also locally abundant.

Since the foundation of St. Petersburg, Ordovician limestones have been the target of extensive quarrying for building purposes. The basements and staircases of all of the buildings in the historical part of the city are made from Ordovician limestone. In most cases individual beds can be recognized within the masonry of these basements. The Lower Cambrian "Blue Clays" are an excellent material for making bricks, whereas the Middle Cambrian pure quartz sand was mined for the glass industry during the last century.

The shells of organophosphatic brachiopods from the Upper Cambrian-Lower Ordovician Tosna Formation are quarried as phosphorite mineral deposits in a number of large quarries between the Narva and Luga river valleys. Middle Ordovician oil shales (kukersite) are mined in the south-west of the region as a fuel for electricity generating stations and for use in the chemical industry. The Middle Ordovician limestones are valuable for the production of lime and Portland cement. Numerous exposures resulting from these economic activities provide excellent opportunities for geological fieldwork and palaeontological sampling.

Detailed study of the Lower Palaeozoic geology and palaeontology of the St. Petersburg region commenced at the beginning of the 19th century. The young British diplomat W. T. H. Fox-Strangways was the first geologist to make a geological map and publish geological observations on the region. He arrived in Russia in 1816, and his first geological article (in French) was published in 1819. In 1824 he summarized his impressions in an article entitled "An outline of the geology of Russia" (Hecker, 1987).

During the next 17 years to 1841, about 90 papers were published on different aspects of the geology of the St Petersburg region. Among the most prominent authors were E. Eichwald, A. Volborth, C. Pander, G. Helmersen and S. Kutorga.

The next few years was marked by the famous geological expedition of R. I. Murchison, sponsored by the Russian government. The result of this expedition was the first geological map of European Russia and the Ural Mountains, as well as the correlation of the carbonate sediments of the St. Petersburg region with the Silurian system of the British Isles and the establishment of the Permian system.

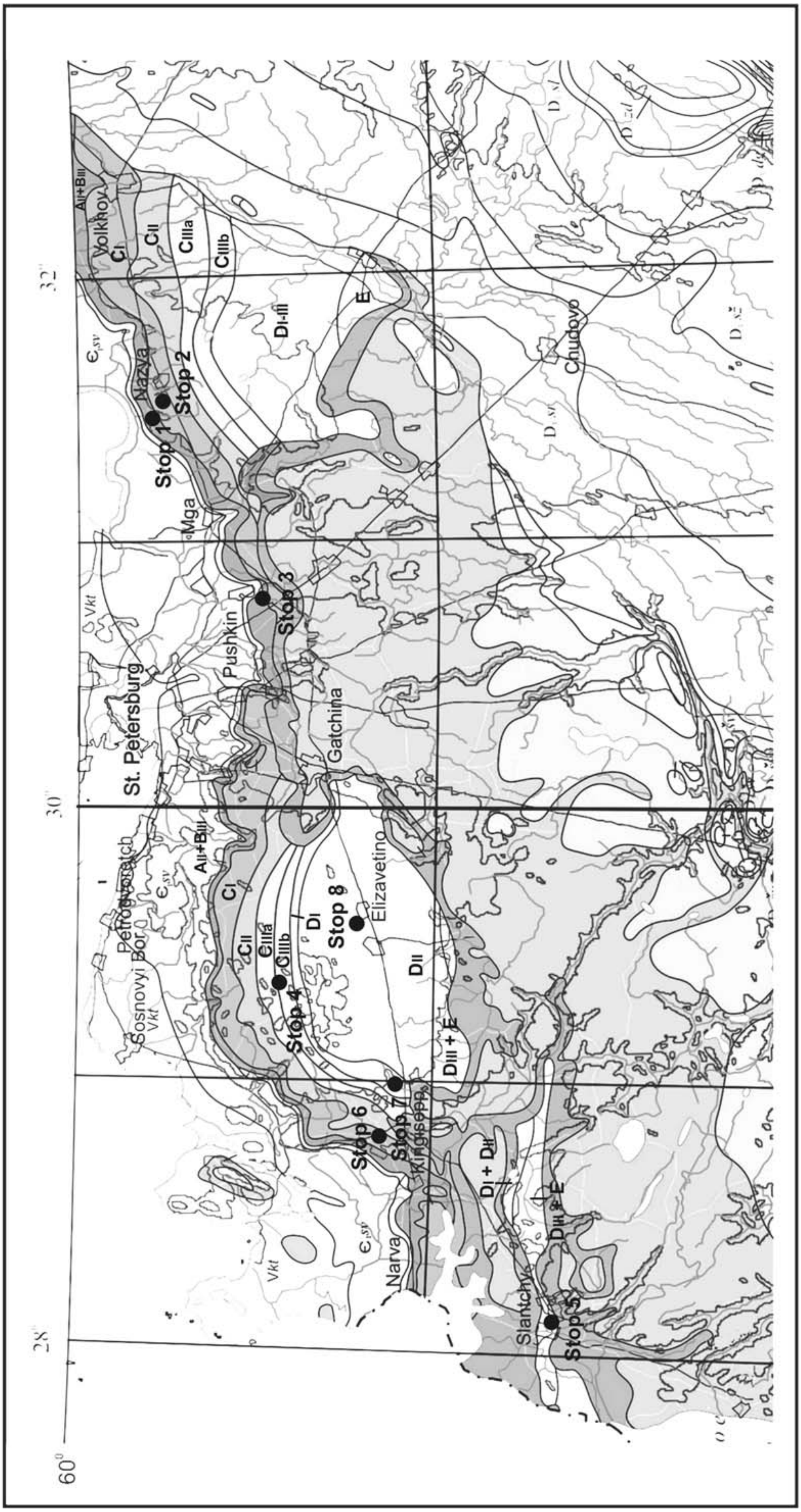

Fig. 1. Geological map of the St. Petersburg Region with the localities visited during the field trip.

In the middle of 19th century important monographs on the paleontology of north-western Russia were published by E. Eichwald, C. Pander and F. Schmidt. Paleontological investigations were accompanied by intensive geological mapping. The first detailed geological map of the St. Petersburg region (1:420 000 scale) was published in 1852 by S. Kutorga after ten years of concentrated fieldwork. A revised geological map of the region was published almost twenty years later by I. Bock. The last part of the 19th century was marked by the works of F. Schmidt who devised an excellent stratigraphic scheme for the entire Lower Paleozoic of the region.

At the beginning of the 20th century a very detailed stratigraphy for the Glint area was made by V. Lamansky (1905) who introduced the α, β and γ indexes for the BII and BIII subdivisions of F. Schmidt. Geological investigations in the region between the two world wars were undertaken by M. Yanischevsky, R. Hecker, L. Rukhin, B. Asatkin and N. Lutkevich. The first boreholes were drilled through the entire Lower Palaeozoic during this time.

After World War 2 the Ordovician of the St. Petersburg region was studied by T. Alikhova (brachiopods), Z. Balashov (cephalopods), T. Balashova (trilobites), and S. Sergeeva (conodonts), as well as numerous geologists from local organizations. The geological evolution of the whole Baltic basin, including the St. Petersburg region, was reconstructed by R. Mannil. Knowledge of the geology of the region was summarized in a multi-authored monograph entitled "Geology of the USSR, v. I, Leningrad, Novgorod and Pskov regions" (Selivanova and Kofman, 1971). Modern research on the region has been undertaken by geologists from St. Petersburg State University, VSEGEI, North-West Geological Survey, St. Petersburg Mining Institute, and the Palaeontological Institute of the Russian Academy of Sciences (Moscow).

CAMBRIAN OF ST. PETERSBURG REGION

The **Lower Cambrian** in the St. Petersburg Region is represented by the Siverskaya Formation (originally defined as the "Blue Clay"). It consists mainly of silty clay (the content of clay minerals commonly does not exceed 30%) with thin interlayers of fine grained sand and silt. In the area, the maximum thickness is 120 m. The "Blue Clay" contain *Platysolenites antiquissimus* Eichwald, *P. lontova* Öpik, *Sabellidites cambriensis* Yanischevsky and a diagnostic assemblage of acritarchs.

The stratigraphic interval from the Middle Cambrian to the lowermost Ordovician (Tremadocian) is represented mostly by quartzose sand and sandstone known as the "*Obolus"* Sandstone; in the past, it has been regarded as the basal unit of the Ordovician. However, Öpik (1929) and Ruhkin (1939) proposed a Cambrian age for a significant part of this unit, and their proposal was substantiated first by the discovery by Borovko (Borovko et al., 1980) of Late Cambrian paraconodonts in the Ladoga Formation in the Izhora river section. The Middle, and most of the Upper Cambrian, is characterized by low diversity assemblages of organo-phosphatic brachiopods, proto- and paraconodonts, providing only a rough correlation with the Cambrian sequence of Baltoscandia.

The **Middle Cambrian** is represented by the Sablino Formation. The lower part of this formation (maximum thickness 11.6 m) consists of laminated and cross-bedded quartzose, coarse to fine grained sand with multidirectional cross-bedding interbedded with thin layers of silt and clay. It does not contain any diagnostic fossils except for an endemic, low diversity assemblage of acritarchs dominated by *Lophomarginata* spp., rare *Aranidium* sp., *Ovulum* sp., *Tasmanites* sp., *Baltisphaeridium* sp. and *Micrhystridium* sp. (Borovko et al., 1984). The upper part of the Sablino Formation usually contains small fragments of obolid shells (*Obolus rukhini* Khazanovich and Popov, *Oepikites macilentus* Khazanovich and Popov, *Obolus transversus* (Pander) and *Oepikites kolchanoivi* Khazanovich and Popov.

The **Upper Cambrian** deposits are represented by the Ladoga Formation. This unit consists of cross-bedded and laminated sand and sandstone interbedded with silt and clay. The lithology and thickness of the Ladoga Formation vary significantly even in adjacent sections, and it is possible that this formation includes several lens-like bodies with complicated stratigraphic and lateral relationships, each of somewhat different age and with its own characteristic fossil assemblages. The lower boundary of the Ladoga Formation is formed by a discontinuity surface with traces of erosion upon the underlying beds of Sablino Formation. The basal layer is usually made up of a coquina of obolids and contains ferruginous ooids up to 1.5 cm in diameter and flat pebbles and boulders up to 70 cm across.

In the eastern part of the Baltic-Ladoga Glint, the Ladoga Formation can be subdivided into two units. The Lower Unit contains a faunal assemblage of organo-phosphatic brachiopods *Ungula* sp., *Oepikites fragilis* Popov and Khazanovich, *Rebrovia chernetskae* Popov and Khazanovich, *Gorchakovia granulata* Popov and Khazanovich, *Angulotreta postapicalis* Palmer, *Ceratreta tanneri* (Metzger), the conodonts *Phakelodus tenuis* Miller, *Furnishina furnishi* Miller, *F. alata* Szaniawski and *Westergaardodina bicuspidata* Miller. Some problematics, like *Torellella? sulcata* Missarzhevski and *Rukhinella spinosa* Borovko also occur. The diversity of organo-phosphatic brachiopods increases significantly compared with the Sablinka Formation. Siphonotretides, acrotretides and conodonts make their first appearance in the sequence.

The Upper Unit is characterized by the brachiopod taxa *Ungula convexa* Pander, *Ralfia ovata* (Pander) and *Keyserlingia reversa* (de Verneuil). The conodont assemblage includes *Phakelodus tenuis* (Miller) together with a diverse assemblage of paraconodonts. Among the later *Furnishina rotundata* (Miller), *Problematoconites perforatus* Miller and *Prooneotodus* aff. *P. gallatini* Miller are the most distinctive forms.

ORDOVICIAN OF ST. PETERSBURG REGION

The Ordovician succession of the East Baltic is now subdivided into 18 or 19 regional stages (Kalio and Nestor, 1990). However, the uppermost Ordovician deposits are absent in the St. Petersburg region (Fig. 2).

The **Pakerort Regional Stage** consists of the upper part of the “Obolus Sandstone” and the “*Dictyonema* Shale”. The former is subdivided into the Lomashka and Tosna formations in the Russian part of the Baltic-Ladoga Glint and adjacent areas (Popov et al., 1989).

The Lomashka Formation is restricted to the area between the Narva and Koporka rivers in the western part of the St. Petersburg region. It rests unconformably on the Lower Cambrian Tiskre and Lukati formations, and consists of laminated and cross-bedded quartz sand and silt with a thin basal brachiopod coquina. Total thickness is about 2.2 m.

The Tosna Formation consists of fine- to medium-grained, cross-bedded quartz sand and sandstone up to 7.5 m thick. In the most complete sections along the Izhora, Lava, Volkhov and Syas river valleys, it rests on the Upper Cambrian Ladoga Formation with some traces of erosion of the underlying deposits and with a basal brachiopod coquina. The shell material is usually reworked from the Ladoga and Lomashka formations. Organophosphatic brachiopods are most abundant in these sections. A complete sequence of conodont zones from *Cordylodus proavus* to *Cordylodus angulatus/ C. rotundatus* is documented.

The Koporie Formation (= “*Dictyonema* Shale”) in the most complete sections between the village of Kotly and the Izhora River consists of bituminous argillite interbedded with fine-grained quartz sand in the lower part, and homogenous black bituminous argillite in the upper part. Total thickness is up to 5.4 m. The formation contains conodonts of the upper *Cordylodus lindstroemi-Cordylodus angulatus/ C. rotundatus* zones, and the graptolites *R. graptolithina* (Kjerulf), *R. rossica* (Obut), *R.* aff. *R. bryograptoides* (Bulmann) and *Anisograptus* sp.

The **Varangu Regional Stage** was introduced by R.Männil as a replacement for the *Ceratopyge* Stage (Männil, 1966). In the eastern part of the Baltic-Ladoga Glint it is represented by the Nazia Formation comprising fine-grained quartz glauconitic sand and clay about 5-30 cm thick that is exposed between the Tosna River and the village of Kipuja. The lower boundary of the Nazia Formation represents an omission surface with traces of submarine erosion of the underlying bituminous argillite of the Koporie Formation. The faunal assemblage includes conodonts of the *Paltodus deltifer* Zone and rare organophosphatic brachiopods.

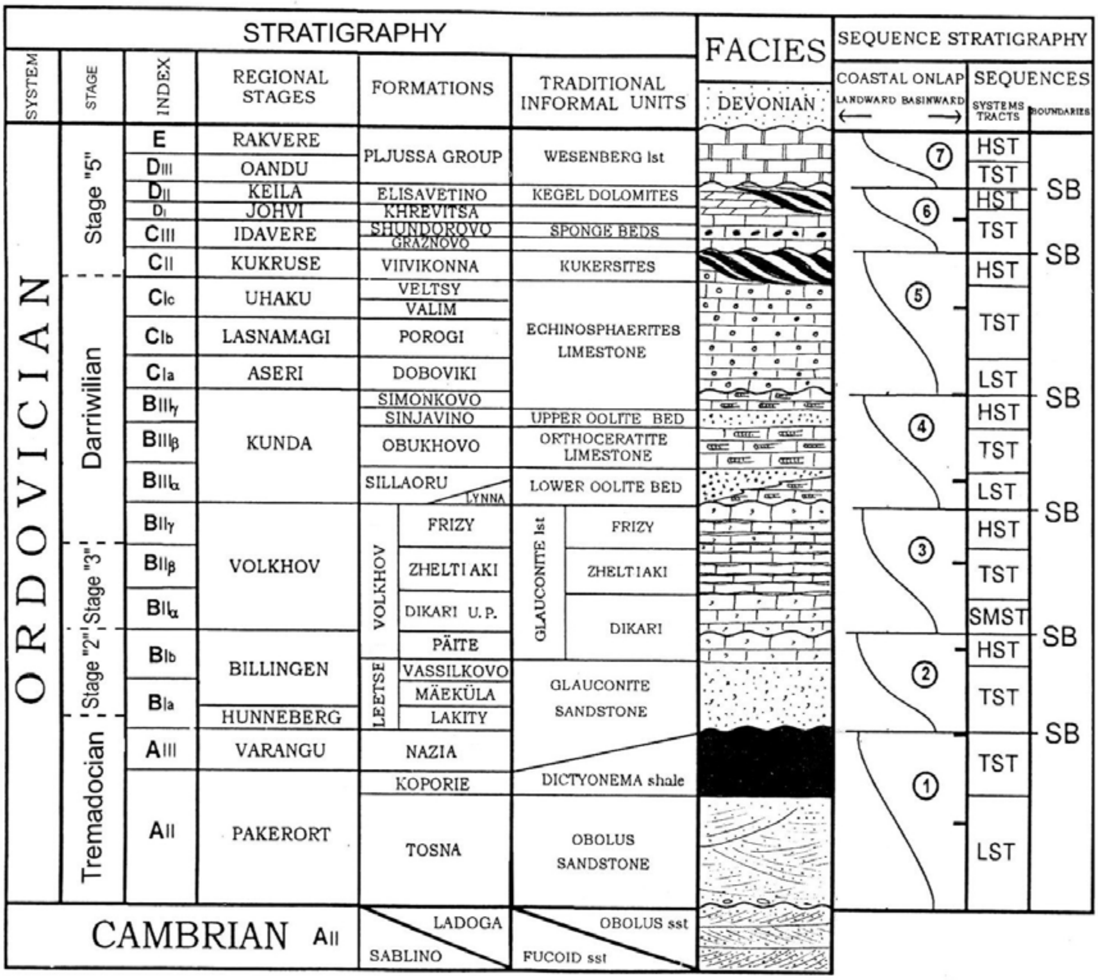

Fig. 2. Stratigraphic scheme of the Ordovician of the St. Petersburg Region showing facies and sequence stratigraphic framework.

The **Hunneberg Regional Stage** is represented by the Lakity Beds (Leetse Formation) of restricted distribution and consisting of a basal bed of fine- to medium-grained quartzose glauconitic sand up to 40 cm thick and overlying greenish grey clay up to 70 cm thick. The Lakity Beds contains graptolites of the *Tetragraptus phyllograptoides* Zone, conodonts of the *Paroistodus proteus* and *Prioniodus elegans* zones and rare brachiopods *Leptembolon lingulaeformis* (Mickwitz), *Eosiphonotreta* cf. *E. acrotretomorpha* (Gorjansky), *Ranorthis* sp., and *Panderina* sp.

The **Billingen Regional Stage** (upper *Prioniodus elegans and Oepikodus evae* conodont zones) in the Russian part of the Baltic-Ladoga Glint is represented by: (1) the Mäekula Beds (Leetse Formation) - quartzose glauconitic sand, calcareous sandstone and clay of about 0.15 - 0.90 m thickness; (2) the Vassilkovo Beds (Leetse Formation) - argillaceous glauconitic limestone with thin clay interlayers of 0.1 - 0.5 m thickness; and (3) the Päite Beds (Volkhov Formation) - four limestone beds varying in lithology from clay-like mudstone to bioclastic grainstone with numerous discontinuity surfaces (0.6 m).

The **Volkhov Regional Stage (BII)** is represented in the eastern side of the Baltic-Ladoga Glint by the Volkhov Formation (Päite Beds exclusive) and roughly corresponds with the "Glaukonitic Limestone" in the classifications of Schmidt (1897) and Lamansky (1905). It consists of bioclastic limestone with scattered glauconite grains and clay totaling up to 6.5 m thick in the outcrop area. The lower boundary of the formation represents an easily recognizable surface of non-deposition, with a glauconitic veneer and numerous amphora-like borings, and is traceable over all the Baltic-Ladoga Glint. The Volkhov Formation is traditionally subdivided into three units: (1) the "Dikari Limestone" (BIIα) of Lamansky (1905); (2) the "Zheltiaki Limestone" (BIIβ); and (3) the "Frizy Limestone" (BIIγ).

The Volkhovian part of the Dikari Limestone (BIIα) consists of hard, bedded, glauconitic limestone varying in structure from bioclastic packstone or grainstone to marlstone, up to 1.6 m thick. It can be subdivided into 10 elementary informal units traceable for a distance of more then 250 km along the eastern part of the Baltic-Ladoga Glint between the Narva and Syas' river valleys (Dronov et al., 1996). The Volkhovian part of the Dikari Limestone contains a conodont assemblage of the *Baltoniodus navis* Zone. A graptolite assemblage recovered from the basal layer of clay underlying the Staritsky unit in Putilovo quarry contains *Tetragraptus amii* Elles and Wood, *T. quadribrachiatus* (Hall), *Azygograptus* sp. and *Thamnograptus* sp. (Dronov et al., 1996).

The Zheltiaki Limestone (BIIβ) consists of up to 1.7 m of argillaceous limestone, yellow, red or variegated in colour, interbedded with clay. Seven informal lithostratigraphic units, varying in thickness from 14 to 39 cm each, can be recognized within the Zheltiaki Limestone between the Tosna and Volkhov river valleys (Dronov and Fedorov, 1995). The Zheltiaki Limestone corresponds to the *Paroistodus originalis* conodont Zone of the Baltoscandian sequence and the *Asaphus (A.) broeggeri* local trilobite Zone, probably chronostratigraphically equivalent to the *Megistaspis simon* Zone of the Scandinavian trilobite sequence.

The Frizy Limestone (BIIγ) consists predominantly of nodular glauconitic limestone, light grey or bluish grey in colour, intercalated with numerous lens-like layers of clay, and totals 3.46 m in thickness in the eastern part of Baltic-Ladoga Glint. The lower boundary of the unit is accentuated by a layer of bluish-grey clay about 4 cm thick. In sections east of St. Petersburg, the Frizy Limestone can be subdivided into seven informal lithostratigraphic units; Dronov and Fedorov, 1995). The Frizy Limestone contains conodonts of the *Baltoniodus norrlandicus* Zone and trilobites of the *Asaphus (A.) lepidurus* Zone that approximately correspond to the *Megistaspis limbata* Zone of Scandinavia.

The **Kunda Regional Stage (BIII)** («Orthoceratite Limestone» sensu lato) has been recently subdivided into five formations (Ivantsov, 2003). The lower boundary of the Kunda Stage is defined by the appearance of the trilobite *Asaphus (A.) expansus* (Wahlenberg) in association with *Asaphus lamanskii* Schmidt, *Megistaspis acuticaunda* (Angelin), *Pliomera fisheri* (Eichwald), the brachiopods *Orthis callactis* Dalman, *Lycophoria nucella* (Dalman), *Ingria flabellum* Öpik, and conodonts of the *Lenodus variabilis-L. crassus* zones above a well-defined surface of non-deposition.

The Lynna Formation (BIIIα LN) in the eastern part of the outcrop area between the Volkhov and Syas rivers consists of grey bioclastic limestone interbedded with clay, attaining a maximum thickness of 3.5 m. West of the Volkhov River, the Lynna Formation thins rapidly.

The Sillaoru Formation (BIIIα+β SL)("Lower Oolite Bed") consists of calcareous clay and highly argillaceous limestone with numerous iron ooids. It can be subdivided into the Nikolskoe (BIIIα NK) and Lopukhinka (BIIIβ LP) Members (Ivantsov, 1990).

The Obukhovo Formation (BIIIβ+γ Ob) ("Orthoceratite Limestone" sensu stricto) consists of light grey bioclastic limestone, sometimes slightly dolomitized, with scattered glauconite grains and numerous cephalopod shells. The characteristic faunal assemblage includes the trilobites *Asaphus (A.) "raniceps"* Dalman, *A. (A.) striatus* (Boeck), *Megistaspis lawrowi* (Schmidt), *Pliomera fisheri* (Eichwald), and the brachiopods *Orthambonites calligramma* (Dalman), *Nicolella pterygoidea* (Pander), *Productorthis eminens* (Pander) etc. The Obukhovo Formation corresponds with the main, lower part of the *Asaphus (A.)"raniceps" - A.(A.) striatus* trilobite local Zone and the upper part of the Baltoscandian *Eoplacognathus? variabilis* conodont Zone.

The Sinjavino Formation (BIIIγ SN) ("Upper Oolite Bed") consists of argilliceous limestone with iron ooids. It corresponds with the upper part of the *Asaphus (Neosaphus) pachyophthalmnus - A.. (A.) minor, A.(Neosaphus) ingrianus -A..(A.) sulevi* and *A. (Neoasaphus) laevissimus* local trilobites zones.

The Simankovo Formation (BIIIγ SM) consists of highly argilliceous limestone with clay intercalations and is about 2m thick.

The **Aseri Regional Stage (CIa)** in the eastern part of the Baltic-Ladoga Glint is represented by the Duboviki Formation comprising 7,5 m of argillaceous limestone overlain by dolomitic limestone. The lower boundary of the formation here consists of a non-deposition surface impregnated with sulphides within the upper part of a bed of hard limestone. The lower part of this bed usually contains *Asaphus (Neoasaphus) laevissimus* Schmidt that is replaced by *Asaphus (Neoasaphus) platyurus* Angelin just above the non-deposition surface. The upper part of the Duboviki Formation corresponds to the *Asaphus (Neoasaphus) punctatus - Asaphus (Neoasaphus) kotlukovi* and *Asaphus (Neoasaphus) kovalevskii - Asaphus (Neoasaphus) intermedius* local trilobite zones (Ivantsov, 1993). In terms of the conodont biostratigraphy of Baltoscandia, the Duboviki Formation corresponds to the *Eoplacognatus suecicus* Zone.

The **Lasnamagi Regional Stage (CIb)** is represented in the eastern part of the Baltic-Ladoga Glint by the Porogi Formation comprising 8.5 m of grey, hard, dolomitic limestone and argillaceous limestone with thin layers of clay. The trilobite *Asaphus (Neoasaphus) bottnicus* Jaanusson and the brachiopod *Chriatiania oblonga* (Pander) are characteristic for this formation but, in general, the exact taxonomy and stratigraphic ranges of bryozoans, brachiopods, trilobites and ostracodes remains very poorly known.

The **Uhaku Regional Stage** (**CIc)** is represented by the grey, mostly thick-bedded dolomitic limestone of the Valim Formation, totalling 5.3 m in thickness, and the mainly argillaceous usually dolomitized limestone of the Veltsy Formation that is 14.5 m thick in the subsurface. The best natural exposures of the Uhaku Stage are situated along the Volkhov River between the dam of the hydropower plant in the town of Volkhov and the village of Gostinopolie. The boundary with the overlying Kukruse Stage is visible in the Alekseevka Quarry near the town of Kingisepp. In the western part of the St. Petersburg region (Izhorian Plateau), deposits of the Aseri, Lasnamagi and Uhaku stages are placed in the Mednikovo Formation. The lowermost Uhaku is characterized by the occurrence of *Xenasaphus devexus* (Eichwald), whereas the uppermost Uhaku contains a diverse assemblage of brachiopods, bryozoans, trilobites and echinoderms. Common species in this assemblage include *Dianulites fastigiatus* (Eichwald), *Lingulasma subcrassum* (Eichwald), *Siphonotreta intermedia* Gorjansky, *Bicuspina dorsata* (Hisinger), *Porambonites aquierostris* (Schlotheim), *P. deformatus* (Eichwald), and *Heliocrinites balticus* (Eichwald).

The **Kukruse Regional Stage (CII)** in the western part of the region is represented by the Viivikonna Formation comprising bioclastic and argillaceous limestone interbedded with kukersite totalling 20 m in thickness. The Alekseevka Quarry represents the only exposure of the Kukruse Stage presently accessible in the St. Petersburg region. The Viivikonna Formation in this quarry is a rather fossiliferous unit that contains a distinctive assemblage of brachiopods (*Pseudolingula? lata* (Pander), *Siphonotreta intermedia* Gorjansky., *Nicolella pogrebovi* Alikhova, *Bicuspina dorsata* (Hisinger), *Bilobia musca* (Öpik)), echinoderms (*Echinosphaerites aurantium suprum* Haeckel), as well as various bryozoans, trilobites, ostracodes, bivalves, gastropods and hyoliths.

The **Idavere Regional Stage (CIII)** is known mostly from boreholes, but is exposed in a number of small isolated natural outcrops and quarries. It is subdivided into the Grjazno Formation (8-30 m thick), consisting of argillaceous and dolomitic limestone with thin layers of kukersite, and the Shundorovo Formation (14-25 m thick), consisting of greenish grey argillaceous, dolomitic limestone with intercalations of kukersite, and beds containing numerous sponge spicules of *Pyritonema*. Information on the diverse fossil assemblages characteristic of the Idavere Stage of north-western Russia was provided by Alikhova (1953).

The **Jõhvi Regional Stage (DI)** is represented in the area south of the eastern part of the Baltic-Ladoga Glint by the Khrevitsa Formation that consists of greenish grey argillaceous dolomitic limestone about 17-21 m in thickness. The best exposure of this formation is along the Khrevitsa River near the village of Jastrebino in the west of the outcrop belt. The characteristic faunal assemblage of the Khrevitsa Formation from this locality includes the bryozoans *Mesotrypa egena* Bassler, *Monotrypa jevensis* Bassler and *Prasopora insularis esthonica* Modzalevskaya, the brachiopods *Orthisocrania curvicostae* (Huene), *Platystrophia lynx lynx* (Eichwald), *Clinambon* *anomalus* (Schlotheim), *Clitambonites schmidti epigonus* Öpik, *Estlandia pyron silicificata* Öpik, and *Sowerbyella (Sowerbyella) trivia* Rõõmusoks, and the trilobite *Toxochasmops maximus* (Schmidt).

The **Keila Regional Stage (DII)** outcrops in numerous old and new quarries south-west of St. Petersburg between the Luga River and the town of Gatchina where it is represented by the Elizavetino Formation of yellow dolomite and argillaceous dolomitic limestone. Fossils are usually poorly-preserved because of strong dolomitization, but the occurrence of the brachiopods *Platystrophia crassiplicata* Alichova, *Horderleyella kegelensis* (Alichova), *Strophomena asmusi* (Verneuil) and the trilobites *Conolichas aequilobus* (Steinhardt), *Illaenus jevensis* Holm, and *Pseudobasilicus kegelensis* (Schmidt) was reported by Alikhova (1953).

The **Oandu (DIII)** and **Rakvere (E) regional stages** are exposed only to the south-west of the St. Petersburg region, close to the Estonian border. They are referred to the Pljussa Group (= Pljussa Stage of Alikhova 1960), which corresponds to the Hirmuse and Rägavere formations in Estonia and consist mainly of white micritic limestones (wackestones) and dolomitized limestones reaching a maximum of 46 m thick in the subsurface area. This is the youngest Ordovician subdivision that can be recognized within the St. Petersburg district. Scattered natural exposures of the Pljussa Group are situated on both sides of the Pljussa River near the town of Slantsy, and on the west side of the Luga River near the village of Sabsk. It is also visible in the large quarry near the village of Pechurki west of Slantsy. Fossil assemblages are not well-studied and are usually dominated by bryozoans and brachiopods, but trilobites, rare rugose corals and echinoderms also occur.

ASPECTS OF SEDIMENTATION

The Ordovician epicontinental basin of Baltoscandia is unusual in many aspects. It is characterized by an extremely low average rate of sediment accumulation, rarely exeeding 1-3 mm per 1000 years, and a very flat bottom topography (Jaanusson, 1982). The Ordovician succession contains numerous sedimentation breaks, some marked by hardground surfaces, and representing relatively short time intervals. Therefore, the composite section is complete from a biostratigraphical point of view.

Although the long-term sedimentation rate in the Ordovician of the St. Petersburg region is comparable to that of a modern deep ocean radiolarian ooze, it cannot be regarded as an example of a classical "condensed section" (Loutit et al., 1988). The short-term sedimentation rate seems to be normal, at least for the relatively shallow-water facies, and a 3-5 cm layer might have been deposited in only a few hours. The contradiction between the normal short-term sedimentation rate and the very low long-term sedimentation rate can be explained by the very low rate of new accommodation space added for sediment to fill: sediment must have been reworked many times before final accumulation. The tectonic stability of the craton is reflected in the stability of the structural-facies zones (Männil, 1966) or confacies belts (Jaanusson, 1982).

The Ordovician deposits of the St. Petersburg region are thought to be very similar to the Estonian deposits and belong to the same North Estonian confacies belt. However, if we consider only the Arenigian interval that outcrops in numerous exposures along the Glint line in Russia, Estonia and Sweden (Oland Island), it would be appropriate to place the Russian multicoloured facies in the transitional zone between typical Estonian grey-coloured facies and typical Swedish red coloured facies (Fig. 3). In comparison with North Estonia, the Russian sections are much more complete and fossiliferous as well as less dolomitized. They are characterized by a greater thickness and a greater amount of clay that seems to be the result of proximity to the Moscow basin. The Russian facies turn to the south-west between Sillamae and Saka in north-eastern Estonia and are known from the boreholes in Central Estonia. Facies boundaries cross the Glint line in a north-eastern direction (Dronov et al., 2000).

There is a consensus of opinion that the Baltic continent migrated during the Ordovician from a subpolar to a subequatorial position in the southern hemisphere (Jaanusson, 1972; Lindström, 1984).

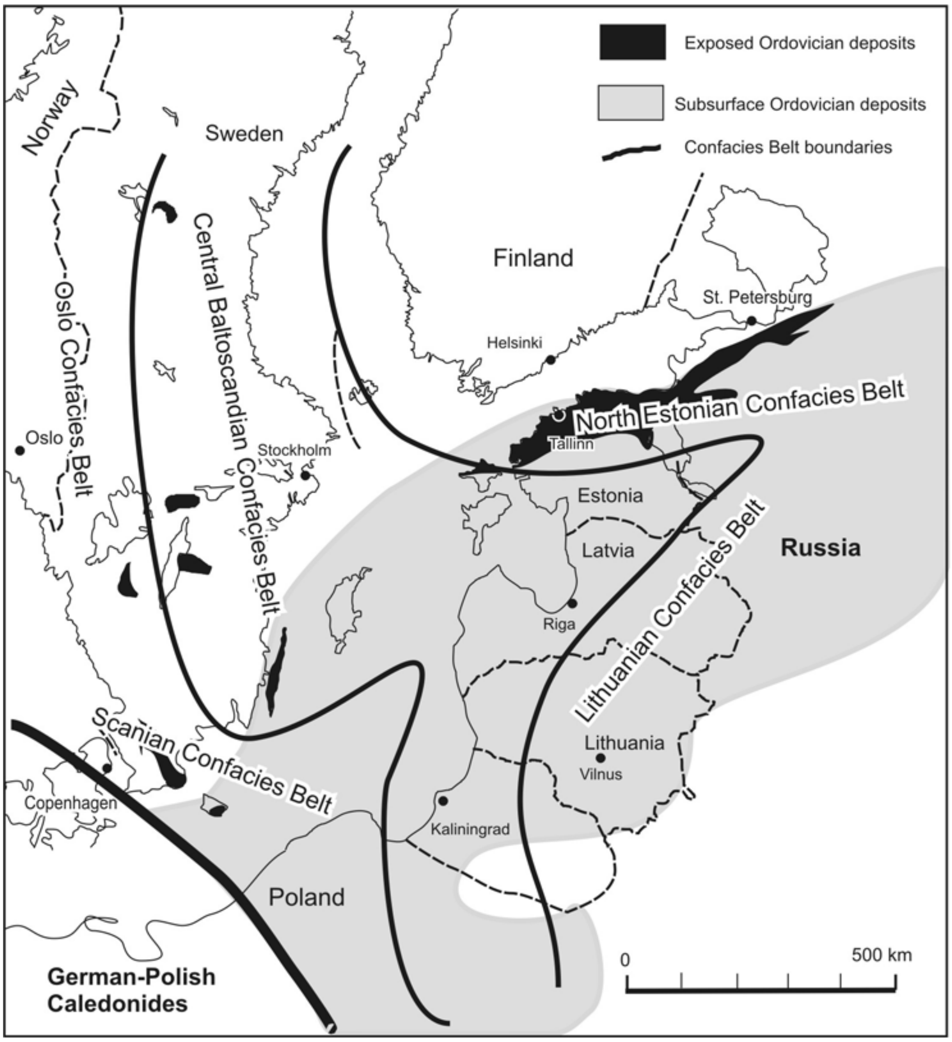

Fig. 3. Confacies Belts in the Ordovician of Baltoscandia.

Paleolatitude is estimated to about 40-60^{o} S during the early part of the Ordovician (Torsvik at al., 1992). Latitudinal migration is reflected in the succession of facies from subpolar, predominantly siliciclastic sands and black shales in the Tremadoc through temperate, bioclastic wackestones in the Arenig-Llanvirn, to tropical, pelmicrites in the Caradoc. Two facies of particular interest are kukersites (oil shales) and Lower Llanvirn ironstones (the so-called Lower and Upper Oolite Beds), the later having an extremely wide lateral extent. Limestones with iron ooids reported from the Lower Llanvirn of the subpolar Urals as well as from the Siberian platform (Judovich et al., 1981; Markov and Markova, 1971). Such a wide distribution of iron oolite facies in the Middle Ordovician can be explained by the suggestion that volcanic ash is one of the main sources of the iron (Sturesson, 1992; Sturesson and Bauert, 1994; Sturesson et al., 1999).

The uppermost Billingenian, Volkhovian and Kundian temperate bioclastic limestones in the St. Petersburg region are interpreted as calcareous tempestites that were deposited in a storm-dominated, shallow-marine environment close to a ramp sedimentary system (Dronov, 1997; 1998) (Fig. 4). The storms generated very characteristic sheet-like skeletal sand beds of considerable lateral extent. In the Upper Billingenian and Volkhovian interval about 30 composite beds and bed packages of storm origin can be traced over a distance of more than 250 km along the eastern part of the Baltic-Ladoga Glint. These beds, that have traditional names given to them by ancient quarrymen, provide a precise time framework for high-resolution regional stratigraphic correlation.

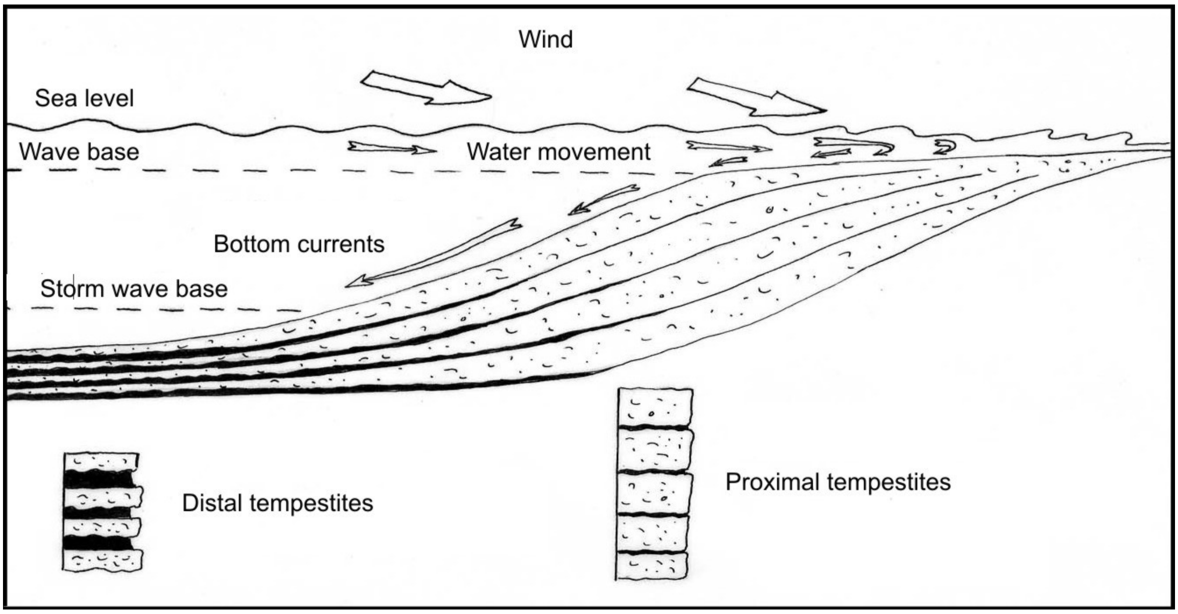

Fig. 4. Simplified model of carbonate tempestites.

Individual storm beds (3-4.5 cm thick) might have been deposited in a few days, whereas amalgamated composite beds (up to 20-30 cm) or bed packages (up to 1m) reflect a time interval of 200,000-400,000 years. Carbonate beds have sharp erosional bases with gutter casts and casts of animal burrows (*Thalassinoides*). During storm events the exhumed and partly washed out burrows were filled with sand, forming characteristic casts at the bases of the storm beds. Most of the layers are distinctly graded and consist predominantly of coarse-grained shell debris. Brachiopods, echinoderms, bryozoans, ostracodes and trilobites are the main contributors. The limestones vary from bioclastic wackestone to packstone and grainstone.

The proximal-distal tempestite trend is obviously recognizable in the sediments. For instance, the "Dikary Limestone" is interpreted as a proximal tempestite based on its coarse-grained composition, amalgamation structures and lack of clay deposition. The Zheltiaky and Frizy Limestones can be interpreted as distal tempestites because the carbonate beds are thinner and finer grained. In modern high-energy shelf seas, distal tempestites may occur at water depths up to and in excess of 50 m. Therefore we can conclude that the water depth ranged from 5 to 50-60 m during the Arenig and lower Llanvirn in the St. Petersburg region.

Another interesting aspect of the Ordovician geology of the St. Petersburg region is the enigmatic organic buildups of mud mound type discovered only recently (Dronov and Ivantsov, 1994; Dronov and Fedorov, 1994, Fedorov, 1999). Warm-water sponge/algal reefs are widespread in the Early Ordovician tropical seaways of North America and China whereas organic buildups in temperate zones had never been reported from the Lower Palaeozoic. All of the buildups are of Arenig age and the largest ones extend approximately 3-4m in height and are about 100-200m in diameter, forming spectacular conical mounds surrounded by haloes of echinoderm debris. Two main facies types can be recognized: clay core facies and micritic crust facies. The clay core facies forms the inner parts of the mounds and is represented by grey or yellow clay intercalated with layers of bioclastic wackestone. Brachiopods, ostracodes, bryozoans, echinoderms, trilobites and even graptolites are common in this facies. The clay humps are covered by a carbonate crust consisting of pink and yellow micritic limestones 0.05-0.5 m thick. Only traces of laminated structure, probably produced by algae or cyanobacteria, and short calcareous needles, interpreted as sponge spicules, can be found in the crust facies. The outer surface of the crust is marked by hardgrounds and is pitted by *Trypanites* borings. The genesis of the buildups is still under discussion. The recent state of knowledge on this enigmatic buildups is summarized by P. Fedorov (2003).

SEQUENCE STRATIGRAPHY AND SEA-LEVEL CHANGES

As mentioned previously, the thickness of the entire Ordovician in the St. Petersburg region does not exceed 200 m. As a consequence it is difficult to apply seismic methods to analyze the stacking patterns of the Ordovician depositional sequences. Nevertheless, Vail-type cyclicity is recognizable in the depositional succession (Van Wagoner et al., 1988). The depositional sequences have a thickness of only 1.5 to 20 m or even less. Parasequences of about 0.20-0.30 m are usual.

The main factors that control thickness as well as lithology and stratal architecture of depositional sequences are: (1) eustatic sea-level changes; (2) tectonic sea bottom movement; (3) sediment supply; and (4) sea floor physiography (Posamentier and Allen 1993). The Ordovician basin of Baltoscandia can be characterized as a starved basin with very little sediment supply, extremely flat sea floor physiography, and long-term tectonic stability. Therefore, the dominant factor is eustasy.

About seven major depositional sequences can be recognized in the Ordovician outcrops of the St. Petersburg region between the basal Ordovician and basal Devonian unconformities. All the sequences represent third-order cycles of relative sea-level changes (in sense of Vail et al., 1977), and have an average duration of between 1,5 and 9,0 My. For ease of reference and identification, individual names have been given to all the depositional sequences (Dronov and Holmer, 1999). From the base to the top they are as follows: (1) Pakerort; (2) Latorp; (3) Volkhov; (4) Kunda; (5) Tallinn; (6) Kegel; and (7) Wesenberg (Fig.2 and Fig. 5).

1) ***The Pakerort sequence*** coincides with the Pakerort regional stage. In St. Petersburg region the sequence comprises shallow-water, cross-bedded quartz sands of the Tosna Formation (lowstand wedge deposits) overlain by the relatively deep-water black shale (“Dictyonema Shale”) of the Koporie Formation (transgressive systems tract deposits). Quartz sandstone of the Lomashka Formation is interpreted as an incised valley fill from this depositional sequence or the remnant of a previous sequence.

2) ***The Latorp sequence*** includes the Varangu, Hunneberg and Billingen regional stages. It encompasses both transgressive (Nazia and Leetse Formations) and highstand (Päite Beds of the Volkhov Formation) systems tract deposits. A quartz sand unit (Nazia Formation), that rests directly on the “Dictyonema shale” is interpreted as a transgressive lag deposit. It seems possible that the Ceratopyge Shale and Ceratopyge Limestone in the inner part of the basin represent lowstand systems tract deposits of this sequence.

3) ***The Volkhov sequence*** coincides with the Volkhov regional stage. The “Steklo” surface at the base of this stage is interpreted as a type 2 sequence boundary. The Volkhovian part of the “Dikary Limestone” corresponds with a lowstand (shelf margin) systems tract, whereas the “Zheltiaky” and “Frizy” Limestones seem to represent transgressive and highstand systems tracts, respectively.

4) ***The Kunda sequence*** coincides with the Kunda regional stage. The interval between the erosional surface at the base and transgressive surface at the top of the “Lower oolite bed” (Lynna and Sillaoru Formations) is interpreted as a lowstand systems tract deposit. The Obukhovo Formation (“Orthoceras Limestone” s.str.) up to the base of the Sinjavino Formation (“Upper oolite bed”) corresponds to a transgressive systems tract, whereas the remainder (Sinjavino and Simankovo formations) up to the unconformity at the base of the Aseri stage seems to represent high-stand systems tract deposits.

5) ***The Tallinn sequence*** comprises four regional stages. Aseri deposits belong to a lowstand systems tract, whereas the Lasnamagi and Uhaku deposits represent a transgressive systems tract. The deepest part of the sequence seems to be the Uhakuan. The Kukruse deposits show clear evidence of basinward progradation that allows them to be interpreted as high-stand systems tract deposits. The upper sequence boundary coincides with the unconformity at the top of the Kukruse stage.

6) ***The Kegel sequence*** includes the Idavere, Jõhvi and Keila regional stages. The lower part of this stratigraphical interval (especially Idavere and Jõhvi stages) is poorly exposed in Russia. For this reason there is not enough information to determine if some of the lithological units (for example Griazno Formation) can represent a lowstand systems tract or may be the sequence begins

directly with a transgressive systems tract. The deepest (transgressive) part of the sequence seems to be represented by the "sponge horizon" (Shundorovo Formation). Khrevitsa Formation also represents relatively deep-water deposits and includes numerous ash beds. The shallowest part of the succession (Keila Stage, Elizavetino Formation) is interpreted as a highstand systems tract deposits. The upper boundary is an unconformity with clear evidence of subaerial exposure.

7**) *The Wesenberg sequence*** includes the Oandu, Rakvere and Nabala regional stages. The thin clay-rich deposits of Oandu regional stage can be interpreted as a transgressive systems tract whereas the shallow-water Rakvere limestone can be interpreted as highstand systems tract deposits. Their upper sequence boundary is expected to be located within the Nabala Stage but in St. Petersburg region the Devonian deposits usually directly overlie the Rakvere micrites of Rägavere Formation.

The stability of the Baltic craton allows the assumption that all of these sequences reflect eustatically induced sea-level fluctuations (Fig. 5). Some of the regressive events seem to be traceable worldwide (Barnes et al., 1996): (1) base of the Pakerort sequence (basal Tremadoc unconformity); (2) base of the Latorp sequence (basal Arenig unconformity); (3) base of the Kunda sequence (basal Llanvirn unconformity).

The most prominent unconformities in the Ordovician of the St. Petersburg Region with extensive erosion of the underlying beds coincide with the base of the Pekerort, Latorp and Wesenberg sequences. The strong erosion and development of these regional unconformities can be regarded as evidences for sea-level drops of a significant magnitude comparable to modern glacial regressions (about 100 m). The Latorp, Volkhov and Kunda sequences demonstrate the deepening of the basin after the regression at the base of the Latorp sequence. The Volkhovian deposits are the most widespread and the total area of marine red beds in the Volkhovian exceeds the area they cover in the Latorpian and Kundan (Männil, 1966). The lower boundary of the Volkhov sequence is interpreted as a 2^{nd} -type sequence boundary (Dronov, Holmer 1999) with a long period of still stand and non-deposition. The magnitude of the sea-level lowering probably did not exceed 10-20 m. The overlying Kunda sequence is very similar to the Volkhov sequence in its lithology. The magnitude of the sea-level drop at the Volkhov/Kunda boundary was larger than that at the Latorp/Volkhov boundary (30-40 m).

There is no evidence of prominent erosion at the base of the Tallinn sequence and it is represented by more shallow water deposits as compared with the underlying Kunda and Volkhov sequences. The shallowing of the basin was not a result of forced regression but rather a consequence of an increasing sediment input. In the Tallinn sequence, the marine red beds in the central parts of the basin were replaced by grey-coloured deposits. The organic-rich kukersite-bearing strata demonstrate progradational stacking patterns and form the highstand systems tract of the sequence.

The Kegel sequence is comparable in lithology with the underlying Tallinn sequence. The unconformity at the base of the Kegel sequence is well developed only in northeastern Estonia and northwestern Russia, where shallow-water kukersite-bearing facies are well developed. The sea-level drop probably did not exceed 10 m. The Kegel sequence is remarkable for its transition from cool-water temperate to warm-water carbonate sedimentation and the rapid growth of reefs.

The unconformity at the base of the Wesenberg sequence is one of the most remarkable in all the Ordovician of Baltoscandia. The regression seems to be comparable in magnitude to that of the Volkhov/Kunda boundary and can be estimated as much as 40-50 m.

The sea-level curve for the Ordovician of Baltoscandia reconstructed based on the sequence analysis (Dronov and Holmer, 2002) is different from that of Vail et al., (1977) and Ross and Ross (1992, 1995). The North American models assumes a prominent sea level drop at the base of the Middle Ordovician and a long-term lowstand during all the «Volkhovian» and Darriwilian (80-100 m lower than in the Lower and Upper Ordovician). In contrast, the data from Baltoscandia points rather to a moderate sea-level drop at the base of Volkhov without any prominent erosion of comparable scale to the erosion events at the base and top of the Ordovician, or at the lower boundaries of the Latorp and Wesenberg sequences. Moreover, the Volkhovian and Kundan highstands seem to be the most prominent transgressions in all of the Baltoscandian Ordovician, which means that the Middle Ordovician was not a lowstand but rather a highstand interval.

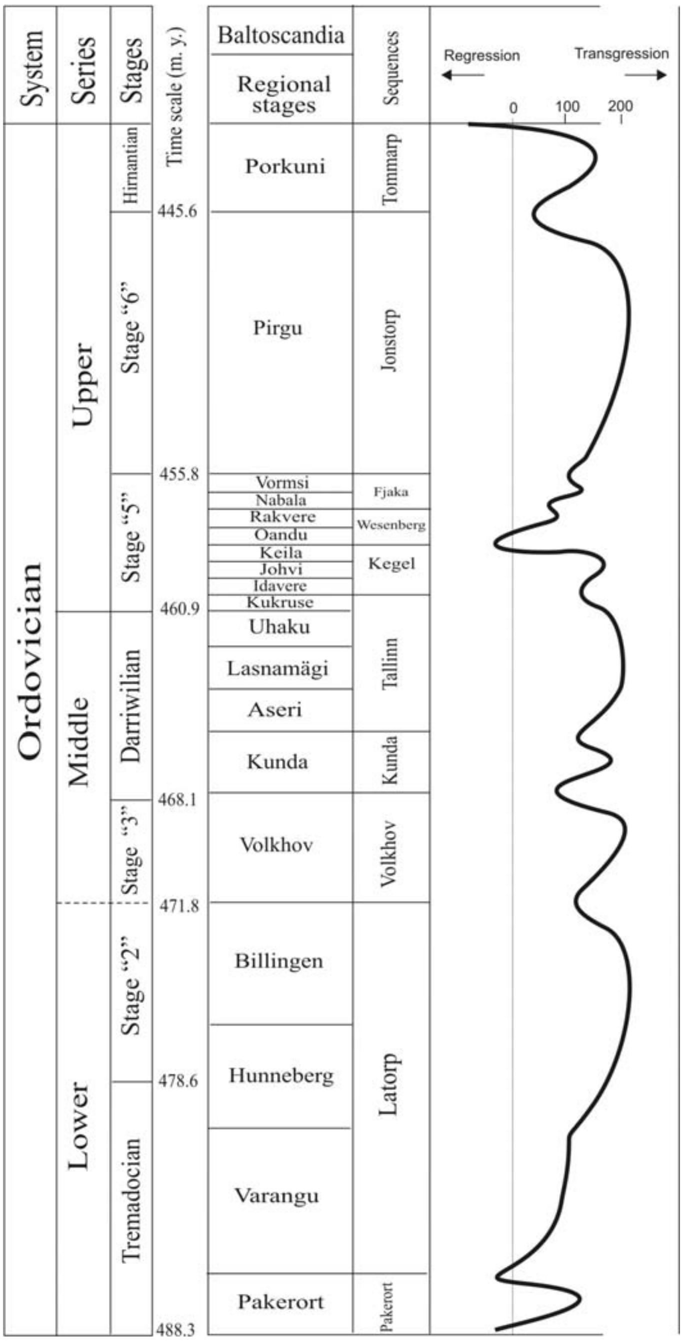

Fig. 5. Sea-level curve constructed for the Ordovician of Baltoscandia.

On the other hand, the sea-level curve published recently by A. Nielsen (2003, 2004) for the Ordovician of Baltoscandia follows with great detail the North American example (Ross and Ross, 1992; 1995). It is based on trilobite ecostratigraphy and facies interpretation for the most deep-water settings of the Oslo and Scanian Confacies belts of Jaanusson (1982). We can conclude therefore that there is a contradiction and obvious disagreement between sea-level curves constructed for the shallow-water part of the basin (Nestor and Einasto, 1997; Dronov and Holmer, 2002) and those based on relatively deep-water sections (Nielsen, 2003; 2004).

It is interesting to note that detailed sea-level curves constructed for the Volkhovian interval are also different. The sediments of this stratigraphical interval in St. Petersburg region were deposited on a sliliciclastic-carbonate ramp within a shallow-marine, storm-dominated environment. These conditions were favourable for the reflection of short-term sea-level fluctuations where even minor changes in depth can cause an abrupt shift of facies. About 8 different lithofacies can be identified in the Volkhovian succession of the region. All the lithofacies can be arranged according to the relative depth of their deposition along the ramp profile. The sea-level curve has been reconstructed based on the shift of these facies along the tempestite ramp profile (Dronov, 1997; 1999).

Major rises of sea-level occurred at the following levels (with reference to the traditional bed nomenclature): (1) Krasnenky; (2) Butina; and (3) Krasnota. All of these events are marked by the appearance of red coloured deposits accumulated in the central relatively deep water part of the basin. Important sea-level drops occurred at the following levels: (1) “Steklo” surface (base of Volkhov); (2) Butok; (3) Tolstenky; (4) Koroba. Overall the sea-level curve is comparable to that constructed by Nielsen (1992, 1995) for the Komstad Limestone in Scania, except for major differences in the interpretation of water depth in the Middle Volkhov. Contrary to the conclusion of Nielsen (1992, 1995), the data on the Russian sections supports the interpretation that the water depth in the Middle Volkhov was greater than that in the Lower Volkhov. As a consequence, the $B_{II}\alpha/B_{II}\beta$ boundary in the shallow-water model (Dronov, 1997; 1999) is interpreted as a deepening (transgressive) event, whereas the same boundary in the deep-water model (Nielsen, 1992; 1995) is interpreted as a shallowing (regressive) event.

The disagreements demonstrate a major difference in facies and stratigraphic interpretations (see Dronov et al., 2005 in the Abstract volume). A special investigation is planned in order to construct a relevant sequence stratigraphic framework (including documentation of stratal geometry and shifts of depocentres and facies) and to develop an enhanced sea-level curve reconstruction for the Ordovician Basin of Baltoscandia. This investigation will be a contribution to the IGCP project 503 “Ordovician Palaeogeography and Palaeoclimate”.

FOSSILS AND BIOSTRATIGRAPHY OF THE ORDOVICIAN IN THE ST. PETERSBURG REGION

Ordovician sedimentary successions in the vicinity of St. Petersburg contain a lot of fossils that have attracted the attention of researchers and fossil-hunters from the beginning of geological studies in the region. However, the state of knowledge of the different faunal and floral groups is remarkably different. Some brief notes on few of the fossil groups are presented below, but the list of fossils that can be found in the Ordovician sections is much longer. Among the unmentioned fossils are trilobites, sponges, bryozoans, chitinozoans, lingulate brachiopods, different types of palaeoscolecids and some other enigmatic fossil remains. The biostratigraphic subdivision of the Ordovician sediments in the Russian part of Baltoscandia as well as in Estonia, Sweden and Norway, in it major part, was traditionally based on trilobites after the well known studies of Schmidt, Lamansky, Tjernvik, however, conodonts as well as some other fossil groups became more and more stratigraphically important for the correlation of the Ordovician strata in the St. Petersburg area with the contemporaneous sediments in other countries of Baltoscandia.

GRAPTOLITES

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In the Ordovician of the St. Petersburg Region graptolites occur sporadically at several stratigraphic levels. They can be relatively numerous in clay deposits (e.g. Hunneberg clays and clay cores of the Volkhovian mud mounds) within the carbonate dominated sequences of the Lower and Middle Ordovician as well as in clayey carbonates (the Kas’kovo village section, Shundorovo Fm.). The disjunctive stratigraphic distribution is more likely connected to taphonomic bias rather than to the absence of graptolites in the faunal communities of the basin during the Ordovician. Taxonomical diversity of graptolites is relatively low; thus the Volkhov graptolite associations include a total of no more than 7 recorded species from all localities. However, despite of the rarity of graptolites their importance for the stratigraphy of the region is obvious. Thus, based on the graptolite findings, the lower boundary of the Volkhov Stage can be correlated with the *Ps. a. elongatus* and *D. (E.) hirundo* Zones of Baltoscandia and with the upper *D. simulans* to *D. (E.) hirundo* Zones of the British graptolite succession. The base of the Darriwilian could be placed within the upper part of the Volkhov succession, though the first rich diplograptid fauna of Darriwilian age appears only in the basal beds of the Kunda Stage.

Lower to Middle Ordovician graptolites in St. Petersburg region have been known since the time of Eichwald (1861). In the last century graptolites were collected from exposures and boreholes by M.E. Janishevsky, A.F. Lesnikova, V.D. Prinada, T.N. Alikhova, V.Ju. Gorjanskii and Ju.E. Dmitrovskaya, and identified by Obut et al. (1991) who gave the first biostratigraphic interpretation.

During the past ten years a large graptolite collections from the Hunneberg-Volkhov interval of the Babino, Kingisepp, and Putilovo quarries and from the Lava River sections were made by A. Ivantsov, L.E. Popov and the present author. Rich material was collected by P. Fedorov (St. Petersburg University) from the Volkhov clayey mud mounds in the vicinity of St. Petersburg. Biostratigraphy and description of the Hunneberg and Volkhov graptolites were published by Koren (in Dronov et al. 1995; Dronov et al. 1998; Tolmacheva et al., 2001; Koren et al., 2004).

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CONODONTS

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Conodonts are one of the few fossil groups that occur in absolutely all rock samples from the Ordovician sedimentary successions in the St. Petersburg Region. However, the abundance of conodonts varies considerably depending on the stratigraphic level sampled. Conodonts are most abundant in clays and sandstones of the Lower Ordovician Hunneberg and Billingen regional stages where their number in places reach 10 000 elements per kilo of rock. Kilogram-sized carbonate samples from the Middle Ordovician interval on average yield less than 500 elements, whereas in the Volkhov Fm. conodonts are approximately two or three times as numerous. The smallest content of conodonts are found in the clayey limestones and dolomites of the Jõhvi and Keila regional stages (Fig. 6).

As a whole the conodont abundance in deposits in the vicinity of St. Petersburg is most likely related to the rate of sedimentation. The one exception is the dolomites of the Keila Regional Stage where the rarity of conodonts is facies dependent and probably connected to the restricted depositional environment during that time. Through the whole Ordovician the conodonts exhibit thermally unaltered colors.

The taxonomical composition of conodont assemblages from the Ordovician of the Russian part of Baltoscandia and the stratigraphic ranges of the distinctive species are generally similar to those of contemporaneous assemblages from other areas in the basin. However, some remarkable differences in the relative abundance of many species have become obvious following the last few years of active conodont studies in the region.

It is widely known that conodonts were first discovered in the first half of 18th century when Christian Pander found microscopic teeth-like elements at several localities in the vicinity of St. Petersburg (Pander, 1856). Pander described twenty-six species and nine new genera of Lower Ordovician conodonts from the glauconitic sandstones of the Leetse Fm. The next studies of conodonts from the St. Petersburg Region were carried out more than 100 years later (Sergeeva, 1963; 1974). Serafima Sergeeva mainly focused her researches on conodonts from the Lower and lowermost part of the Middle Ordovician interval. She described numerous new species and succeeded in drawing up the first conodont zonal biostratigraphic succession for the northwestern part of Russia.

Other specialists have considered the conodonts of the St. Petersburg area only sporadically. For example, Stig Bergström illustrated and briefly described the conodont assemblage of the *Prioniodus elegans* Zone from the Tosna River localities (Bergström, 1988). Nelia Borovko with Serafima Sergeeva and Viive Viira studied conodonts from the quartz sands of the Cambrian – Ordovician boundary interval (Borovko and Sergeeva, 1981; 1985; Viira et al., 1987; Popov et al., 1989). It is important to understand that studies of conodonts from these kinds of sediments are extremely laborious and this work is to be much admired.

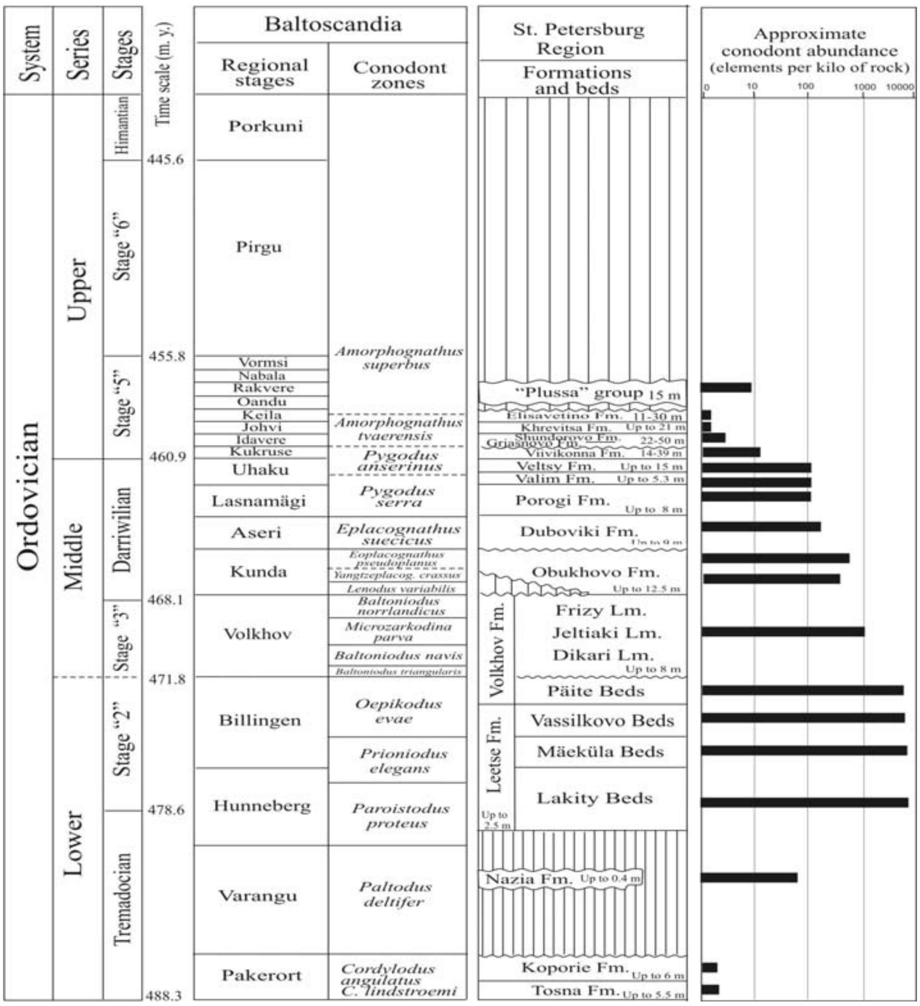

Fig. 6. Stratigraphic scheme of the St. Petersburg Region with the approximate abundance of conodonts.

Despite such a successful start of conodont research, at the end of 20th century the conodonts from the St. Petersburg Region have been studied much less detail than those from Sweden, Norway and Estonia. My studies have partly filled this gap, especially for the Lower and lower part of the Middle Ordovician interval (Tolmacheva et al., 2001a; Tolmacheva et al., 2001b; Tolmacheva and Fedorov, 2001; Tolmacheva et al., 2003; Löfgren and Tolmacheva, 2003; Tolmacheva et al., 2003; Tolmacheva in press, 2005). Conodonts from the upper part of the Middle and Upper Ordovician remain enigmatic however and worthy of comprehensive study in the future.

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OSTRACODS

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Ostracods (Arthropoda, Crustacea) are common and diverse in the St. Petersburg region throughout the interval of uppermost Lower Ordovician – Upper Ordovician. Ostracod density in the rock volume is variable, the highest estimate – more than 3000 specimens per 100g - was documented in the upper part of the Volkhov Stage (Tolmacheva et al., 2003). The total number of Ordovician ostracod species is difficult to estimate for the area, as the older publications (e.g. Neckaja, 1966, 1973) refer mainly to the northwestern part of the East European Platform in a very generalized manner. In a review chapter of the taxonomic monograph on ostracods of the Ordovician of the Russian (East European) Platform, A. I. Neckaja (1973) describes changes in taxonomic composition of ostracods in the interval from the middle part of the Volkhov Stage up to the Porkuni Stage, making no clear distinction between the occurrences in the vicinity of St. Petersburg and other areas of the East European Platform.

Investigation of the group has always been closely related to the research activities in Estonia, where the taxonomic composition and distribution of Ordovician ostracods is well studied (see Meidla and Sarv, 1990, Sarv and Meidla, 1997, for a summary and references). Available evidence confirms general similarity between the faunas of northern Estonia and of vicinity of St. Petersburg.

The taxonomic composition and distribution of Ordovician ostracods in St. Petersburg area is specifically addressed by Neckaja (1966), but in this monograph the locality information is available only for the type specimens. Only two new species (*Circulina dibulbosa* and *Circulina infecta*) can be referred to the particular area with certainty (coming from the interval 24.44-38.6 m of core K-311, Bolshie Korchany, Leningrad Region – Neckaja, 1966, pp. 14-15). Five new ctenonotellid species of the genera *Protallinnella, Tallinnella* and *Tallinnellina* are described by Sarv (1963) from the outcrops near St. Petersburg (Lynna, Lava, Simonkovo, Obukhovo).

The earliest Ordovician ostracods in the East European Platform were documented in the St. Petersburg area by L. Melnikova (1999). The material comes from the Billingen Stage at the

Popovka, Volkhov, Lava and Syas rivers. The assemblage comprises exclusively new species (*Lavatiella spinosa*, *Dronoviella lauta*, *Conchoprimitia leonidi*, *C. suavia*, *Unisulcopleura tolmachevae* and *Hithis proximus*) and is up to now not documented from other areas with certainty.

Distribution of ostracods in the interval of the uppermost Billingen-Kunda stages is thoroughly documented by L. Melnikova (in Ivantsov and Melnikova, 1998), T. Meidla and O. Tinn (in Tolmacheva et al., 2003). The topmost Billingen Stage is characterized by *Conchoprimitia gammae*, *Rigidella mitis*, *Tallinnellina viridis* and *Brezelina palmata*. The Volkhov Stage is characterized by extraordinarily high faunal density in this area (see above) and reveals *Conchoprimitia gammae*, *Rigidella mitis*, *Ogmoopsis bocki* (?=*O. viridis*: Melnikova, 1998), *Incisua ventroincisurata* (a synonym of this species is also *Miniconchoides minutus*, see Tinn and Meidla, 2004, p. 215), *Piretopsis (Protallinnella) grewingkii* and *Glossomorphites digitatus.* In the Putilovo section, the assemblage is characterised by high degree of evenness, which is the result of time averaging (Tolmacheva et al., 2001). In the vicinity of St. Petersburg, the Volkhovian ostracod assemblage resembles the coeval assemblages described from the Saka and other sections in North Estonia (Meidla et al., 1998; Tinn, 2002 and references therein). Some early ostracod taxa of uncertain affinity, recorded only from St. Petersburg region, can change our views on early ostracod evolution (*Lavachilina evae*: Tinn and Meidla, 2002). In the Kunda Stage, *Conchoprimitia gammae*, *Incisua ventroincisurata*, *Piretopsis (Protallinnella) grewingkii, Aulacopsis simplex* (=*Collibolbina simplex*: Melnikova) and *Asteusloffia acuta* (=*A. acutus*: Melnikova) are more common species, the diversity of the faunal assemblage increases in the uppermost part of the stage (Zvanka section: Ivantsov and Melnikova, 1998, fig. 2).

The detailed data on younger ostracod assemblages in the vicinity of St. Petersburg is not published. The data by L. Sarv (manuscript) allows to conclude that the succession of palaeocope ostracods from this interval is largely similar to that in northern Estonia. The youngest assemblages recognised in the area refer to the Rakvere Stage.

The Upper Ordovician dolomites in the St. Petersburg area (Nabala Stage?) are almost barren. In the Pskov Region, these beds contain sparse *Eoleperditia*? sp. which could perhaps occur also in more northern sections.

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ACRITARCHS

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Acritarchs are normally abundant, diverse and perfectly preserved in the tectonically undisturbed Ordovician shallow-water sequences of the eastern part of the Baltic basin. The first acritarch investigation in the Saint-Petersburg region coincides with the pioneering microphytological research in Russia. The fundamental monograph by Timofeev (1959) was the most complete and representative study demonstrating the high diversity and variability of Lower Palaeozoic acritarchs at that time. However, this first taxonomical classification did not survive throughout the years. Thus, the careful species descriptions and graphical drawings presented at that time are not now of much use. Anyway, this group of microphytofossils has attracted the much deserved attention of biostratigraphers. In early 1980s, acritarchs from the *Obolus* Sandstone and *Dictyonema* Shale, in addition to other data, helped to solve questions on the stratigraphical position and division of the monotonous Cambrian sand sequence (Volkova and Golub, 1985). In fact, in the region considered, acritarchs have a high biostratigraphical potential that is comparable with that of conodonts and graptolites, at least for the Late Cambrian and the Early-Middle Ordovician Series (Raevskaya, 1999; Tolmacheva et al., 2001; Ribecai et al., 2002; Raevskaya et al., 2003; 2004).

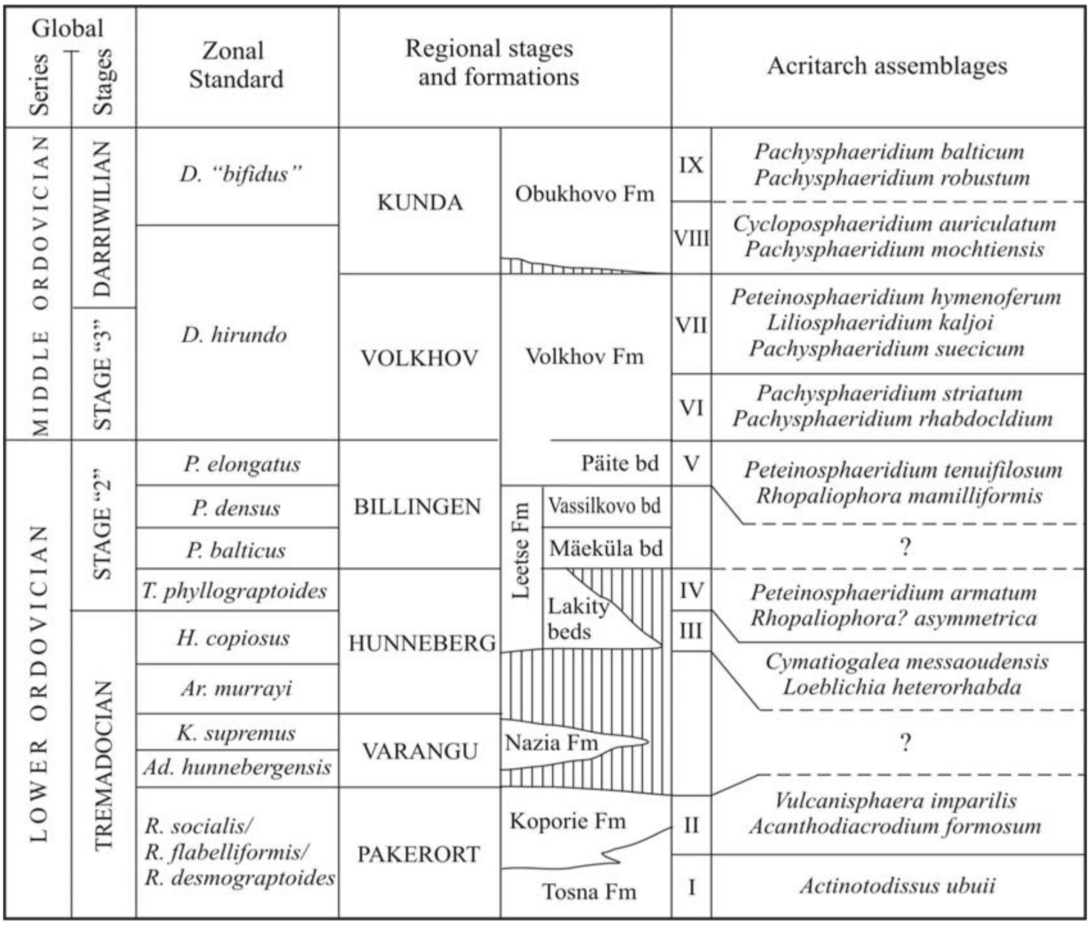

Fig. 7. Acritarch biostratigraphy in the Lower and Middle Ordovician of the St. Petersburg region.

Stratigraphical distribution

Although the sediments of the all of the three Ordovician series yield numerous acritarchs, the Lower and Middle Ordovician intervals are the best characterized palynologically. Nine consecutive acritarch assemblages have been established in the Saint-Petersburg region (Fig. 7). The two first assemblages characterize the Parkerort Regional Stage. Sediments of the Varangu Regional Stage are better preserved in Estonia and are more fossiliferous there in comparison to the St. Petersburg sections. Volkova (1995) described an acritarch assemblage with *Aryballomorpha grootaertii, Athabascaella playfordii* and *Dasydiacrodium tremadocum* from the Upper Tremadocian of Estonia. This assemblage should be placed between our II and III acritarch assemblages. No acritarchs have been found in the Mäeküla and Vassilkovo members of the Billingen Regional Stage. Therefore, the boundary position between assemblages IV and V is not yet clear. Younger levels are very rich in acritarchs. Two assemblages (VI and VII) from the Volkhov and two assemblages (VIII and IX) from the Kunda regional stages have been identified. The Upper and uppermost Middle Ordovician strata are characterized by acritarch taxa ranging from the Kunda Stage without remarkable taxonomical changes throughout the whole interval and the general microphytofossil quantity decreases towards the top.

Lateral distribution

Only sporadic and taxonomically poor microphytofossil associations occur around and within the mud-mound bioherm structures that are widely distributed in Ordovician strata in the St. Petersburg region. No acritarchs are present throughout the dolomitized successions exposed in the Sablino and Tosna river outcrops. Oxidized yellow-reddish parts of the Ordovician sequences (Zheltiaki) are also barren or contain rare small and morphologically simple forms (*Leiosphaeridia, Micrhystridium*) of limited stratigraphical use. To the west of the region (in the Kingisepp, Slantsy and Alekseevka quarries and in Estonia) in the Upper Ordovician development of kerogen-rich kukersite deposits, a normal marine phytoplankton community is substituted by a mostly monospecific association with the dominance of *Gleocapsomorpha prisca* Zallesky, 1917. The latter is referred to as a mat-forming cyanobacterial organism similar to the living alga *Enthophysalis*.

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ECHINODERMS

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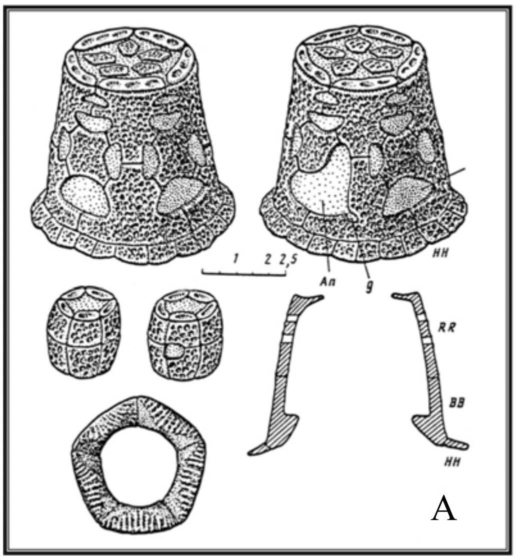
Echinoderms are among the most abundant and widespread marine organisms in the Baltic Ordovician basin. Pioneering investigations of their skeletal parts from Estonia and the St. Petersburg region were started by L. von Buch, A. Volborth and O. Jaekel (Volborth, 1864, 1866; von Buch, 1840; Jaekel, 1899, 1901, 1902, 1918) in the first half of the XIXth century. At that time there was no clear idea about the morphology of these organisms because they are usually preserved as detached plates and fragments. Findings of complete skeletons are very rare. Therefore, the first Jaekel reconstruction of a complete specimen from the Ordovician Limestone was based on his imagination and resulted in the description of a fantastic creature - "Himera of Jaekel". Many years after this description was presented, Hecker (1964) demonstrated that his colleague had mistakenly combined fragments of five different echinoderm genera belonging to four different families of three different classes and two subtypes. Eltysheva, Stukalina and Hints (e.g. Eltysheva, 1966) described crinoid ossicles and other echinoderm material from the Baltic States. The discovery of the most complete specimens of crinoids, eocrinoids and carpoid echinoderms has been recently documented by Arendt and Rozhnov (e.g. Arendt and Rozhnov, 1995, Rozhnov, 1994, 2002; Rozhnov and Jefferies, 1996).

The first appearance of echinoderms in the Baltic basin is well correlated with the increasing of carbonate content in the glauconitic sands of the Billingen Stage. During the Volkhov Stage they rapidly became dominant in the benthic communities of soft ground, hard ground and bioherms. The most diverse echinoderms occur in bioherm biotopes due to the varied living conditions present there. The Middle Ordovician bioherms are represented by mud mounds with a micrite cover. The superposition of neighboring individual bioherms covered by a common micrite crust, and their subsequent erosion, constructed a locally rather complicated bottom surface. This event was responsible for different water mass mobility and ground characteristics even at closely located areas. The mosaic structure of the bioherm fields was occupied by a unique community of a mixture of soft and hard ground echinoderms in varying quantitative proportions. In distinction to a purely soft ground community, the bioherm population has low percentage of rombifer cystoids (*Echinoencrinites*), astrocystid diploparids, bolboporitids, but has a high percentage of rhopalocystid eocrinoids and perittocrinids (*Crinoidea*). It is more difficult to characterize the representatives of the hard ground echinoderms in a bioherm community, because they are usually poorly preserved and are rarely buried *in situ.* Nevertheless, it can be noted that rhypidocystids are less abundant in the bioherms, whereas crinoids are more common. There are also some endemic echinoderms, such as *Simankovocrinus* (Fig. 8:A) and *Paracriptocrinites* that occur only in a bioherm community.

Ecologically, a bioherm community contains filter feeders of 0 to 1m tiering (layering) that could consume food particles from bacterial to small multicellular size. Bioherms stopped their development at the beginning of the Kunda Stage. Hence, their associated echinoderm community and the hard ground community also disappeared (Fig 8:B). This possibly was a result of regression at the Volkhov/Kunda boundary and related to the resultant change in configuration of currents.

The Billingenian echinoderms have been found only in the eastern part of the St. Petersburg region. They are represented exclusively by incomplete fragments and are difficult to identify exactly. Among them the crinoid ossicles of three disparid inadunate genera *Asterocrinus, "Haplocrinus monile"* and *Sphenocrinus* are the most common. Parts of rombifers are comparatively rare, possibly due to taphonomic effect, because the skeletons of these organisms normally disintegrate upon death. They are represented by the genus *Echinoencrinites* of the gliptocystitid superfamily. Fragments of diploporids belonging to the family *Asteroblastidae* occur at about the same frequency. Rare parts of rhypidocystids (eocrinoids) more likely belong to the genus *Rhipidocystis*. Thus, the first stage of echinoderm invasion to the eastern part of the Baltic basin is characterized by the occurrence of a typical Palaeozoic evolutionary fauna: crinoids, rombifers, diploporids and rare eocrinoids of distinctive Ordovician affinity.



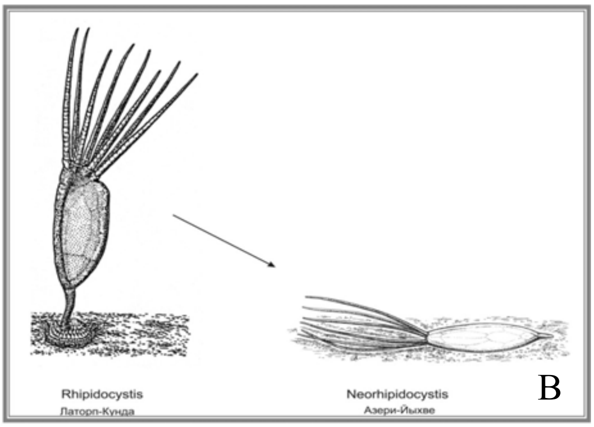


Fig. 8.A. Endemic eocrinoids *Simonkovicrinus* and *Paracryptocrinites*. B. At the beginning of Kunda tendency to come nearer to the surface of ground appeared among some echinoderms.

All Billingen echinoderms, excluding the genus *Asterocrinitus*, continue into the Volkhov Stage, where their quantity and diversity are significantly increased. For example, *"Haplocrinus monile"* becomes dominant in the lower part of the Volkhov Stage (Dikari). Fragments of *Sphenocrinus* occur up to the upper Kunda. The type species of the genus *Rhipidocystis* ranges throughout the Volkhovian. Its skeletal elements are often rock forming in the Zheltiaki and Frizy limestones. The invasion of the Palaeozoic fauna continues with the appearance of two new disparid genera in the Lower Volkhovian. At the middle of the Volkhovian Stage, this invasion and the development of already existing echinoderms have a mass character. Echinoderms reach their diversification maximum at the class level at the end of the Volkhovian. Here, typical Ordovician *Crinoidea, Rhombifera, Diploporida, Eocrinoidea* and *Asteroidea*, *Ophiocistoidea, Stylophora, Edrioblastoidea* all occur together. One unusual echinoderm, *Bolboporites* (Fig. 9:A) is of particular interest. Eltysheva considered them to be spines of the sea starfishes. Afterwards they were described by Rozhnov and Kushlina (1994), who demonstrated the existence of brachiole in their morphological structure and proved their eocrinoid affinity. The biggest diploporita, *Mesocystis*, with a thecal size up to 15cm in diameter is common in the Zheltiaki. Almost all these echinoderms are typical representatives of the Palaeozoic evolutionary fauna. Only stylophors, edrioasteroids and eocrinoids have Cambrian evolutionary faunal appearance, but they have so many dissimilarities with their Cambrian ancestors, that can be assigned to this fauna only conventionally. Such echinoderm diversity occur up to the end of the "Arenigian" and the lower part of the Kunda Stage.

In the middle part of the Kunda Stage echinoderms are extremely rare. But in its upper part they again became abundant. Most of the taxa are descendants of the "Arenigian" fauna. These taxa include crinoids, gliptocystid rombifers and eocrinoids. In addition to these forms, several echinoderms typical for younger levels such as *Hemicosmites* and *Heckericystis* first occur (Fig. 9:B). Skeletal elements of *Volchovia* (*Ophiocistioidea*) are locally common as well. This renewal of the "Arenigian" fauna becomes the most strongly pronounced since the beginning of the Aiseri. Among the rombifers, *Echinosphaerites* appears and became dominant. Sphaeronitid and glyptosphaeritid diploporites also appear and became numerous, whereas asterioblastid diploporites completely disappear. The crinoid diversity is abruptly reduced. *Hoplocrinus* (hybocrinids) and *Baltocrius* (disparids) became dominant. Coronata echinoderms make their first occurrence. Among the eocrinoids, *Bockia* first occurs and *Cryptocrinites* is more common. The "Arenigian" components of the echinoderm fauna disappear at the beginning of the Llandeilo, where Llanvirnian genera took dominance. No new echinoderm genera appear at this level, except a descendant of *Rhipidocystis* – the genus *Neorhipidocystis* and a new eocrinoid genus of unclear morphology – *Polyptychella*. In the Uhaku Stage the echinoderm fauna does not principally differ from the older one.

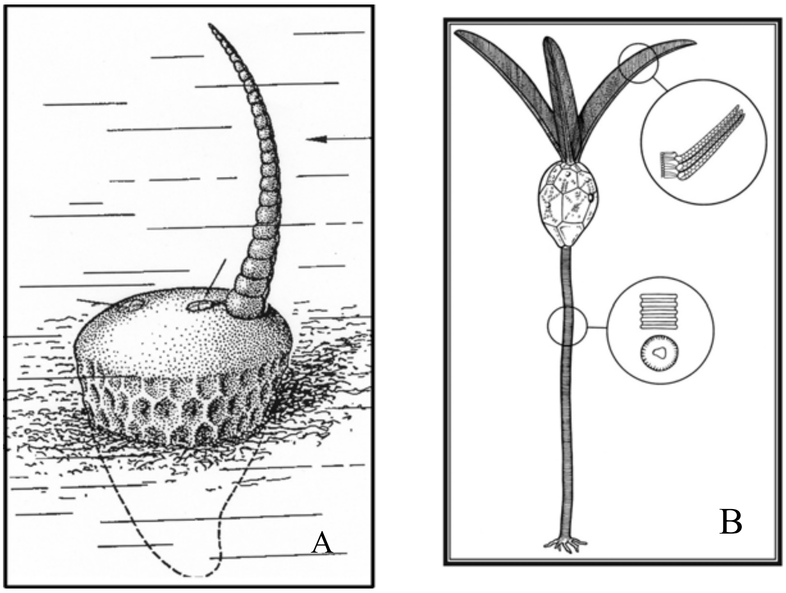


Fig. 9. A. The reconstruction of *Bolboporites*.
B. The reconstruction of *Hemicosmites* (Rhombifera).

Many new taxa occur in the Kukruse Stage. All forms of echinoderms are barely elevated above the bottom. Some North American elements appear, as, for example, a new genus similar to *Cupulocrinus*. The first echinoderm attributed to the genus *Bothriocidaris* also occurs. The community has a warm-water character. Echinoderm diversity continues to increase in the Idavere Stage. A rich fauna of this age has been recently discovered to the west of St. Petersburg. It includes local forms that existed here before and new ones coming from Gondwana. The most characteristic feature of this fauna is the pygmy size of its members. This is possibly a result of cold currents coming in and the resultant cooling of the region. A new discovery of a cornut stylophora (*Lagenocystis*) gives evidence to support this argument. The later form is typical of cold water Gondwana seas. To the west, in Estonia, the coeval fauna is less diverse and has normal sized elements. Younger sediments are preserved mostly in Estonia.

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RHYNCHONELLIFORMEAN BRACHIOPODS

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History of the Ordovician brachiopod researches in the St Petersburg region counts more than one and three quarters of a century since pioneering publications by E.Eichwald (1829) and C.Pander (1830). Subsequently a significant number of the Ordovician rhynchonelliformean brachiopod taxa were described by E.Eichwald, E.Verneuil, A.Pahlen, J.Wysogorskii and V.V.Lamansky. By the beginning of the twenties century satisfactory knowledge on the Early to Mid Ordovician brachiopod diversity of St. Petersburg region was acquired, however in a view of a lack of substantial progress in the revision of all these faunas during the last century many of the brachiopod species now require a revision and real stratigrafical ranges of the most of the species described in the nineteenth century remain inadequately known. Part of the original brachiopod collection of Eichwald and collections of Lamansky and Pahlen are still preserved in the Department of Historical Geology, St. Petersburg State University and Central Research and Exploration (CNIGR) Museum, but important collections of Pander and Wysogorskii have been lost completely and a fate of the old collection studied by Verneuil, that is presumably in Paris, remains unclear. As well as there was no practice of preservation and curation of research collections in the Geological Survey, St.Petersburg State University and VSEGEI, little is still preserved except originals to the monographic studies and important brachiopod collection assembled by T.N.Alichova from the Ordovician cores is also destroyed.

As a consequence, well it is difficult to understand original taxonomic concept of numerous taxa cited in the literature that are based on the publications from nineteenth century and have never been revised since.

In the 30-th years of the last century A.Öpik has pointed on the existence of nomenclatorial confusion in understanding of numerous brachiopod taxa widely distributed in the Ordovician deposits of North Estonia and St. Petersburg region. Unfortunately, the fundamental taxonomic revision of the faunas was out scope in subsequent studies of Lesnikova (1923) and Alichova (1951, 1953, 1969). These publications together with data published by Gorjansky (1969) on craniiformean and rhynchonelliformean brachiopods represent the main source of present knowledge of the Ordovician brachiopods of the St.Petersburg region applied to the biostratigraphical studies (Rescheniya…, 1987).

Among more recent studies on the important information on the Early to Mid Ordovician Clitambonitoidea, Dalmanelloidea, Orthoidea, and Syntrophioidea can be found in publications by Rubel (1961, 1963), whereas Hints (1975) published a fundamental taxonomic revision of the Ordovician endopunctate orthides from the East Baltic including the St. Petersburg region. That includes a revision of *Paucicrura navis*, *Howellites wesenbergensis,* and *Horderleyella kegelensis* common in early to late Caradoc in the western part of the St. Petersburg region.

There are also several publication by A. Oraspóld and A. Róómusoks dedicated to the description of rhynchonelliformean brachiopod taxa from the Estonian part of the North Estonian Confacies Belt with a reference to the species that also occur in the St.Petersburg region was under discussion.

In addition several new rhynchonelliformean species have been described from the Ordovician (Arenig to Caradoc) of the St. Petersburg region (Rubel and Popov, 1994; Zuykov, 1995, 1999; Egerquist, 1999, 2003; Zuykov and Hints, 2002), but only two large generic groups of species (*Orthambonites* and *Platystrophia*) have been substantially revised; and the East Baltic Porambonitidae are currently under revision. Publication by Jaanusson and Bassett (1993) is of particular interest, because it represent a first fundamental revision of the Baltoscandian taxa that belong to the '*Orthambonites* group' defined by Pander (1830) and this approach can be used to other Pander's genera and species that require a revision. Being one of the most commonly quoted in stratigraphical, paleontological and educational papers, *Orthambonites* Pander (1830) in Russian literature was regarded generally as a synonym of *Orthis* Dalman (1828). As a result of comprehensive study, Jaanusson and Bassett restricted usage of the generic name '*Orthambonites*' to a small group of early Darriwilian brachiopods from Baltoscandia, whereas numerous species previously referred to that genus were re-assigned to several other orthid genera.

The rhynchonelliformean brachiopods usually identified as *Platystrophia* (s.l.) are widespread and abundant in the Ordovician and Lower Silurian deposits of the East Baltic that contain the most complete record of evolutionary history of the group corresponding its whole known stratigraphic range (Zuykov, 2001). Paskevicius (2000) used some species of *Platystrophia* as the index taxa of the local biostratigraphical units for the Caradoc-Ashgill of Lithuania. Recent revision has led to an improved understanding of morphology, taxonomy and systematic of *Platystrophia*-like brachiopods (Zuykov, 2003; Zuykov and Harper, in press.). In order to stabilize the concept of the genus, *Porambonites costatus* Pander, 1830 is formally proposed (Zuykov and Harper, 2004) as the type species of the genus to replace *P. biforata* King, 1850; the latter is considered to be a *nomen dubium*. In the revised diagnosis, *Platystrophia* (s.s.) is restricted to a large group of Arenig to Late Caradoc species from Baltoscandia and Avalonia, whereas Ashgill and lower Silurian taxa of these regions and Laurentia are assigned to the three new genera (including *Siljanostrophia* Zuykov and Egerquist, 2005). In the St. Petersburg region *Platystrophia* (s.s.) can be found through the stratigraphical interval from the Volkhov to Oandu regional stages. Moreover, *Platystrophia putilovensis* Zuykov (1999) from the Volkhov Regional Stage (*Baltoniodus norrlandicus* conodont Biozone) of St. Petersburg region (Putilovo quarry) is the oldest known representative of the genus.

Popov, Egerquist, Zuykov (2005) recently provided a new account on syntrophiidine brachiopods from the St. Petersburg region. In particular, they revised *Idiostrophia digitata* [=*Terebratula digitata* Leuchtenberg 1843] from the Volkhov Stage, *Rhynchocamara*? *acuminatus* [= *Porambonites acuminata* Pander, 1830)] from the Kunda Regional Stage, *Parastrophina dura* [= *Camerella dura* Oraspõld, 1956] from the Oandu Regional Stage. The family Porambonitidae is one of the most distinctive groups of Baltic brachiopods, but it has not been the subject of any comprehensive study since that by Teichert (1930). Newly available material demonstrates considerable morphological variability among Early Ordovician porambonitids; in particular, a presence of the shells with only multicostellate ornament (*Eoporambonites*) or completely smooth surfaces (*Porambonites*). The poorly known type species of *Porambonites*, *P. intermedius,* belongs in fact to the smooth porambonitids and is markedly different from taxa traditionally referred to the genus. Generic affinities of the majority of species currently assigned to *Porambonites* (Teichert 1930) must be reconsidered in the future.

Recently, taxonomic composition and biodiversity patterns of brachiopod fauna in the Middle Ordovician (Volkhov Regional Stage) of St. Petersburg region (the Putilovo Quarry) were analysed by Egerquist (Tolmacheva et al., 2001, 2003). She also described new orthid genus *Leoniorthis* Egerquist (2003) that also occurs in North Estonia.

Madison (2004a, b, c) studied the morphology of orthid larval shells and details of deltidial structures in clitambonitid brachiopods from St. Petersburg and Pskov regions, whereas Vinn and Rubel (2000) revised the spondylium and related structures in the clitambonitidine brachiopods from the Estonia and St. Petersburg region.

The unique complex of benthic fauna dominated by brachiopods has been found in the Gryazno Formation (Idavere Regional Stage) of the Klyasino quarry, western part of St. Petersburg region (Zuykov and Hints, 2001). Two new species, *Estlandia hispida* and *Platystrophia klyasinoensis*, were described already from this locality (Zuykov, 1995, Zuykov and Hints, 2002).

In spite of considerable progress in the Ordovician brachiopod studies of the St.Petersburg region in recent years many groups, in particular clitambonitoids, porambonitoids, plectambonitoids and some orthides require a revision. Inadequate information on stratigraphical ranges of most of known species and poor state of previously assembled brachiopod collections suggest existing gap in their knowledge cannot be filled without sampling of new material and biostratigraphical observations in the field.

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CORALS

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The Ordovician corals of St. Petersburg region have not been monographically studied. One of the first workers to mention corals of St. Petersburg region was Cherkesov (Cherkesov, 1936), who described some observations of the life-time position of the "Ijev *Rugosa*" (Oandu or Rakvere Regional Stage, *clingani* – zone) on a bedding plane on the left bank of the Pljussa River. A few species of *Rugosa* have been listed from the lower and middle Late Ordovician (Jõhvi to Nabala Regional Stage) of the St. Petersburg region in several papers (Kaljo, 1956; 1958a, b; Reiman, 1958; Weyer, 1978; 1983; 1984; 1993; 1997): *Streptelasma orientalis* Kaljo, 1958, *Kenophyllum canaliferum* (Reiman in Kaljo, 1958), *Lambelasma atavum* (Kaljo, 1958), *Rectigrewingkia lutkevichi* (Reiman, 1958), *Primitophyllum primum* Kaljo, 1956. The type material for *Lambelasma narvaense* Weyer, 1984 comes from the Rakvere Stage of the boundary area of Estonia and the St. Petersburg Region (Weyer, 1984).

Two rugose coral suborders *Calostylina* and *Streptelasmatina* are dominent in the lower and middle parts of the Upper Ordovician in the St. Petersburg region. According to some preliminary data, rugose corals are most widespread in the Oandu and Rakvere regional stages and are represented with sparsely distributed small and middle-sized solitary corals. Thus, a solitary coral fauna *Lambelasma atavum* (Kaljo, 1958), *Lambelasma narvaense* Weyer, 1984, *Lambelasma* sp., *Dybowskinia dybowskii* Weyer, *Coelolasma* sp., *Coelostylis* sp. was found in the Oandu and Rakvere limestones in the Pechjurki Quarry near the Pljussa River. Also, a new *Heliolitoidea*-species (*Coccoseris* sp. nov.) will be described in the future from the Rakvere Stage of the same locality after additional material has been studied.

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CEPHALOPODS (ORDER ENDOCERIDA)

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The greatest success of the nonammonoid ectocochlian cephalopods came in the Ordovician Period with evolutionary pulses in the Tremadoc (total-55 genera, Endocerida genera-15), Arenig (total-178 genera, Endocerida-66), Llanvirn (total-131, Endocerida-43), Llandeilo (total-112, Endocerida-24), Caradoc (total-135, Endocerida-24) and the Ashgill (total-129, Endocerida-12) (Crick, 1993). All Ordovician cephalopod assemblages of the Baltoscandian are represented by 197 genera, assigned to 11 orders. About 30 genera have been found in the Ordovician sections of the Baltic-Ladoga Glint (Balashov, 1968; Kiselev, 1990, 1997). The representatives of four large orders of Cephalopods (Endocerida, Tarphycerida, Orthocerida and Discosorida) are found more frequently in the Ordovician deposits from this region. The fauna of the Baltoscanda nonammonoid cephalopods is very important for stratigraphic correlation because this fauna fills a taxonomical gap between the Lower Ordovician fauna of North America and the upper Middle Ordovician faunas of Siberia, China and North America (Barskov et al., 1994). Cephalopods from the Ordovician deposits of the Baltic region have been mentioned and described in the classical publications by F. Schmidt, E. Eichwald, C. Teichert and Z. Balashov. Later Dzick (1984), Kiselev (1990; Kiselev et al., 1993) and Kröger (2004) have revised some genera. However, the taxonomical status of many taxa has not been clear until recently and revision of the described forms is required.

The sediments of the Ladoga region include a Cephalopod (“Ortoceratite”) Limestone” where not only species of the genera “Orthoceras s.s.” but also of the orders Endocerida, Actinocerida and Oncocerida with an orthoceraconic form of shell are represented. These taxa are more often found in the Cephalopod Limestones in most of the outcrops on the Volkhov River. The following representatives of five genera of the order Endocerida have been found in the sedimentary successions of the St. Petersburg region:

Latorp Regional Stage - *Dideroceras leetsense* Bal., 1968;

Volkhov Regional Stage - *D. frisense Bal.,* 1968; *D. glauconiticum* (Heinrichson, 1935); *Dideroceras popovkense* Bal., 1968; *D. laxiseptatum* Bal., 1968;

Kunda Regional Stage - *D. incognitum* (Schroder, 1881); *Paracyclendoceras cancellatum* (Eichwald, 1861); *Dideroceras pribalticum* Bal., 1968;

Aseri Regional Stage - *Proterovaginoceras belemnitiforme* (Holm, 1885);

Lasnamagi Regional Stage - *Cameroceras paldiscense* Bal., 1968; *C. tallinense* Bal., 1968; *Dideroceras rectestrigatum* (Schroder, 1881);

Uhaku Regional Stage - *Cameroceras planum* Bal., 1968; *Dideroceras rectestrigatum* (Schroder, 1881); *Cameroceras planum* Bal., 1968;

Idavere Regional Stage - *Rossicoceras depressum* Bal., 1968; *Cameroceras spongistariticum* Bal., 1968;

Keila Regional Stage - *Rossicoceras depressum* Bal., 1968; *Cameroceras aluverense*, Bal., 1968.

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SCOLECODONTS

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Scolecodonts, the jaws of polychaete worms (Annelida, Polychaeta, Eunicida) are very common and diverse microfossils starting from the Middle Ordovician. More than 120 Ordovician apparatus-based species have been recorded from the Baltic area making this the best-known region for scolecodonts in the world (Hints et al., 2004, Hints and Eriksson, in press).

Studies of acid-resistant microfossils (such as chitinozoans and conodonts) in the St. Petersburg region (Leningrad District) have also revealed frequent occurrence of scolecodonts. They are expected to occur in most carbonate and clayey rocks except for the red-coloured and strongly dolomitised ones. To date, however, only part of the succession in the St. Petersburg region has been studied with particular aim on scolecodonts. The study is currently in progress and the published record is limited (Hints, 1998; Hints, 2000). Most of the data currently available come from the Uhaku, Kukruse, Haljala (Idavere and Jõhvi) and Keila stages.

The Uhaku–Kukruse interval has been studied in the Alekseevka quarry near Kingisepp town. Although the material has not been published so far, it can be concluded that the fauna is very similar to that recently described from NW Estonia both in taxonomic composition and assemblage structure. The fauna is dominated primarily by *Pistoprion* sp. C sensu Hints 2000, *Pteropelta gladiata* Eisenack, *Mochtyella cristata* Kielan-Jaworowska, "*Mochtyella*" *fragilis* Szaniawski and several species of *Oenonites* and *Ramphoprion*. In addition, *Atraktoprion* sp. A sensu Hints 2000, *Euryprion rarus* Kielan-Jaworowska, *Rhytiprion magnus* and *Xanioprion* sp. are typical components of this fauna. As in NW Estonia, no distinct changes can be followed in the polychaete fauna at the Uhaku-Kukruse boundary interval.

The Kukruse–Haljala (Idavere) interval has been collected for acid-resistant microfossils in the Klyasino quarry, some 60 km west of St. Petersburg. This section is stratigraphical prolongation of the sequence exposed in the Alekseevka quarry. The scolecodont assemblage containing some 30 species in Klyasino is, however, somewhat different from that of the Alekseevka quarry. The most notable difference is the absence of *Pistoprion* sp. C sensu Hints 2000. The disappearance of this species in Estonian sections occurs in the middle of the Kukruse Stage, hence its absence in Klyasino may also be a stratigraphical indication. The Kukruse-Haljala (Idavere) boundary in Klyasino, identified by chitinozoans and lithological criteria, coincides with the disappearance of some ramphoprionids, *Rhytiprion magnus* and "*Mochtyella*" *fragilis*. The range of *Euryprion rarus*, that in northern Estonia is confined to pre-Idaverean strata seems to be wider in Klyasino extending to the Idaverean strata.

Scolecodonts have also been studied in the interval from the Haljala (Idavere) to Keila stages of the Apraksin Bor (Krasnyje Gory No 17) drillcore, some 80 km SE of St. Petersburg. 24 species of jawed polychaetes have been recovered from this locality, including two new species, *Ramphoprion peterburgensis* and *Incisiprion edentulus* (Hints 1998). Generally the assemblages turned rather similar to those recovered from northern Estonia, especially for the Idaverean part of the succession, dominated by various species of *Oenonites*, *Protarabellites*, *Mochtyella* and others (Hints 1998). However, the post-Haljalan faunas of Apraksin Bor display some distinctive features. For instance, several predominating species, like *Oenonites tuberculatus* (Kielan-Jaworowska), *Kozlowskiprion brevialatus* Kielan-Jaworowska, *Oenonites* cf. *wyszogrodensis* (Kozlowski) and *Incisiprion incisus* (Kielan-Jaworowska) are recovered in northern Estonia in markedly lower frequency. In turn, *Oenonites gadomskae* (Kielan-Jaworowska), *O. latus* (Kielan-Jaworowska) and various placognaths are absent or very rare in contemporaneous strata of the Apraksin Bor section.

As a summary it should be noted that the interval between Uhaku and Keila stages is characterised by no less than 40 different species of jaw-bearing polychaetes in the St. Petersburg region (further studies will certainly enlarge this number). The absolute frequency of scolecodonts is comparable to that of conodonts, occasionally more than 1000/kg. Usually 10 to 20 species were recorded in a sample. The most common genera include *Oenonites*, *Mochtyella*, *Pistoprion*, *Pteropelta*, *Protarabellites*, *Ramphoprion*, *Xanioprion*, *Tetraprion*, *Kozlowskiprion*, *Incisiprion*, *Atraktoprion*, *Leptoprion* and *Kalloprion*. Most of the species recovered are long-ranging (e.g., *Pteropelta gladiata*), but some with restricted distribution and thus possible stratigraphical value were also found. The scolecodont assemblages of the St. Petersburg region appeared to be very similar to those of northern Estonia. This is not surprising taken that the geographical area in question is limited. Starting from the Keila time the some differences between the polychaete faunas of northern Estonia and NW Russia seem to have emerged which most likely reflects increased facies differentiation within the Baltoscandian palaeobasin.
Further studies are needed to expand the knowledge on scolecodonts of the St. Petersburg region. Most promising is perhaps early Middle Ordovician succession — faunas of that interval are globally very poorly known, but crucial for understanding the early history and rise of jawed polychaetes, a group that turned very successful throughout the entire Phanerozoic.

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FORAMINIFERS

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Recent studies on the biostratigraphy of Ordovician strata in the vicinity of St. Petersburg has shown that the Lower and basal Middle Ordovician deposits contain numerous monothalamous agglutinated foraminifers (Tolmacheva et al., 2001; Nestell and Tolmacheva, 2004). This is the first data on the findings of foraminifers in the northwestern Russia. However, in Baltoscandia (herein considered to include northwestern Russia, Sweden, Norway, Estonia, Lithuania, Latvia, and northern Germany), foraminifers are known from the Middle Ordovician of Latvia (Bykova, 1956), the *Didymograptus bifidus* graptolite Zone of the Lower Llanvirnian (Middle Ordovician) of northwestern Germany (Riegraf and Niemeyer, 1996), and horizons B_{II} and C_{I} of the Middle Ordovician, and Caradoc and Ashgill strata (in the British Series) of the Upper Ordovician of East Prussia (Eisenack, 1954, 1967).

In northwestern Russia, foraminifers were discovered in the classic sections of the Latorp Regional Stage (Hunneberg and Billingen stages in the wider sense) in the Lava River canyon and in the Putolovo Quarry. At these localities, foraminifers are abundant, more than several hundred tests per 1 kg of sediment, and appear to be restricted to strata of the Lakity Member of the Leetse Formation. Only rare foraminifers were found in the general area in similar age Ordovician exposures on the Tosna and Popovka rivers.

The clays of the Lakity Member yield a diverse assemblage of foraminifers composed of 11 species. The species *Lakites ordovicus* Nestell and Tolmacheva 2004, *Amphitremoida asperella* Nestell and Tolmacheva 2004, *A. orbicularis* Nestell and Tolmacheva 2004, *A. longa* Nestell and Tolmacheva 2004, *A. rugosa* Nestell and Tolmacheva 2004 (Nestell and Tolmacheva, 2004), and also *Psammosphaera micrograna* Eisenack, 1932 occur in the lower part of clays as well as in the upper part. The species *Amphitremoida laevis* Nestell and Tolmacheva 2004, *A. batuliformis* n. sp., *Lavella cucumeriformis* Nestell and Tolmacheva 2004, *Thuramminoides*? sp. and *Arenosiphon*? sp. appear for the first time in the upper part of the clays.

Foraminifers of the Volkhov Stage have been collected from the clay core of a microbial mud mound in the Putilovo Quarry. The most diverse assemblage of agglutinated foraminifers was recovered from the basal *Baltoniodus triangularis* conodont Zone that yields following species: *Lakites* n. sp., *Thuramminoides* n. sp., *Sorosphaerella* aff. *S. cooperensis* (Conkin, Conkin and Thurman 1979), *Sorosphaera*? sp., *Colonammina* n. sp., *Tholosina* n. sp., *Saccammina*? sp., *Lagenammina* sp., *Ammolagena silurica* Eisenack, 1954, and *Hyperammina*? sp. The clay of the *Paroistodus originalis* conodont Zone contains very small, compressed and poorly preserved tests of the genera *Amphitremoida* and *Thuramminoides*.

The foraminiferal tests of the genera *Lakites* and *Amphitremoida* are composed of very rare and small (3-5µm) quartz and K-feldspar (5-10µm in length) grains as well as of products of K-feldspar degradations, muscovite and sericite that are among the most common grains and compose more than 95% of foraminiferal tests.

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TRACE FOSSILS

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Ordovician sediments of St. Petersburg region contain rich and diverse ichnofossil assemblages. In contrast to shelly fauna, however, which have been collected and studied here for more than two centuries, trace fossils never been a subject of systematic research. Vishniakov and Hecker (1937) where the first who interpreted specific structures visible on the surfaces of Ordovician rocks in St. Petersburg region as made by ancient organisms. For a long time *Trypanites* borings (Vishniakov and Hecker, 1937) and "Amphora-like" burrows (Vishniakovand Hecker, 1937; Männil, 1966) or borings (Orviku, 1940) were the only ichotaxa described from the region. Some of the ichnogenera such as *Skolithos*, *Thalassinoides*, *Bergaueria* and *Chondrites* have been but only briefly mentioned in the literature (Dronov, et al., 1996).

In recent years a special investigation on the Ordovician trace fossils have been undertaken in the region (Dronov, Mikuláš and Logvinova, 2002, Mikulas and Dronov, 2004a, 2004b, Savitskaya, 2004, Ershova and Fedorov 2004). These papers document peculiarity and virtually basic importance of the present ichnoassemblages and ichnofabric features, e.g., for understanding the evolution of complex behaviour of in-fauna (including the ability to colonize hard substrates) and for sequence stratigraphy and transgression/regression history of the region. Paper covering the systematic ichnology of the area is in preparation. The aim of the present contribution is to present a brief synopsis of a state of art in an ichnological studies in the Region. Most of the materials with a few exceptions came from the natural outcrops of the Lower and lower part of the Middle Ordovician along the Baltic-Ladoga Glint line.

Systematic synopsis

BURROWING TRACES

The ichnogenus ***Amphorichnus*** Männil, 1966, is represented in the region by several forms, whose can be regarded separate, not-yet described ichnospecies (Fig. 10). Modern revision of *Amphorichnus* has not been done yet; but we conclude, considering analogous treatment of similar ichnotaxa, especially *Gastrochaenolites* Leymerie, that a diagnosis of *Amphorichnus* should be broadened, including all drop-like, bulbous or vase-like burrows **in soft substrates**. *Amphorichnus papillatus* Männil, 1966 sp. (div. isp.), shows a sharp extremity on the base of the chamber. Bulbous and "torpedo-like" forms have not given ichnospecific names yet. It is notable that the different forms may occur altogether (e.g. base of Kunda stage in the Putilovo Quarry) but in other sites and stratigraphic levels some of them highly prevail (cf. Ershova and Fedorov, 2004). These traces are interpreted by dwelling burrows of filter-feeders of unknown systematic position. *Amphorichus* is widespread in Hunneberg, Billingen, Volkhov, Kunda and Haljala stages of the region.

The ichnogenus ***Arachnostega*** Bertling, 1992 has so far only the type ichnospecies *Arachnostega gastrochaenae* Bertling, 1992. These are represented by burrow systems formed of straight, curved or broken tunnels on the surface of internal moulds of invertebrate shells, most often molluscs. Forms considered to be initial ones are simply branched; full developed systems consist of irregular polygonal meshes. The structures might have both feeding and dwelling purpose. Besides Bertling (1992), who described Arachnostega from shallow-marine Jurassic sediments, the trace has been recognized in the Ordovician (e.g., Aceňolaza and Aceňolaza 2003). In the Ordovician of the St Petersburg Region, *Arachnostega gastrochaenae* is common through the Kunda regional stage.

The ichnogenus ***Arenicolites*** Salter, 1857 is represented by simple U-shaped burrows without the reworked material between the limbs (spreite). Distance between the limbs is several (up to 5) cm, diameter of shafts/tunnels 3-5 mm. Vertical size of the structure is up to several centimetres but it can be influenced by erosion, therefore it might be originally larger. For this imperfect preservation, we cannot determine our finds on ichnospecific level as done, e.g., by Fillion and Pickerill (1990). *Arenicolites* is generally interpreted as a dwelling burrow of suspension feeders or predators (e.g., Bjerstedt 1988). In our region, *Arenicolites* have been found in the middle substage (BIIβ) of the Volkhov stage.

The ichnogenus ***Bergaueria*** Prantl, 1945 is represented by shallow, basically hemispherical to cylindrical solitary burrows (convex hyporeliefs or full reliefs) circular in section, perpendicular to bedding planes. Diameter of them is mostly 10-20 mm; ratio depth /diameter vary in most cases from 0.5 to 2.0. Base of burrows is hemispherical, rarely flat or conical. Surface is smooth; wall lining is absent. The fill corresponds to the surrounding (and also overlying) rock. It is homogeneous, structureless, and probably passive. The burrows occur often in rather dense populations, showing very uniform way of preservation. Fill is rich in glauconite, which makes the convex hyporeliefs contrasting in its colour with the surrounding biodetritic limestone. *Bergaueria* is considered to be a shallow-water trace fossil, probably the domichnion and/or cubichnion of anemones (Pemberton, Frey and Bromley, 1988). In the studied region, *Bergaueria* is most common in the Bratvennik and Butok Beds of the Dikari Unit. Occassionally it occurs also in the Zheltiaki and Frizy Units of the Volkhov Formation.

The ichnogenus **Chondrites** Brongniart, 1828. Trace fossils attributable to *Chondrites* occur mostly as groups of sections of tunnels. On vertical sections of the rock, elliptical sections highly prevail, representing cross-sections of flattened horizontal and oblique tunnels. Estimated average width of the tunnels prior its diagenetic deformation is 1.0 - 1.5 mm. Location and orientation of sections suggest that originally the system of passages had a rhizoidal shape. This is supported by less frequent finds of thin branching tunnels on horizontal division planes. Size of the whole systems can be estimated to several centimetres both horizontally, and vertically. The presumed shape of the system corresponds to the ichnogenus *Chondrites* as described by numerous authors, most extensively by Fu (1991) and Uchman (1999). *Chondrites* often follow the pre-existing ichnofacbrics; it often re-burrows tunnels of *Thalassinoides*. *Chondrites* is very common in certain layers of Leetse Formation and in Zheltenky Bed of the Zheltiaky Unit (Volkhov Formation).

The ichnogenus ***Conichnus*** Männil, 1966 consists of conical, deep holes (more often preserved as their fills in lower bedding planes). Base of the cone is not sharp but finger-shaped; depth of the trace is 1.5 to 2 x higher than its diameter; wall unlined, sometimes bearing irregular radial ornament (modified after Pemberton et al. 1988). *Conichnus* occurs locally at the base of the basal beds of the Leetse Formation in the Syas River valley (Victoria Ershova, *pers. comm.* 2004). It represents probably dwelling burrows of anemones or similar organisms.

Diplocraterion Torell, 1870 is characterized by vertical U-shaped burrow; contrary to *Arenicolites*, the vertical limbs are at least in certain portion of the trace joined by the lamina of reworked sediment (so-called *spreite*) (e.g., Fillion and Pickerill, 1990). The ichnogenus is rare in the described area; the only finds come from decoration stones of the Kunda section (unknown locality), where the spreiten-structure is perfectly visualized.

Gyrochorte Heer, 1865 is usually preserved as low, straight to moderately curved mounds (convex epireliefs) with a typical "chevron-like- sculpture (cf. Häntzschel, 1975). In the studied area, the ichnogenus was found so far only in thin-bedded quartzose sandstones of the Pakerort sequence at Sablino.

Palaeophycus Hall, 1847 is characterized by straight to slightly curved, smooth or ornamented, typically lined, essentially cylindrical, chiefly horizontal structures. Branching, if present, is irregular. Fill is typically massive, structureless (cf. Fillion and Pickerill, 1990). These traces are usually interpreted as open dwelling burrows. In the St Petersburg Region, Palaeophycus occurs as one of the main components of ichnofabric in the uppermost paer of the Latorp sequence, in the uppermost part of the Volkhov sequence (Koroba) and at the base of Kunda (Putilovo Quarry, Sablino, Lava River).

The ichnogenus ***Phycodes*** Richter, 1850 is composed of horizontal, subhorizontal to oblique bundled burrows, often preserved as convex hyporeliefs. Overall "ground plan" is fasciculate, flabellate, fan-like etc. Individual ichnospecies differ strongly by the number of branchings, size, and presence/absence of spreiten-like structures (adapted from Fillion and Pickerill, 1990). Inb the St Petersburg Region, the ichnogenus occurs rarely in the top of the lowstand systems tract of the Volkhov sequence (called Dikari), namely in the Butok Layer.

Planolites Nicholson, 1873 consists of unlined, rarely branched, straight to tortuous, smooth to irregularly ornamented, horizontal to slightly inclined tunnels. Tunnels are circular to sub-circular in cross-section, filled typically with the material differing from the host rock. Branching, if present, is irregular (Pemberton and Frey, 1982). *Planolites* is an important component of the ichnofabric of transgressive system tract (Zheltiaki) of the Volkhov Sequence.

Rusophycus Hall, 1852 is most typically formed by shallow, short, horizontal bilobate burrows (pits in concave epirelief, moulds in convex hyporelief). Lobes may be smooth or ornamented by transverse to oblique scratch marks (e.g., Osgood, 1970). *Rusophycus* is interpreted as resting traces of trilobites; it is an integral part of Palaeozoic occurrences of the classical Cruziana Ichnofacies. *Rusophycus* was found rarely in transgressive system tract (Zheltiaki) of the Volkhov Sequence at the Putilovo Quarry.

Skolithos Haldeman, 1840 is represented by unbranched, vertical to steeply inclined, cylindrical to subcylindrical, usually unlined burrows. Walls may be smooth or annulated, fill massive (passively transported) (adapted after Alpert, 1974). The ichnogenus (especially if occurring in monotonous, high-density assemblages) is characteristic for high-energy marine conditions that fall into the "classical" *Skolithos* Ichnofacies (e.g., Seilacher, 1967). In the studied area, *Skolithos* forms a conspicuous, nearly monospecific assemblage in quartzose sands/sandstones of the Pakerort sequence (e.g. Sablino).

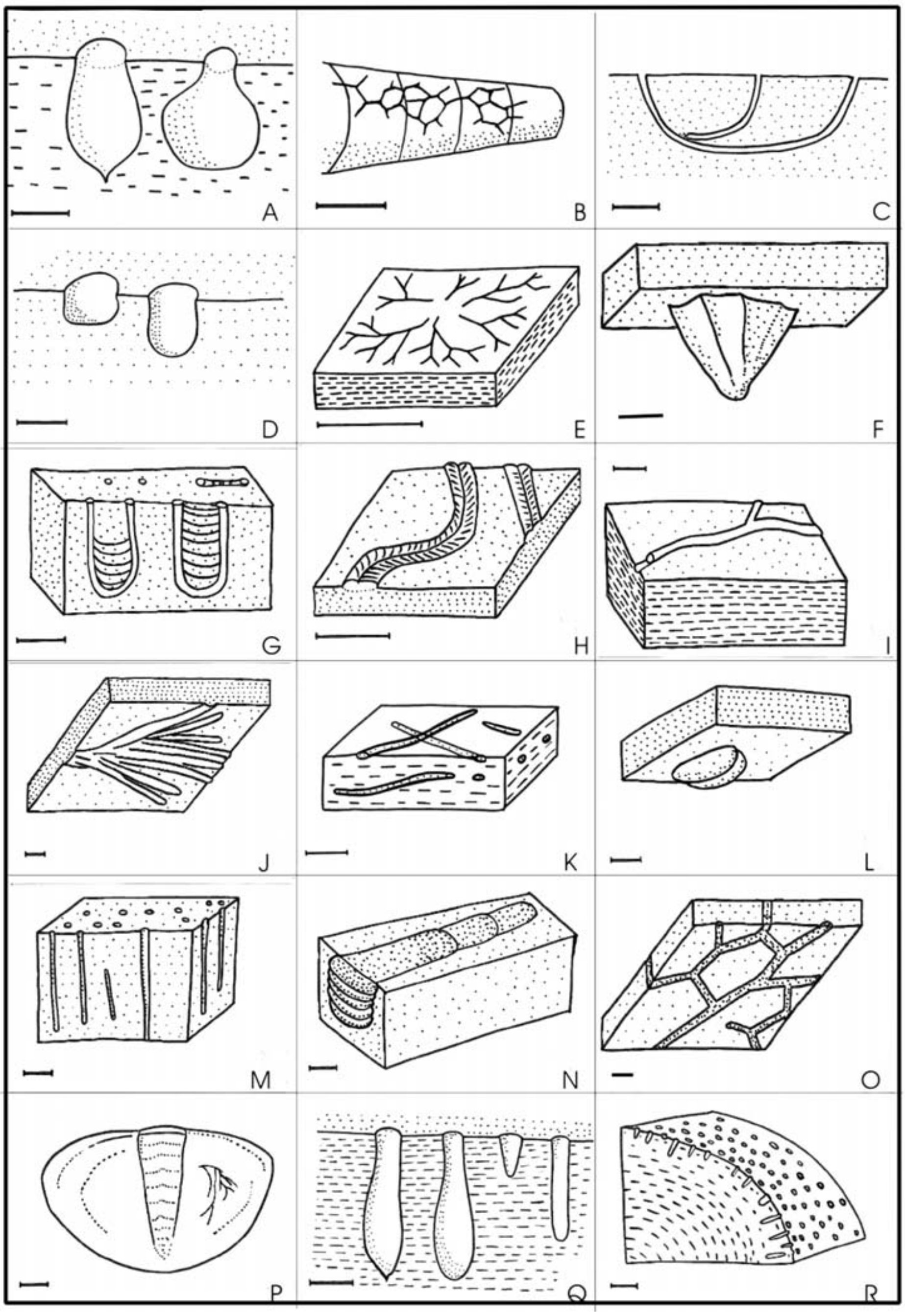

Fig. 10. Schematic drawings of the ichnogenera mentioned in the paper: A, *Amphorichnus*; B, *Arachnostega*; C, *Arenicolites*; D, *Bergaueria*; E, C*hondrites*; F, *Conichnus*; G, *Diplocraterion*; H, *Gyrochorte*; I, *Palaeophycus*; J, *Phycodes*; K, *Planolites*; L, *Rusophycus*; M, *Skolithos*; N, *Teichichnus*; O, *Thalassinoides*; P, "bryozoan borings"; Q, *Gastrochaenolites*; R, *Trypanites*. Scale bars = approximately 1 cm.

The ichnogenus ***Teichichnus*** Seilacher, 1955 is the morphologically simplest spreiten-structure, consisting of wall-shaped, approximately vettzical lamina of reworked sediment; the wall resembles a pile of trough-like bodies bordered by a tunnel (modified after Seilacher, 1955). It is a trace of feeding on soft sediment. In the studied area, the only well recognizable finds of *Teichnichnus* come form the basal beds of the Kunda sequence, i.e. the basal oolithic layer, at Putilovo Quarry.

Thalassinoides Ehrenberg, 1944 represents three-dimensional burrow systems consisting predominantly of smooth-walled cylindrical tunnels. They branch more-or less systematically; branchings are Y-shaped to T.shaped. Tunnels may be enlarged at bifurcation points. Each system usually has essentially horizointal component (subsurface tunnel network) and vertical shafts joining the tunnels with the bottom surface (modified after Howard and Frey, 1984). *Thalassinoides* is a common component of ichnofabrics especially in the transgressive and highstand system tracts of the Volkhov sequence (Zheltiaki and Frizy Mrembers; Putilovo, Sablino, Lava, Lynna and other localities).

BORINGS

"**Bryozoan borings**". Richly fossiliferous layers of the highstand system tract of the Volkhov sequenece (Frizy) contain numerous large bioclasts (especially pygidia of asaphid trilobites) bearing thin networks of tunnels bored into the shell substrate. The networks consist essentially of arcuate tunnels branching at acute angles. As these structures have not been studied in detail yet, no ichnogeneric name is suggested for them; by analogy with, e.g., the ichnogenus *Talpina*, they can be considered bryozoan borings (cf. Bromley, 1970).

The ichnogenus ***Gastrochaenolites*** Leymerie, 1842 is one of the most grequent boring structures in the fossil record. It consists of drop-like chambers of circular, elliptical, almond-shaped or nut-shaped cross-section; the cross-section of the neck region may differ from that of the lower part of the chamber. Well-known drop-like structures found on hardgrounds of the Volkhov sequence have been placed to *Gastrochaenolites* by Ekdale and Bromley (2001) under the name *G. oelandicus*. However, the situation is extremely complicated both by the presumed variability of substrates, and by the variability of the trace itself (not only drop-like, but also spherical, pencil-like or conical borings/burrows occur altogether). Nevertheless it is evident by cross-cutting of large biocalsts that at least some of these structures are real borings, made in the hard substrate.

Trypanites Magdefrau, 1932 is the morphologically simplest boring, formed by single-entrance, cylindrical or sub-cylindrical, unbranched borings in lithic substrates, having circular cross-sections throughout length. The axes of the borings may be straight, curved or irregular; diameter and depth are highly variable (adapted from Bromley and D'Alessandro 1987). In the studied area, large *Trypanites* is common in certain hardgrounds („Karandashi" structures), shallow minute *Trypanites* occurs on surfaces of Hecker-type mud mounds (Syas River, Putilovo Quarry a.o.) and on certain hardgrounds (surface underlying the Zheltiaki Member).

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GEOLOGICAL EXCURSIONS

Day 1. Friday, 19th of August: Putilovo Quarry and Lava River Canyon

Stop 1: Ravine in the north-western side of the Putilovo Quarry.
Stop 2: Mining field of the "Dikari Limestone", the Putilovo Quarry.
Stop 3: Carbonate mud mound, the Putilovo Quarry.
Stop 4: Kunda in the southern part of the Putilovo Quarry.
Stop 5: Old quarry on the left bank of the Lava River and natural outcrops on the opposite side of the valley.

As we leave St. Petersburg, we follow the St. Petersburg-Murmansk highway for some distance along the northern bank of the Neva River before crossing the river south of the town of Schlisselburg and enter an area of Lower Cambrian rocks covered by a blanket of Pleistocene glacial and post-glacial deposits. Upon reaching the Nazia River, the Baltic-Ladoga Glint becomes visible as a high escarpment situated about 2-4 km south of the highway. Ten minutes later we make a turn to the south and climb onto the Glint on the eastern side of the village of Putilovo, passing through the village and moving in a westerly direction to enter the Putilovo Quarry (Fig. 1).

Intensive quarrying started here at the beginning of the XVIIIth century when Peter the Great decided to erect a new capital of Russia on swampy islands of the mouth of the Neva River. He granted many privileges to the inhabitants of the village of Putilovo on the condition that they would quarry limestone for building purposes in St. Petersburg. At the present time, the Ordovician hard limestone, which is known in the local informal geological nomenclature as the "Dikari Limestone" (Lamansky, 1905), is quarried only in two large quarries east of St. Petersburg. The oldest one is located west of the village of Putilovo and the other one is located south-east of the village of Babino on the right bank of the Volkhov River.

There is an old tradition among the quarrymen in the vicinity of St. Petersburg to give names to certain limestone beds or bedsets. The stability of this nomenclature reflects the lateral persistence of these lithologic units. About 15 elementary informal lithostratigraphic units can be recognized in the "Dikari Limestone", and up to 14 units in the overlying part of the Volkhov Formation (Dronov et al., 1996; Dronov and Fedorov, 1995). With some variations in thickness and lithology, all of these units can be traced with certainty in all of the sections east of St. Petersburg and are also recognizable in the majority of the western sections along the Baltic-Ladoga Glint as far as the Udria cliff in Estonia. The Lower Ordovician section in the Putilovo Quarry gives a good opportunity to study in detail this informal lithostratigraphic subdivision of the Volkhov Formation.

Another interesting geological feature of this area is a carbonate mud mound developed on the discontinuity hardground surface at the top of the Billingen in the eastern part of the Putilovo Quarry. This mud mound was discovered in 1993 (Dronov and Fedorov, 1994, 1997) and seems to be the largest and best preserved organic buildup of its type in the vicinity of St. Petersburg. The remnants of another large mud mound can be seen in the westernmost part of the quarry.

Stop 1. Ravine in the northwestern side of the Putilovo Quarry

The lowermost Lower Paleozoic deposits in the Putilovo Quarry crop out along the ravine cutting the escarpment of the Baltic Ladoga Glint in the northern side of the quarry about 2 km west of the village of Putilovo. The best section of the Hunneberg and Billingen deposits is exposed here about 25m downstream from the road crossing the ravine. The sequence is as follows (from the base to the top):

Pakerort Stage
Tosna Formation (AII Ts)

About 1 m of medium- to fine-grained, brownish grey, cross-bedded quartz sand with numerous shell fragments and coquina of obolid brachiopods. It has been known as "Obolus sandstone" since the last century. The content of phosphatic shell material increases significantly in the upper 0.6 m of the unit. The cross bedded quartz sand of the Tosna Formation is regarded as a shallow water, intertidal or even a beach deposit. The top of the formation coincides with a transgressive surface.

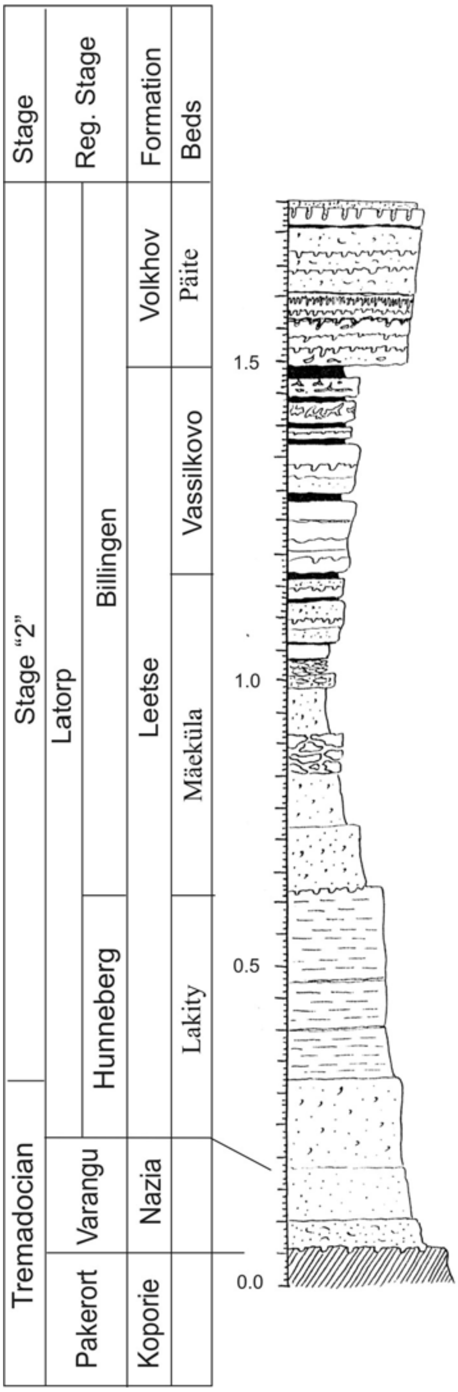

Fig. 11. The Putilovo section in the ravine.

Koporie Formation (AIII Kp)

Black, bituminous argillite 0.23 m thick. The traditional name for this unit is the "Dictyonema shale" and specimens of *Rabdinopora* (*Dictyonema*) *flabelliforme* can occasionally be found at this particular locality. The rapid shift from a cross-bedded quartz sand depositional environment to a black shale environment is interpreted as a drowning event. The base of the Koporie Formation is regarded as a transgressive surface, whereas the top seems to represent a sequence boundary marked by an erosional surface pitted by vertical borings several centimeters deep.

Varangu Stage
Nazia Formation (BI Nz)

About 0.23 m of grey fine-grained quartz sand with numerous shell fragments of organophosphatic brachiopods redeposited from the underlying Upper Cambrian and Lower Ordovician strata. The unit contains flat breccia of bituminous argillite up to 10 cm in diameter, usually slightly inclined to the bedding surface. The fossil assemblage includes numerous conodonts of the *Paltodus deltifer* Zone. This unit can be interpreted as a transgressive lag deposit at the bottom of the transgressive systems tract. Traditionally it has been regarded as a part of the "Glauconite sandstone" (Fig. 11).

Hunneberg Stage
Leetse Formation (BI Lt), Lakity Beds.

About 1.07 m of glauconitic sand and clay. At the base of the unit there is a 0.27 m bed of dark green glauconitic sand with numerous subvertical, subhorizontal and oblique burrows infilled with bluish-grey clay. The fossil assemblage contains conodonts diagnostic of the *Paroistodus proteus* Zone. The middle part of the unit is represented by bluish or greenish grey, thinly laminated clays. The upper 0.28 m contains rare conodonts belonging to *Prioniodus elegans* in association with numerous transitional species from the underlying *Paroistodus proteus* Zone. The uppermost 0.20 m of the beds is represented by dark green strongly bioturbated glauconitic sand. Traditionally it has been regarded as a part of the "Glauconite sandstone" subdivision.

Billingen Stage

Leetse Formation, Mäeküla Beds

About 0.55 m of dark green glauconitic sand interbedded with glauconite-bearing clay. Traditionally this unit belongs to the

"Glauconite sandstone". The lower 0.20 m of the unit contains a conodont assemblage of the *Prioniodus elegens* Zone. The uppermost part is represented by red calcareous clay.

Leetse Formation, Vassilkovo Beds

About 0.81 m of greenish-grey and multicoloured sandy and argillaceous limestone with clay intercalations. Traditionally this unit also belongs to the "Glauconite sandstone". In the lower part, limestone beds contain numerous grains of quartz and glauconite as well as hardground surfaces accentuated by yellow ferruginous impregnation and amphora-like borings 0.04 m deep. Some of the hardground surfaces are very smooth and covered by a glauconitic veneer. The uppermost 0.23 m of the unit is represented by nodular argillaceous limestone interbedded with red clay. Conodont assemblage of *Oepikodus evae* Zone appears in the first limestone beds of the Leetse Fm.

Volkhov Formation, Päite Beds (Dikari Limestone).

The lower boundary of the Päite beds coincides with the beginning of the "Dikari Limestone" unit which represents the lowest subdivision of the "Glauconite Limestone" in the traditional terminology. The hard, well bedded limestones of this unit are an excellent building material that has been quarried here since the foundation of St. Petersburg. The "Dikari Limestone" consists of 15 informal elementary units that can be traced along the Russian part of the Baltic-Ladoga Glint from the Syas River in the east to the Utria Cliff in Estonia in the west (Dronov et al., 1996; 2000) (Fig. 12). In the original sense of Lamansky (1905), the BIIα limestone is a formal equivalent of the "Dikari Limestone". Since the lower boundary of the Volkhov stage has been moved to the so-called "Steklo" nondepositional surface within the Dikari unit, the BIIα interval includes only the upper 10 informal units that correspond to the Saka Beds in Estonia (Kaljo 1987). The Päite Beds consists of four informal units; from the base to the top these are: (1) Barkhat; (2) Melkotsvet; (3) Krasnenky; and (4) Beloglaz (Fig. 13). These units form a shallowing upward succession. The basal units are characterised by clay-like mudstone and bioclastic wackestone with rare glauconite grains, whereas the Beloglaz is a relatively thick (0.20 m) bed of bioclastic packstone or grainstone with numerous scattered glauconite grains.

Zeleny (Green) Unit (0.09-0.30m)

This unit is a bioclastic limestone bed enriched with glauconite. It is correlated with the Billingen/Volkhov boundary interval and includes several smooth hardground surfaces covered by light green glauconitic veneers. One of these surfaces has been named "Steklo" (the glass) by local quarrymen. Lamansky (1905) traced this surface along the Baltic-Ladoga Glint from the Syas' River in the east to the cape of Pakri in the west (Dronov et al., 1993). This unit represents a first order stratigraphic marker that coincides with the boundary between the Billingen and Volkhov regional stages. It also can be interpreted as a type-2 sequence boundary (Dronov et al., 1995).

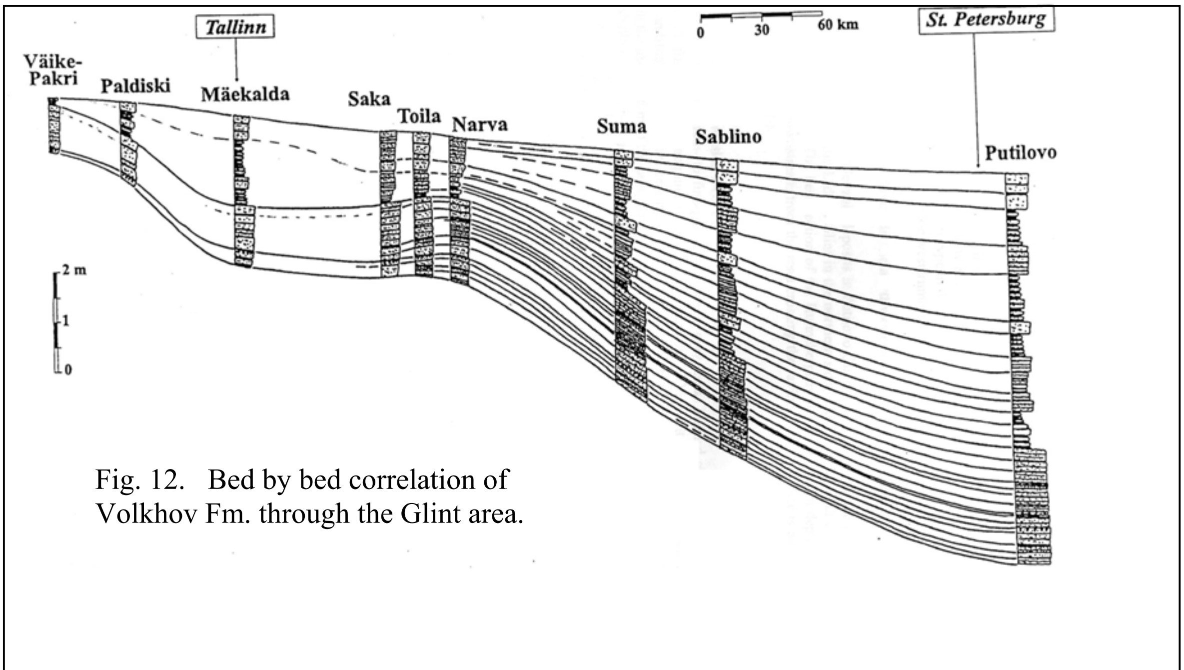

Fig. 12. Bed by bed correlation of Volkhov Fm. through the Glint area.

Stop 2. Mining field of the "Dikari Limestone", the Putilovo Quarry

Following south along the ravine we enter into the mining field of the "Dikari Limestone" (upper Billingen and Volkhov) in the western part of the Putilovo Quarry. There is an old tradition among the local quarrymen to give names to distinctive beds and bedsets as well as to some bedding surfaces. Objectively, this informal terminology reflects some distinctive lithological and sedimentological features, such as hardness and homogeneity of the rock, mode of intercalation, distribution of colours as well as content of coarse- and fine-grained clastic material. This informal terminology has been adopted for subdivision of the Volkhov Formation on numerous elementary units that, to a significant degree, are traceable all over the eastern part of the Baltic-Ladoga Glint (Dronov et al., 1996, 2000) (Fig. 12). The active mining field in Putilovo Quarry provides a good opportunity to look more precisely at this informal lithostratigraphic subdivision of the Volkhov Formation.

Volkhov Stage

Volkhov Formation, Dikari Limestone (BIIα)

The upper part of the «Dikari Limestone», which corresponds with the Saka Member in Estonia, consists of ten distinctive units (from the base of the top): (1) Staritsky; (2) Krasny; (3) Butina; (4) Zhelty; (5) Nadzhelty; (6) Magonky; (7) Konoplasty; (8) Pereplet; (9) Bratvennik; (10) Butok (Fig. 13, Plate I:D). The most remarkable of these is the Butina unit, comprising 0.01- 0.05 m of relatively soft red marlstone. This unit is the best marker and may be interpreted as a short-term invasion of relatively deep water conditions. The rocks of the Dikari are represented by predominantly grey bioclastic packstone or grainstone with numerous scattered glauconite grains. Distinctive hardground surfaces emphasized by yellow goethitic impregnation are very abundant on some levels (Krasny, Zhelty, Nadzhelty, Konoplasty) and some of these surfaces are pitted by different kinds of borings. The informal units mentioned above usually consist of 4 to 8 elementary layers 3-4.5 cm thick. Most of the layers are distinctly graded. Brachiopods, echinoderms, bryozoans, ostracodes and trilobites are the main fossils. The uppermost unit of the Dikari Limestone (Butok) has a distinctive hardground non-depositional surface on the top marked by an extensive yellow impregnation about 1.5-2 cm deep, and vertical borings of *Trypanites* type. It is interpreted as a transgressive surface and evidence for an abrupt increase of water depth.

Volkhov Formation, Zheltiaki Limestone (BIIβ)

The Zheltiaki Limestone differs from the underlying rocks of the "Dikari" in having more argillaceous material within the carbonate rock, the appearance of numerous clay layers, and the variegated mostly red and yellow colour of the rocks. Glauconite is usually rare or absent. The faunal assemblages recovered from interbeds of clay are usually dominated by brachiopods, ostracodes and echinoderms, whereas those from the beds of limestone look somewhat different, in particular containing many more trilobites. These differences can be explained by the tempestite origin of the limestone beds. The yellow and red colours of the rocks and finer grain size in comparison with underlying and overlying strata point to the relatively deep water origin of the Zheltiaki Limestone. The Zheltiaki can be subdivided into 7 informal lithostratigraphic units (from the base to the top): (1) Serina; (2) Zheltenky; (3) Krasnota; (4) Tolstenky; (5) Serenky; (6) Lower unit of intercalation; (7) Upper Unit of intercalation (Fig. 14, Plate I:B). These units are traceable over a distance of more then 200 km along the Glint line.

Volkhov Formation, Frizy Limestone (BIIγ)

The Frizy Limestone consists of flysch-like intercalations of greenish grey bioclastic limestone and bluish grey clay, both containing scattered glauconite grains. The member can be subdivided into 7 informal lithostratigraphical units (from the base to the top): (1) Lower unit of intercalation; (2) Sliven; (3) Middle unit of intercalation; (4) Gorelik; (5) Upper unit of intercalation; (6) Podkoroba; (7) Koroba (Fig. 15, Plate I:A). These units are traceable at least over the eastern part of the region between the Volkhov and Tosna river valleys. The proximal-distal tempestite trend is clearly recognizable in the sediments. The most distal facies of the Frizy Limestone, however, are closer to the shore than the red coloured tempestites of the Zheltiaki Limestone.

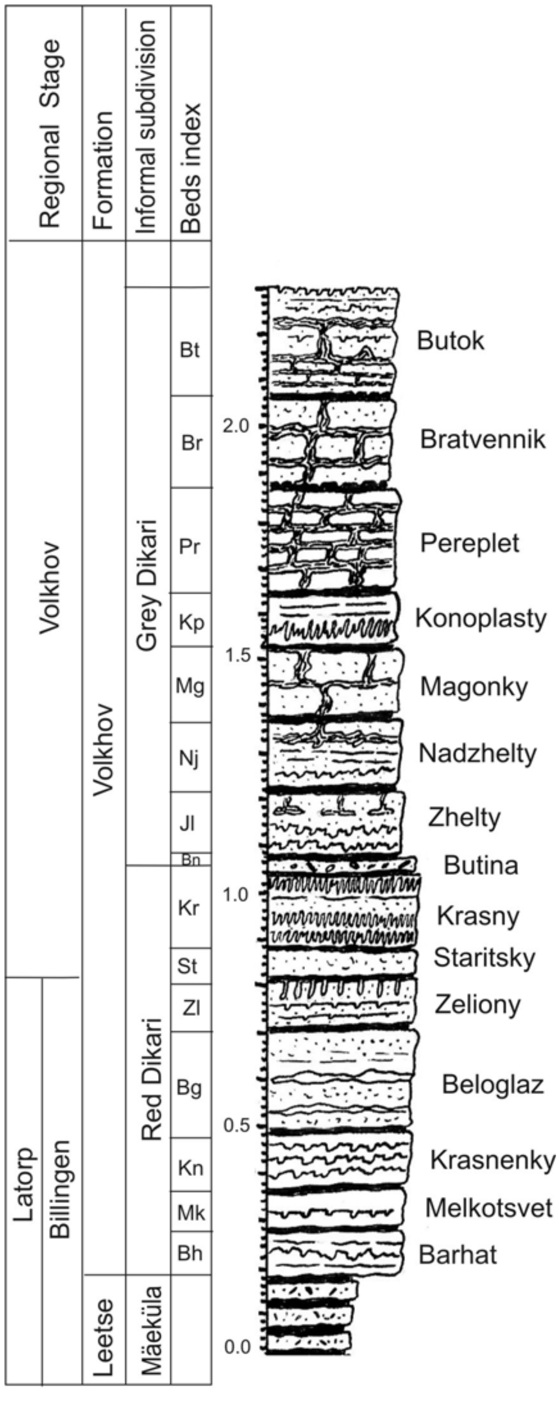

Fig. 13. The section of “Dikari Limestone” in the Putilovo Quarry.

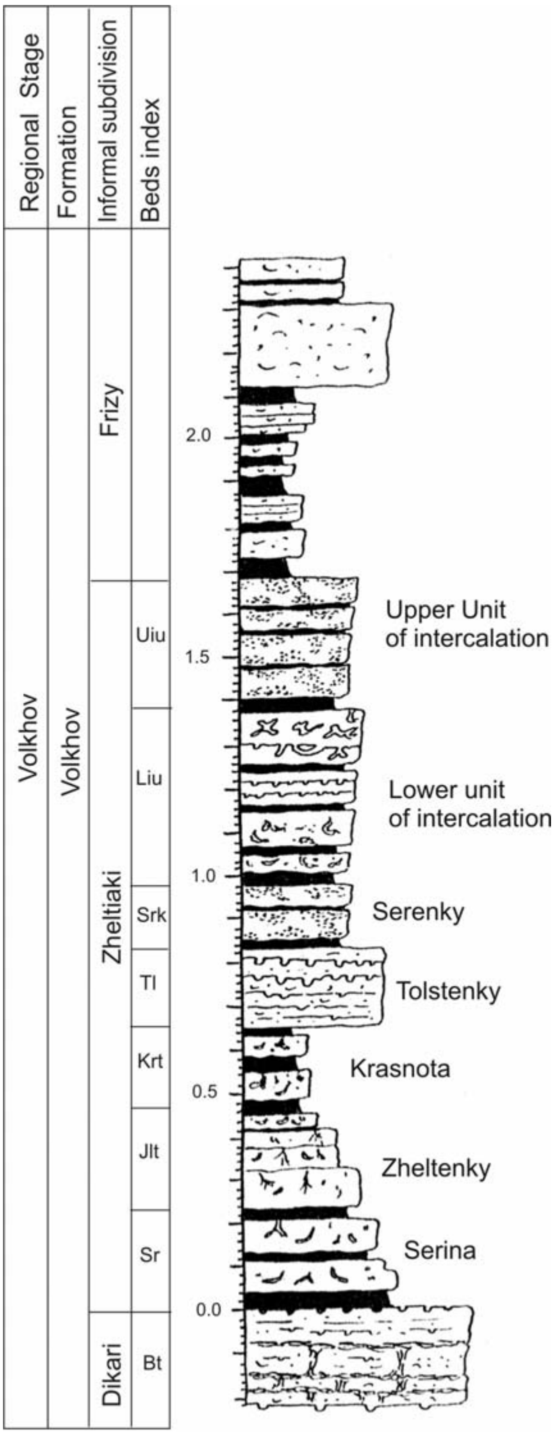

Fig. 14. The section of "Zheltiaki" Limestone" in the Putilovo Quarry.

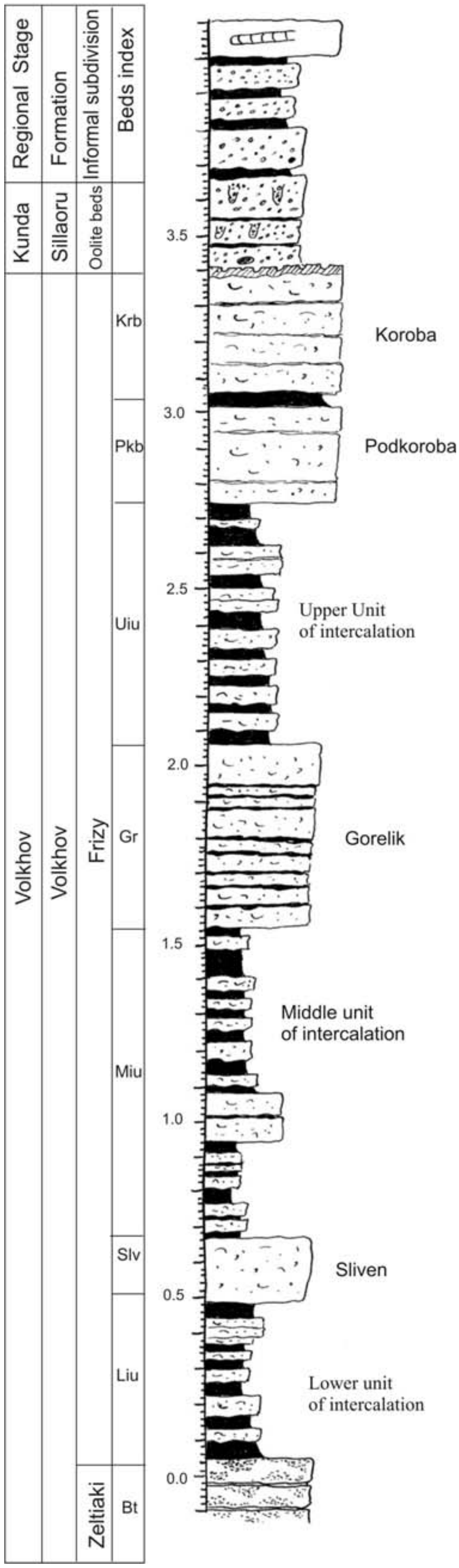

Fig. 15. The section of "Frizy Limestone" in the Putilovo Quarry.

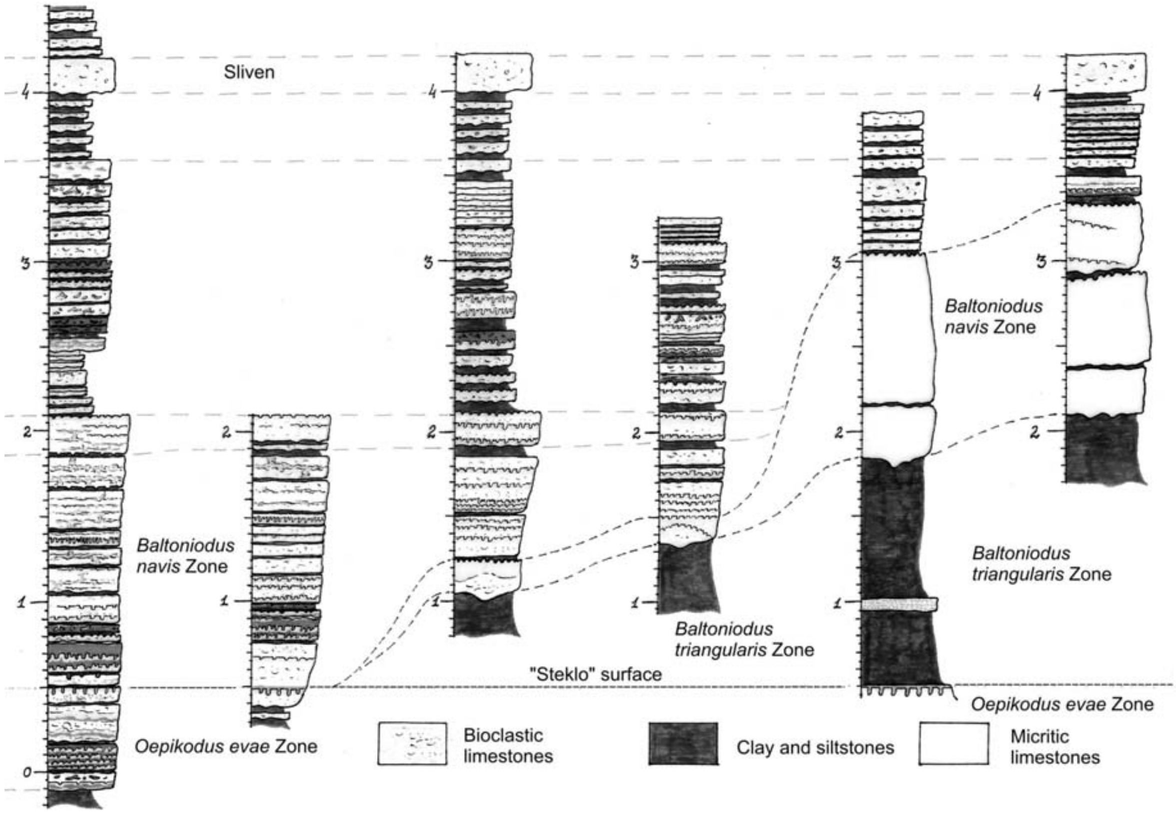

Fig. 16. Schematic drawing of the Putilovo mud mound.

Stop 3: Carbonate mud mound, the Putilovo Quarry

Organic buildups represent a poorly known but characteristic feature of the Lower and Middle Ordovician geology of the St Petersburg region. Recent studies have shown organic buildups of mud mound type to be widespread in the Middle Ordovician Volkhov deposits not only in the St. Petersburg region, but also in northern Estonia, including the Cape of Pakerort and the Pakri Islands (Dronov and Fedorov, 1997). In the western part of the St. Petersburg region and northern Estonia, these buildups are represented by so-called ‘embryonic humps’ that are similar in dimensions and appearance to the synsedimentary folds described by Lindström (1963) in the Lower Ordovician of southern Sweden. Up to the present time, large well-developed mud mounds have been found only to the east of St. Petersburg.

One of the largest buildups, about 230 m across and 4-5 m high, is preserved in the central part of Putilovo Quarry at the eastern side of the mining field. The part of the mud mound presently accessible for study is about 50 m across and 4 m high. It rests on the flat hardground surface formed on top of the Päite Beds. The central part of the mound consists of a large lens of silty clay and calcareous clay rich in glauconite with two layers of hard, thin laminated sparitic limestone, 0.15-0.19 m thick, near the base (Fig. 16, Plate I:C,E). Elementary laminae 3-5 mm thick are accentuated by the distribution of glauconite grains concentrated along the bedding surfaces. The lower part of this lens is represented by greenish grey clay with fine laminae of brownish red clay, nodules and small lenses of grainstone, wackestone and micritic limestone. The clay becomes brownish red and reddish grey in color in the upper part. Peripherally, within a distance of 25-50 m, the clay is replaced by bioclastic limestone and all 10 elementary units of the Volkhovian part of the Dikari Lm. become recognizable (Fig. 16, Plate I:C,D). The clay hump is covered by a yellow micritic crust up to 0.5 m thick in the upper part of the mound. The outer surface of the crust is accentuated by a hardground surface usually pitted by *Tripanites*-like borings.

It is interesting to note that, according to the local history, there were similar structures in old quarries in the vicinity of the village of Putilovo. The quarrymen recount stories retold by their fathers and grandfathers about strange places in the limestone plateau where all beds of the “Dikari Limestone” were rotted out. Nowadays about seven large mud mounds are known from the two working quarries and river valleys in the eastern part of the region. They may represent the oldest Phanerozoic organic buildups on the Russian platform and the only temperate Lower-Middle Ordovician ‘reefs’ known in the world (Dronov, 1996).

Stop 4: Kunda in the southern part of Putilovo Quarry

The Kunda is the uppermost stratigraphic subdivision of the Ordovician sequence exposed in the Putilovo Quarry. There is no single section where this deposit is exposed continuously and its characteristics described below are based on the study of several exposures in the southern part of the quarry (Fig. 17). Lithostratigraphic subdivision of the Kunda Stage deposits are according to Ivantsov (2003).

Kunda Stage

Sillaoru Formation (BIII $\alpha+\beta$ Sl)

The Sillaoru Formation, or “Lower Oolite Bed” according to the traditional terminology, is represented by about 0.7 m of bioclastic limestone enriched with iron ooids interbedded with layers of clay that also sometimes contain iron ooids. The lower boundary of the formation coincides with the distinctive phosphatized hardground surface that is regarded as a sequence boundary. The formation consists of two members one of which belong to the BIIIα whereas the other belongs to the BIIIβ “subhorizons”.

Obukhovo Formation (BII $\beta+\gamma$ Ob)

The Obukhovo Formation, or “Orthoceratite Limestone” sensu stricto in traditional terminology, consists of light grey bioclastic limestone (wackestone to packstone) interbedded with bluish grey clay. The limestone contains numerous cephalopod shells. The base of the formation coincides with a transgressive surface at the top of the “Lower Oolite Bed” where iron ooids disappear. Glauconite grains are usually concentrated in the lower part of the formation.

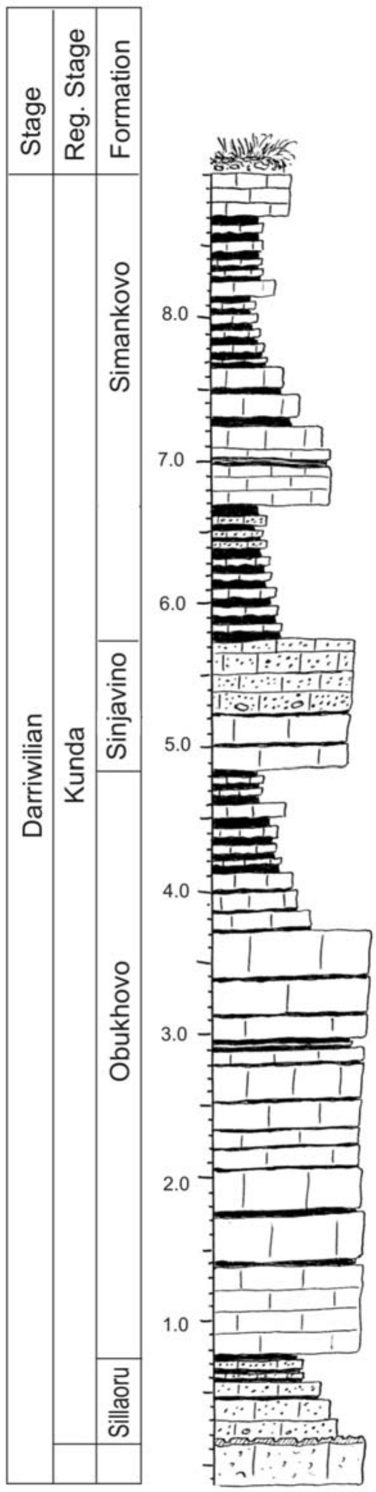

Fig. 17. The Kunda Stage section in the Putilovo Quarry.

The "Upper White Bed" of Lamansky (1905) is a hard, cavernous light grey limestone up to 0.2 m thick situated about 1.30 m above the base of the formation. The bottom of this bed coincides with the BIIβ/BIIγ boundary. Asaphid trilobites are very common.

Sinjavino Formation (BIIIγ Sn)

The Sinjavino Formation is represented by a rather massive limestone unit that stands out from the underlying and overlying units of limestone and clay intercalation. It consists of two parts: (1) bluish grey bioclastic limestone without iron ooids (0.45 m) and (2) bluish grey bioclastic limestone with numerous well-developed large (2-3 mm in diameter) iron ooids and rare ferruginous limestone pebbles about 2-3 cm in diameter. This part of the formation has been traditionally regarded as the so-called "Upper oolite bed". The thickness of the oolite-bearing unit is about 0.40 m and the thickness of the entire formation is about 0.85 m.

Simonkovo Formation (BIIIγ Sm)

The Simonkovo Formation in Putilovo Quarry is represented by 4 m of flysch-like limestone and clay intercalations. About 0.95 m from the base of the formation there are two layers of bioclastic limestone, each 0.02-0.04m thick, with light brown iron ooids. The top of the formation is not exposed in the quarry and the Kunda/Aseri boundary cannot be seen here.

Stop 5: Old quarry on the left bank of the Lava River and natural outcrops on the opposite side of the valley

We return to Putilovo village, turn to the south-east and drive about 15 km to the village of Vassilkovo. About 300m downstream from the village there is an old quarry on the left bank of the Lava River canyon, opposite the village of Gorodishche. The upper part of the Volkhov and lower part of the Kunda stages are well exposed in this quarry. The Zheltiaki and Frizy limestones in this section show no significant differences with the pattern observed in Putilovo Quarry and all of the informal stratigraphic units can be easily recognized. There is also a good view of the Ordovician rocks exposed in a high cliff on the opposite side of the Lava River beneath the village of Gorodishche (Plate I:F). The outcrops in the old quarry on the left bank of the Lava River canyon provide a good opportunity to study the "Lower oolite bed" (Sillaoru Formation) more closely. The quality of the exposures here is much better than in Putilovo Quarry for this particular stratigraphic interval.

Volkhov Stage
Volkhov Formation (BII VL)

The lower part of the formation (Dikari Limestone) is not exposed in this quarry. It can be studied only on the opposite side of the canyon where all 15 units seen in Putilovo Quarry can be easily recognized. The middle part of the formation (Zheltiaki Limestone) outcrop in the northern part of the quarry and all 7 constituent units are easy to identify. In the same locality the best exposure of the Frizy Limestone succession can be demonstrated, with all 7 units recognizable.

Kunda Stage
Sillaoru Formation (BIII α+β Sl)

The outcrops in the old quarry opposite the village of Gorodishe provide a good opportunity to study the iron oolite bearing deposits of the Sillaoru Formation (the "Lower oolite bed" in traditional terminology). The formation consists of two members.

Nikolskoe Member (BIIIα NK) - 0.65 m of argillaceous greenish grey bioclastic limestone with numerous small brown iron ooids and ferruginous bioclasts. It is interesting to note that the iron ooids in the unit are usually concentrated in subvertical burrows of *Skolithos*-type. Flat pebbles of glauconitic limestone covered by *Trypanites* borings occur in the lower part of the unit. The trilobite *Asaphus (Asaphus) expansus* (Wahlenberg) and numerous brachiopods are recorded from this member. The base and the top of the Nikolskoe Member are marked by hardground surfaces with *Trypanites*-like borings. The basal unconformity is interpreted as a sequence boundary.

Lopukhinka Member (BIIIβ LP) - 0.18m of clay, calcareous clay and bioclastic limestone intercalations, both containing numerous large (about 2 mm across), well-developed iron ooids. Layers of clay 0.02-0.05m thick are present at the base, at the top and in the middle of this unit. The trilobites *Asaphus (A.) "raniceps"* Dalman are relatively common.

The whole Sillaoru sequence demonstrates a shallowing upward succession.

Obukhovo Formation (BIII β+γ Ob)

The Kunda Stage deposits in the Lava River canyon do not differ much from those seen in Putilovo Quarry. The Obukhovo Formation or "Orthoceratite limestone" sensu stricto is represented by about 3.4 m of grey bioclastic limestone interbedded with bluish grey clays. The limestone contains rare glauconite grains and common cephalopod shells. The trilobite *Asaphus (Asaphus) "raniceps"* Dalman is most abundant in the basal 0.75 m of the formation. A bed of hard light grey massive bioclastic limestone of 0.25 m thick (the "Upper White bed" of Lamansky (1905)) can be seen in the upper part of the section. The uppermost part of the formation is not exposed in the quarry.

Stop 6. The right bank of the Tosna River near the bridge.

In a small sand quarry on the right bank of the Tosna River not far from the bridge we have an opportunity to study Middle Cambrian, Upper Cambrian and Lower Ordovician (Tremadocian) siliciclastic deposits (Fig. 18, Plate II:A). The section is as follows (from the base to top):

MIDDLE CAMBRIAN
Sablino Formation

In the outcrop we can see only the upper part of the Sablino Formation (about 4 m). It is represented by white, pink and yellowish fine grained quartz sand with thin (1-2 cm) lenses of blue clay at some levels. The most characteristic features of these sands are presence of well developed herringbone cross-stratification and abundance of vertical burrows of *Skolithos* type. No shelly fossils can be seen in this pure quartz sand except at the very top of the formation where rare shells of organo-phosphatic brachiopods can be found. The upper boundary of the formation coincides with a regional unconformity and depositional sequence boundary. It can be interpreted as a type-1 sequence boundary because of clear evidence of erosion of the underlying sediments and subaerial exposure.

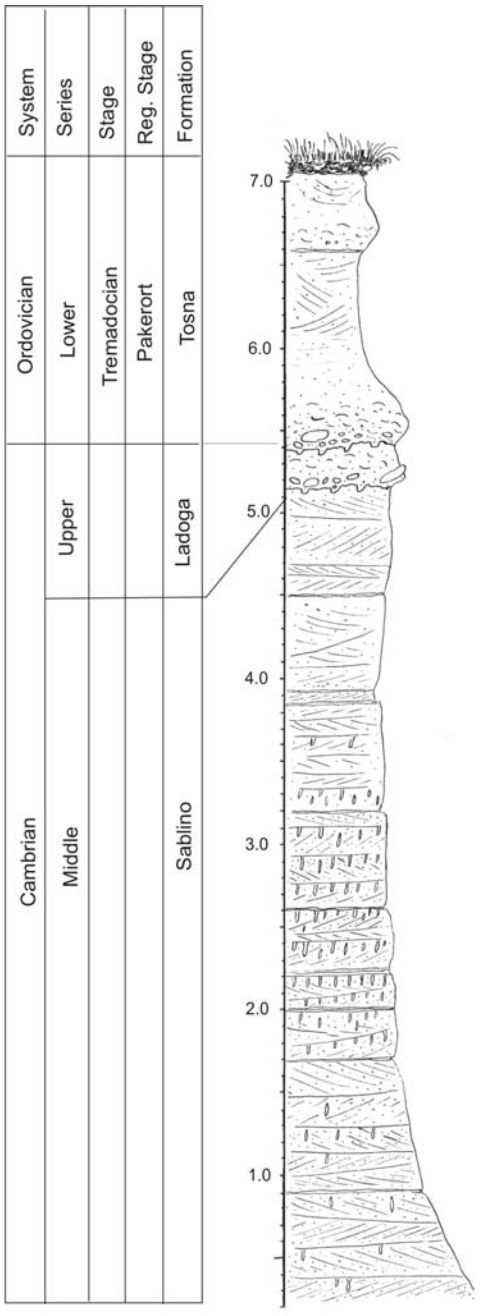

Fig. 18. The Tosna River section near the bridge.

UPPER CAMBRIAN
Ladoga Formation

About 0.25 m of light grey, medium to coarse grained, cross-bedded quartz sand with numerous well-preserved shells of organo-phosphatic brachiopods. The Ladoga Formation differs from the underlying Sablino Formation by its grey colour, grain size (more coarse grained) and the amount of brachiopod shells. The lower boundary of the formation represents an uneven erosional surface with cavites and pockets up to 5-20 cm deep. The pockets are filled with a coquina of organo-phosphatic brachiopods and pebbles of hard quartz sandstone up to 20 cm in diameter. The fossils include the brachiopods *Ralfia ovata, Ungula convexa, Keyserlingia reversa* and the paraconodonts *Prooneotodus aff. gallatini* Miller and *Problematoconites perforatus* (Popov et al., 1989).

The upper boundary also coincides with regional unconformity.

LOWER ORDOVICIAN (TREMADOC)
Pakerort Regional Stage
Tosna Formation

The Tosna Formation is represented by brownish medium grained quartz sand with well developed trough cross-bedding and numerous shell fragments of organo-phosphatic brachiopods scattered in the rock. In contrast with the underlying Ladoga Formation, unbroken shells are rare. The formation consists of two fining upward cycles clearly visible in the outcrop (Plate II:A). The lower one corresponds to the Lower Tosna Subformation and the upper one to the Upper Tosna Subformation, accordingly. The lower boundary of the formation represents a regional erosion surface with cavites and pockets up to 0.15 m deep. Pebbles of hard quartz sandstone can be seen on this surface.

The lower 0.20-0.25 m of the Lower Tosna Subformation is represented by more coarse grained sand and contain a coquina of organo-phosphatic brachiopods redeposited from the underlying Ladoga Formation together with well preserved shells of *Obolus apollinis* and *Helmersenia ladogensis.* The conodonts *Cordylodus proavus* have been recorded from the lower 0.25 m and upper 0.10 m (Popov et al., 1989). Total thickness of the subformation is 1.4 m.

The Upper Tosna subformation starts with a coarse grained interval up to 0.25 m thick that which passes upwards into a medium to fine grained sand with trough cross-stratification and small fragments of reworked obolid shells. The conodont *Cordylodus lindstromi* occurs at about 0.6-0.7 m below the top of the unit. The uppermost 0.10 m of the subformation is represented by brownish red fine-grained quartz sandstone with secondary cement of iron oxide (oxidized pyrite). The thickness of the subformation is 1.5 m. On the other side of the road we can see a continuation of the section:

Koporie Formation

Black, bituminous shale up to 0.18 m thick. The black shale could serve as an excellent marker horizon, but no *Rabdinopora (Dictyonema) flabelliforme* has ever been reported from this shale in the Sablino region. The base of the formation displays a clear shift from shallow-water to deep-water facies and is interpreted as a transgressive surface. The top of the formation is a sequence boundary (Plate II:B).

Billingen Regional Stage
Leetse Formation, Nazia and Mäekula beds

Directly on the black shale of the Koporie formation rest about 0.08 m of quartz sand. The sand is medium grained with scattered glauconite grains and small reworked fragments of obolid shells. Quartz sand corresponds to the bed of quartz sand that rests on the “Dictyonema Shale” in the Nazia River valley and in Putilovo Quarry. The later one had been described as the Nazia Formation (Borovko et al., 1983). At the present time, we think that conodonts of Varangu age that had been reported from this unit in the Nazya River valley are redeposited and the actual age of this basal bed is younger. It is interpreted as a transgressive lag of the Latorp depositional sequence.

Mäekula Beds consists of two units: 1) About 0.20 m of medium grained quartz sand with abundant scattered glauconite grains and a discontinuity surface accentuated by a layer of yellowish grey quartz-glauconitic sand about 0.04 m thick with ferruginous impregnation in the middle; 2) About 0.12 m of argillaceous limestone with scattered grains of quartz and glauconite. Fossils include the brachiopods *Panderina abscissa, Ranorthis minima, Paurorthis resima, Angusticardina recta, Porambonites latus* and *Plectella uncinata,* the trilobites *Krattaspis viridatus* Öpik, *Cybele* sp., *Megistaspis leuchtenbergi* (Lamansky), *Megistaspis pogrebovi* (Lamansky), *Megalaspides schmidti* Lamansky, *Megalaspides? inostranzewi* Lamansky, *Proasaphus* sp., *Europeites lamanskyi* (Balashova), the conodonts *Prioniodus elegans* Pander, ostracods (Popov et al., 1989).

Leetse Formation, Vassilkovo Beds

Consists of three units: 1) About 0.04 m of bluish green clay with a thin red band in the middle. The unit contain the brachiopods *Panderina tetragona, Antigonambonites excavatus* and *Pectella crassa;* 2) About 0.06-0.08 m of bluish green argillaceous limestone with rare glauconite grains. The brachiopods *Acrotreta subconica*, *Panderina tetragona*, *Antigonambonites excavatus*, *Paurortis resima*, *Angusticardinia striata*, *Plectella crassa* (Popov, 1997), the trilobites *Proasaphus primus* Balashova, *Ottenbyaspis* sp. nov. and *Krattaspis viridatus,* the conodonts *Oepikodus evae* (Lindström), *Stolodus stola* (Lindström) occur; 3) About 0.16 m of argillaceous limestone with glauconite grains interbedded with greenish grey clay.

Volkhov Formation, Dikari Limestone

The lowermost part of the Dikari Limestone is represented by four distinctive beds: 1) Barkhat (0.08 m), 2) Mekotsvet (0.08 m), 3) Krasnenky (0.12 m) and 4) Beloglaz (0.21 m). The beds have characteristic features that allow these beds to be traced from the Putilovo Quarry (about 70 km). The succession of the beds demonstrates a shallowing upwards trend. It is interpreted as a highstand systems tract of the Latorp depositional sequence (Dronov and Holmer, 1999).

On top of the Beloglaz rests the Zelenyj Bed (0.03 cm) with a prominent flat hardground surface covered by a thin glauconite veneer. The surface is pitted by so-called "Amphora-like borings" (*Gastrohaenolites oelandicus*). This surface marks the base of the Middle Ordovician series and is interpreted as a type 2 sequence boundary. This boundary is easy to recognize in any Dikari succession including the outcrop at Stop 6 and 8.

Stop 7. The Sablino caves

The famous Sablino caves are artificially made old sand mines. The beginning of the mining activity in the region goes back to the reign of Catherine the Great in the XVIIIth century. It was a time when the first glass industry had been established in Russia. The most intensive mining encompasses a period from 1860 till 1930 (Natal'in, 2001). The sand was carried out in baskets to the entrance of the caves, and then loaded onto barges and transported down the Tosna River to glass factories in the town of Nikol'skoe and St. Petersburg. In the beginning of the XXth century, the sand was also transported by rail from the Sablino railway station.

At the present time, 14 artificial caves are known in the Sablino region (11 caves are in the Tosna River canyon and 3 caves in the Sablinka River canyon). All of the caves have been made in the pure white fine grained quartz sand of the Middle Cambrian Sablinka Formation. Later on, due to collapses of unconsolidated sand masses from the roofs of underground galleries, the caves come up to the level of the Ladoga and Tosna formations and further up to the base of the carbonate succession. This process made it possible to see a wider stratigraphic interval.

The present excursion to the "Levoberezhnaya" (Left-bank's) cave provides an excellent opportunity to study the Cambrian/Ordovician and Tremadoc/Arenig boundaries (Plate II:E). The Cambrian/Ordovician boundary coincides with the base of the Pakerort depositional sequence (Dronov and Holmer, 1999) and is represented by an erosional unconformity marked by redeposited sand and sandstone pebbles, and some clay lenses. The Tremadoc/Arenig boundary is marked by a sharp contact between the black shales of the Koporie Formation (transgressive systems tract of the Pakerort sequence) and a quartz sand of the Nazia Formation (transgressive lag deposits at the base of the transgressive systems tract of the Latorp depositional sequence. Both boundaries denote a prominent sea-level drop with subsequent erosion of the underlying sediments. In the case of the Pakerort sequence, almost all of the Upper Cambrian deposits have been eroded. The absence of highstand systems tract deposits in the Pakerort sequence demonstrates deep erosion at the base of the overlying Latorp depositional sequence.

The underground galleries of the "Levoberezhnaya" cave provide also a good opportunity to study well developed cross-stratification including the herringbone cross-stratification characteristic for ancient siliciclastic tidalites. Spectacular mechanoglyphs can be seen on the ceiling of some galleries. These mechanoglyphs are interpreted as traces of ice crystals imprinted on clay laminas deposited on the surface of an ancient tidal flat during a period of subaieral exposure (Dronov and Popov, 2004). Taking into account the position of the Baltica paleocontinent in the Middle Cambrian (Thorsvik et al., 1992) it seems natural to have traces of sinsedimentary freezing in subaerially exposed surfaces.

The picturesque underground lake in the "Levoberezhnaya" cave is a result of a ground water infiltration into the mining maze. The water depth in the central part of the lake is about 2 m and the length of the lake is about 60 m (Natal'in, 2001).

Stop 8. Outcrop on the left bank of the Tosna River 300 m downstream from the Tosna waterfall.

Leaving the cave we return to the bus and drive southward along the Tosna River. After 2 km we approach the northern outskirts of the village of Gertovo where we leave the bus and make a short walk to Tosna canyon. The best outcrop is situated in a mouth of a little creek flowing to the Tosna River from the left (Plate II, D). Unfortunately, because of a landslide we cannot see the Koporie and Leetse formations in this outcrop at the present time as they are covered by fallen rocks. Quartz sands of the Sablino, Ladoga and Tosna formations can be seen in small outcrops 20 m upstream from the creek mouth. The section is as follows:

MIDDLE CAMBRIAN
Sablino Formation

About 2 m of pink or white medium to fine grained quartz sand with multidirectional cross-stratification. The brachiopods *Obolus rukhini* Khazanovich and Popov and *Oepikites macilentus* Khazanovich and Popov have been reported from this outcrop (Popov, 1997).

UPPER CAMBRIAN
Ladoga Formation

Up to 0.20 m of medium to coarse grained quartz sand with a coquina of the organo-phosphatic brachiopods *Ralfia ovata, Ungula tetragona* and *Keyserlingia reversa*. The lower and upper boundaries of the formation represent regional unconformities and sequence boundaries.

LOWER ORDOVICIAN
Tosna Formation

2.5 m of medium grained quartz sand with multidirectional cross-bedding and numerous reworked small fragments of obolid shells. The lower boundary represents an uneven erosional surface, accentuated by a layer of clay about 0.03 m thick.

In the main outcrop (Plate 2, D), the carbonate succession of the Volkhov Formation can be studied in great detail. The thickness of all units (beds and bedsets) in the Tosna River valley is less than in Putilovo quarry. It is diminishes westwards (compare Fig. 13 and Fig. 19). But all beds are recognizable. The succession looks as follows:

MIDDLE ORDOVICIAN
Volkhov Formation, Dikari Limestone, Red Dikari (Plate II:F)

In contrast to the sections in Putilovo quarry and the Lava River canyon, there is no basal layer of clay underlying the Dikari Limestone. The boundary between the Barkhat Bed and the underlying limestone is represented by a well developed smooth hardground surface covered by a thin glauconite veneer. The Barkhat and Melkotsvet beds here are reduced in thickness more than two times in comparison with the succession in Putilovo quarry, whereas the Krasnenkij bed retains its individual characteristics and thickness without significant change. The thickness of the Barkhat and Melkotsvet beds, that can not be distinguished with certainty in this outcrop is, 0.07 m.

The Krasnenkij Bed is easy to recognize, especially on the weathered surfaces of fallen limestone blocks, because of its strong red and yellow colours. The bed contain up to four nondepositional surfaces with a yellow, iron-enriched impregnation. Glauconite grains are rare or absent. Thickness is 0.12 m.

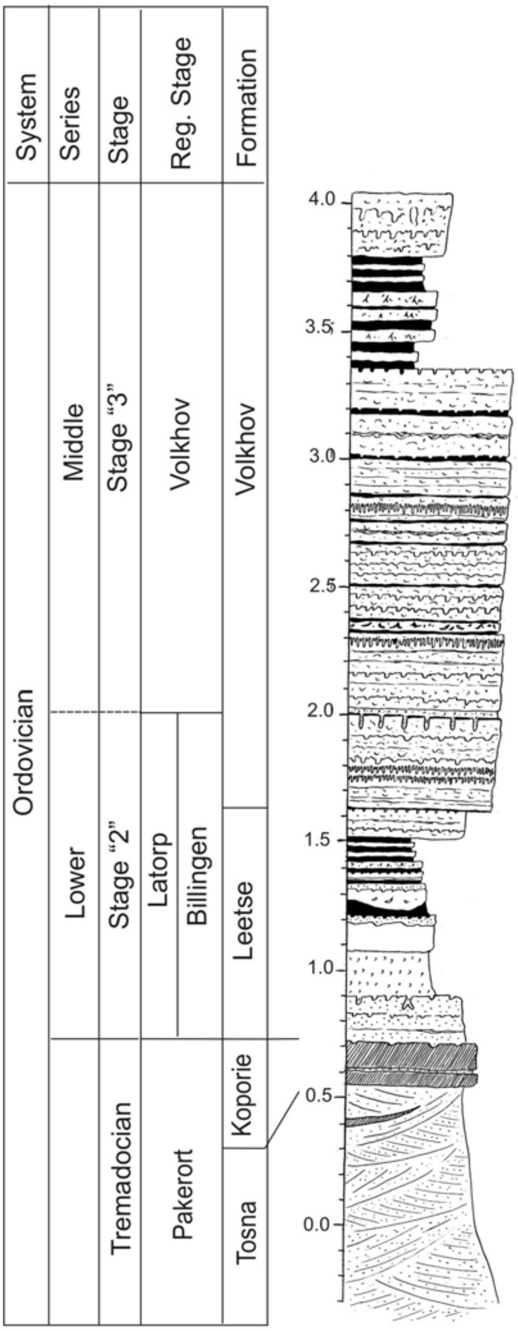

Fig. 19. The Tosna River section near the Tosna waterfall.

The Beloglaz Bed is 0.21 m thick and consists of light coloured bioclastic packstone or grainstone. It is also characterized by numerous scattered glauconite grains and fragments of echinoderm skeletons.

The Zeleny Bed is 0.04 m thick. It is highly enriched by glauconite grains. Near the base of the Zeleny Bed a smooth hardground surface pitted by "Amphora-like" borings (Gastrochaenolites oelandicus) is well developed (Plate II:C). The borings, filled with glauconite grains, protrude deep into the underlying Beloglaz Bed. This surface marks the base of the Middle Ordovician Series and the lower boundary of the Volkhov depositional sequence. It is interpreted as a type-2 sequence boundary without prominent shift of facies, subaerial exposition and erosion of underlying beds.

The Staritsky Bed is about 0.16 m and enriched by glauconite grains. The top of the bed is accentuated by a hardground surface covered by glauconite veneer.

The Krasny Bed is also 0.16 m. It contains several hardground surfaces penetrated by numerous narrow, vertically oriented borings of about 3-4 cm in height and with diameters of 2-3 mm ("Karandashi")

The Butina Bed is represented by red highly argillaceous limestone 0.03 m thick. *Thalassinoides,* and *Planolites* are characteristic trace fossils for this bed. The marine red bed facies of the Butina Bed display a short invasion of relatively deep-water facies into the shallow water settings. It marks a short transgression.

Volkhov Formation, Dikari Limestone, Grey Dikari

The following beds are recognizable in the Grey Dikari: 1) Zheltyj (0.14 m) – bioclastic packstone or grainstone with several hardground surfaces marked by yellow iron impregnation; 2) Nadzhelty (0.16 m) – varies from bioclastic wackestone to grainstone. The bed is similar to the underlying Zhelty Bed; 3) Miagon'ky (0.08 m) – greenish grey bioclastic packstone with numerous scattered glauconite grains; 4) Konopljasty (0.10 m) – the bed can be easily recognized in the outcrop because it contain numerous vertical borings ("Karandashi"); 5) Pereplet (0.14 m) – greenish grey bioclastic packstone with a well developed *Thalassinoides* burrowing system; 6) Bratvennik (0.16 m) – a bed of hard greenish grey bioclastic packstone, separated from the underlying bed by a layer of clay 3-5 mm thick. At the base of this bed *Bergaueria* trace fossils are especially well developed; 7) Butok (0.18 m) – grey bioclastic wackestone. In contrast to the section of Putilovo Quarry, there is no extensive ferruginous impregnation at the top of the Butok Bed, but *Trypanites* borings remain characteristic. The total thickness of the Dikari Limestone in the Tosna River valley is 1.98 m. In Putilovo Quarry it is 2.20 m.

Volkhov Formation, Zheltjaki Limestone

All of the 7 informal lithostratigraphic units that are present in Putilovo quarry can be identified in the Tosna River valley. They are (from the base to the top): (1) Serina; (2) Zheltenky; (3) Krasnota; (4) Tolstenky; (5) Lower unit of intercalation; (6) Upper unit of intercalation. The base of the Zheltjaki Limestone coincides with the hardground surface at the top of the Butok Bed. It is interpreted as a transgressive surface and the base of the transgressive systems tract (Zheltiaki). The total thickness of the Zheltiaki Limestone in the Tosna River valley is 0.93 m in comparison with 1.69 m in Putilovo Quarry.

Volkhov Formation, Frizy Limestone

The Frizy Limestone is interpreted as a highstand systems tract of the Volkhov depositional sequence. Its total thickness in the Tosna River valley is 2.1 m, whereas in Putilovo Quarry it is 3.40 m. All of the bed and bedsets displayed in Putilovo Quarry are recognizable in the Tosna River valley. The Frizy Limestone in the outcrop makes an almost vertical wall that is difficult to access, but all the beds are clearly visible from a distance.

Sillaoru Formation

On the top of the Volkhov Formation with a regional unconformity and a sequence boundary at the base rests the Sillaoru Formation or the “Lower oolite bed”. It is represented by grey argillaceous bioclastic wackestone with numerous small brown iron ooids and ferruginous bioclasts. The iron ooids are usually concentrated in subertical burrows of *Skolithos* type. The thickness of the “Lower oolite bed” in the outcrop is 0.42 m. In the Lava River canyon it is 0.93 m. The Sillaoru Formation is interpreted as a lowstand systems tract of the Kunda depositional sequence.

The Tosna waterfall can be seen directly from the outcrop at a distance of about 300 m upstream on the Tosna River. It creates a magnificent view on this part of the valley. The height of the waterfall is about 2.0 m.

Day 2. Saturday, 20th of August: Middle and Upper Ordovician of the Izhorian Plateau.

Stop 9: Old quarry on the outskirts of the village of Kas'kovo. "Sponge Beds", upper Idavere Stage.
Stop 10: "Wesenberg" limestones and dolomites in Pechurky Quarry. Rakvere Stage.
Stop 11: Oil shale (kukersite) bearing deposits in the Alekseevka Quarry. Uppermost Uhaku and Kukruse Stages.
Stop 12: Jõhvi Limestone in the Khrevitsa River valley
Stop 13: "Kegel" dolomites of the Elizavetino Quarry

Leaving St. Petersburg we take the road to Krasnoe Selo, the former suburb that is now transferred into a city district. Here we climb the Baltic-Ladoga Glint and enter the Izhorian Plateau region. This region has the most fertile soil around St. Petersburg and was the first place were agriculture developed. In the fields and forest of the Izhorian Plateau numerous prehistoric burials can be seen having the form of mounds or groups of mounds arranged in a symmetrical order.

The flat surface of the Izhorian Plateau is disrupted near Krasnoe Selo by a prominent group of hills known as the "Duderhoff Hills". Each hill is an anticlinal fold with Lower Cambrian "Blue clay" and Middle Cambrian quartz sandstone in the core and the Ordovician limestones forming the limbs. Some of the folds are even slightly overturned. The origin of these uplifts is still under discussion but the majority of specialists are inclined to regard them as glaciodislocations. Duderhoff Mountain is the highest point in the St. Petersburg region.

It is interesting to note that Roderick Murchison when he made his famous journey to Russia regarded the dislocations in the Ordovician of the St Petersburg region as evidence of the Caledonian orogeny. It also interesting that the origin of the German sounding name goes back to the Lappish population. According to some Laplandian dialects "Duddar" is a high mountain without forest on the top.

Passing Krasnoe Selo we make a turn to the south-west and follow the St. Petersburg to Tallinn highway. Half an hour later we reach the villages of Shundorovo and Kaskovo where we make our first stop to investigate the Middle Ordovician sponge-bearing deposits of the Shundorovo Formation.

Stop 9. Old quarry on the outskirts of the village of Kas'kovo.

In the small old quarry near Kas'kovo village we have an opportunity to study the Middle Ordovician Idavere Stage limestones with numerous remnants of siliceous sponges. Idavere Stage deposits are poorly represented in natural outcrops and are known mostly from wells and small quarries in the eastern part of Izhorian Plateau. The sponge-bearing deposits have been subdivided from Idavere Stage of F. Schmidt by B. Asatkin (1931) who called them "Sponge Beds". Subsequently T. Alikhova (1953) gave them the name "Shundorovo Beds" after the name of the nearest village.

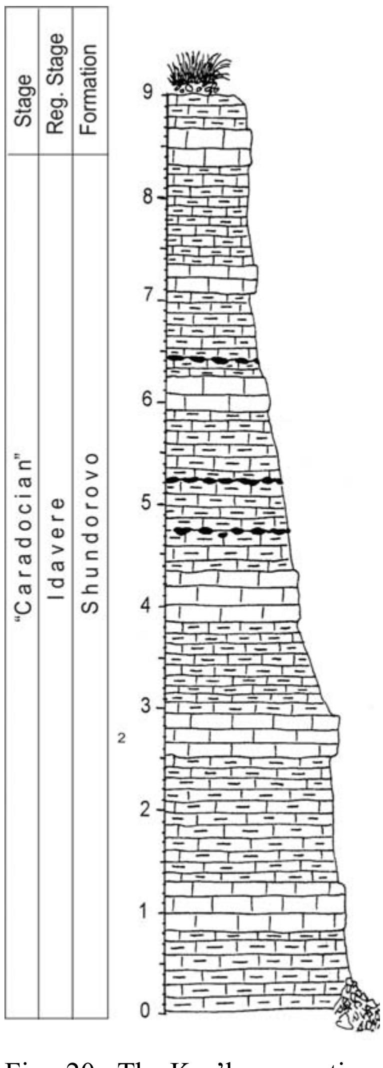

Fig. 20. The Kas'kovo section.

The "Sponge Beds" are now known as the Shundorovo Formation and correlated to with the upper part of the Idavere Stage.

The most noticeable feature of the beds are the numerous fossils of the siliceous sponges *Carpospongia globosa* (Eichwald), *Aulocopium aurantium* Oswald, *Caryospongia juglands* (Quenstedt) Rauff, and *Hindia sphaeroidalis* Duncan. The lower and upper boundaries of the Shundorovo Formation is marked by bentonite layers but unfortunately these cannot be seen in Kas'kovo Quarry where neither the base nor the top of the formation are exposed (Fig. 20). However, about 8m of marlstone-limestone intercalations with chert horizons and traces of secondary dolomitization can be studied.

Leaving Kas'kovo quarry we return to the St. Petersburg-Tallinn highway and continue our drive to the west. Near the village of Opolie we pass a beautiful Russian Orthodox church. About 2 km to the north-west of this church there is a large quarry with kukersite-bearing deposits which we will visit on our return journey. We cross the Luga River downstream of Kingisepp (formerly Jamburg), make a turn to the south and follow to the Kingisepp-Slantsy road. On the left bank of the Luga River there are huge quarries in the "Obolus Sandstone". Phosphatic shells of numerous inarticulate brachiopods which are extremely abundant in this unit are the main source of phosphorite for the plant in Kingisepp.

The town of Slantsy was established in the 1930s as a town for miners extracting kukersite oil shales for the Electric Power plants. Nowadays most of the mines are in the process of closing. We pass Slantsy and cross the Plussa River on both banks of which small outcrops of the Middle Ordovician Plussa Group limestones can be seen. After crossing the bridge we make a turn to the north-west and after 10 minutes drive reach the entrance to the Pechurki Limestone Quarry.

Stop 10. "Wesenberg" limestones and dolomites in Pechurky Quarry

The huge quarry in Pechurky is the main source of pure limestone for the concrete factory in Slantsy. Because of intense dolomitization of the underlying beds, only the uppermost 4 or 5 m of light grey pure micritic limestones is used (Fig. 21, Plate IV:A). Here we have an opportunity to study tropical Ordovician carbonates of the upper Caradoc and compare them to the Arenig and lower Llanvirn temperate carbonates which we saw in Putilovo Quarry and the Lava River canyon. The Baltic continent was situated at 60°S in the Arenig and at 30°S in the Caradoc (Wilde, 1992). Note the lack of glauconite grains and dominance of pale-coloured micrites in the "Wesenberg Limestome" of the Pechurky Quarry.

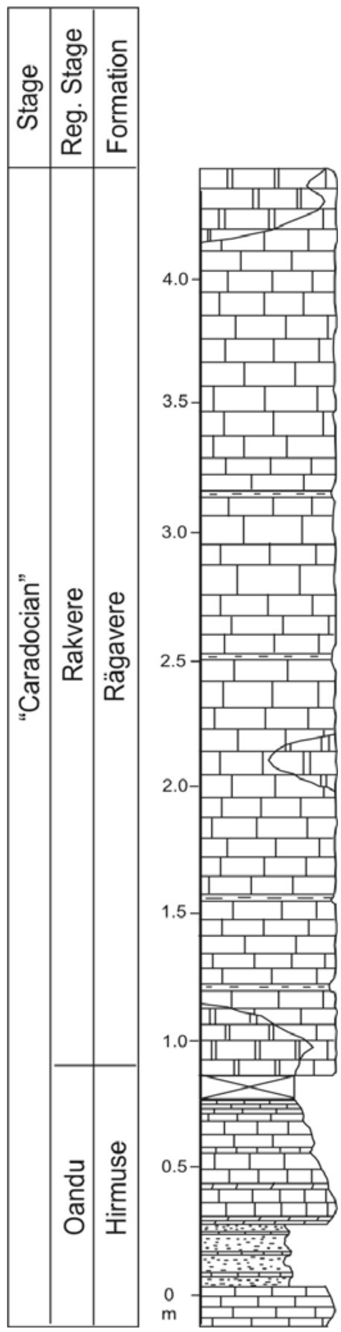

Fig. 21. The Pechurki Quarry section.

At the bottom of the quarry predominantly in trenches a greenish brown crystalline secondary dolomite can be observed for a visible thickness of about 1 m. This dolomite is overlain by a relatively thin (0.4-0.5 m) unit of limestone and clay intercalations. The rocks of this unit are multicoloured (grey, yellow and red) and extremely fossiliferous. Brachiopods and bryozoans are the dominant groups (Plate IV:E). The pale grey, well bedded micritic limestone forms the walls of the quarry. In places the limestone is dolomitized and the brachiopods and bryozoans destroyed. The fauna of this locality needs to be studied more closely. Here is the best opportunity to collect well-preserved bryozoans.

Leaving Pechurky quarry we return to Slantsy and via Kingisepp to the church in Opolije village where we make a turn to Alekseevka village and enter the Alekseevka Limestone Quarry.

Stop 11. Oil shale (kukersite) bearing deposits in the Alekseevka Quarry

Here we have an opportunity to study the upper part of the Mednikovo Formation (upper Uhaku) and the lower part of the kukersite-bearing Viivikonna Formation. Kukersite and organic-rich shale containing the *Gloeocapsomopha*-kerogen occur at three main stratigraphic levels in the Ordovician succession of the world: (1) in the Upper Arenig - Lower Llanvirn (Kunda Stage of western Estonia, Goldwater Formation of the Canning Basin and Horn Valley Siltstone of the Amadeus Basin of Australia; (2) in the Lower Caradoc (Kukruse Stage of the East Baltic and Glenwood Formation of the Iowa Basin in the USA; and (3) in Upper Caradoc Keila and Rakvere Stages of the subsurface in Russia as well as in the Guttenberg Member of the Decorah Formation of the Iowa Basin and Red River Formation of the Williston Basin (Kõrtz, 1992). The East Baltic oil shales form the largest and economically most important deposits, particularly those from levels in the Kukruse Stage. The deposit have been exploited since 1916 and the total output has exceeded 770 million tonnes (Kaljo and Nestor, 1990).

The Alekseevka Quarry was opened for the Alekseevka concrete factory (Plate III:A). They use only pure marls and limestones of the upper Uhaku. Kukersites are not commercially exploitable in this quarry but a good opportunity is presented to study them. The exposed section appears as follows (Fig. 22, Plate III:F,D,B):

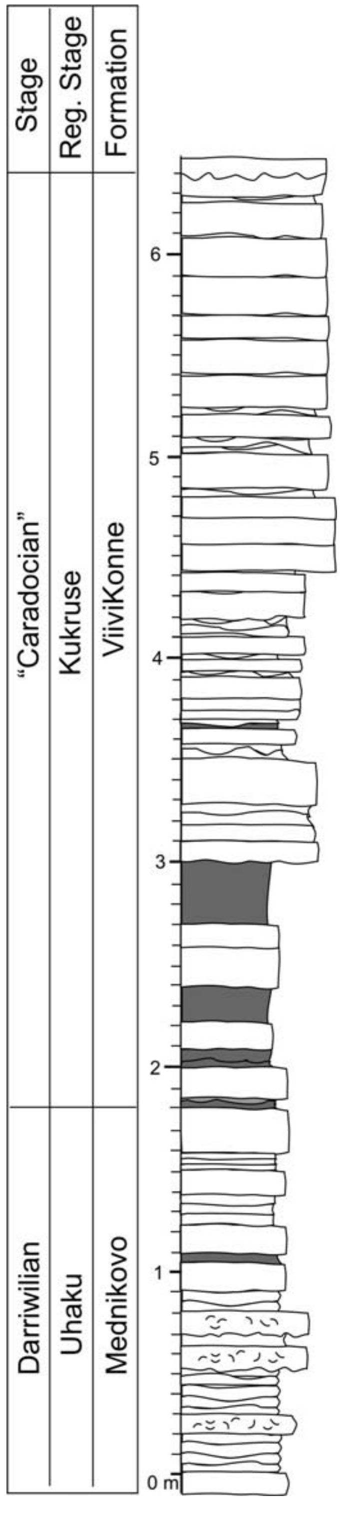

Fig. 22. The Alekseevka Quarry section.

Uhaki Stage

Mednikovo Formation (CIc Md)

Bluish-grey marlstone and limestone intercalations (3 m). Limestone beds are emphasized by weathering. The transition between limestone and marl is gradual, without sharp contacts. The rocks are mostly mudstones with scattered graptolite fragments. They are interpreted as relatively deep water deposits.

Kukruse Stage
Viivikonna Formation (CII Vv)

The lower boundary of this formation coincides with the base of the lowermost relatively thick (8 cm) kukersite bed. The kukersite-bearing unit consists of four kukersite beds separated by limestone layers. These limestone layers have their own names which were given to them by local quarrymen. Each layer can be traced to the Slantsy mining district and to north-eastern Estonia for a distance of more than 100 km. The succession of kukersite-bearing units are as follows (from the base to the top):

Kukersite bed (IY) about 16 cm thick and consisting of two oil shale units separated by a limestone layer 0.02-0.03 m thick.

Sinukha ("The Deep Blue") bed of bluish bioclastic limestone about 12 cm thick separating kukersite bed IY from kukersite bed III.

Kukersite bed (III) about 22 cm thick and without limestone intercalations.

Kulak ("The fist") a bed of bituminous limestone 14 cm thick.

Kukersite bed (II) with a thickness of about 20 cm.

Plita ("The plate") a prominent bed of hard bioclastic limestone about 26 cm thick.

Sputnik ("The satellite") a limestone bed 7 cm thick separated from the underlying unit by a marl layer.

Kukersite bed (I) of 32 cm thick (Plate II:C,E).

The top kukersite bed is overlain by a unit of bluish grey bedded limestone of 65 cm in thickness which is close in colour and internal structure to the limestone beds of kukersite-bearing unit. The upper part of the section in this quarry does not contain kukersites. It is represented by yellowish-grey limestones (predominantly bioclastic wackestones) with numerous subvertical burrows emphasized by dolomitization (3.70 m thick). Echinoderms, brachiopods and bryozoans are the dominant groups. The thickness of individual layers ranges from 3 to 6 cm.

Stop 12. Jõhvi Limestone in the Khrevitsa River valley.

The best locality to study the Jõhvi regional stage in the St. Petersburg Region is located on the right bank of the Khrevitsa River about 50 m upstream from the railway bridge (Plate 4, D). Unfortunately no stage boundaries can be seen in the outcrop. The section (about 6 m thick) is as follows (Fig. 23):

Khrevitsa Formation

All the visible section is represented by an intercalation of limestone, partly dolomitized, and marls. The section has been subdivided into 9 units (from the base to the top):

1) A relatively hard bed of grey bioclastic limestone 0.03 m thick. Fragments of crinoid skeletons up to 2 mm and unidentifiable fragments of trilobites are abundant.

2) Greenish grey thin bedded bioclastic clayish limestone. The fossil record includes echinoderms, bryozoans, brachiopods, trilobites, cephalopods, ostracodes and graptolites. Trace fossils are represented by "jõhvilites" (*Amphorichnus pappilatus* Männil). The trilobites are: *Asaphus (Postasaphus) jewensis* (Schm.), *Platillaenus jevensis* (Holm) and *Chasmopina* gen. et sp. indet. Thickness is 0.02 m.

3) Yellowish grey dense and massive dolomitized limestone about 0.2 m thick. The fossil record includes crinoids, brachiopods, bryozoans and dendroid graptolites as well as "jõhvilites". Trilobites are rare and represented by only one species *(Reraspis? rosenthali* (Schm.)).

4) Grey thin bedded clayish bioclastic limestone (wackestone) about 0.17 m thick. The thickness of the individual layers is about 1.5-4 cm. The fossil record include echinoderms, brachiopods, ostracodes, bryozoans, trilobites (*Rollmops wenjukowi* Schm.) and rare "jõhvilites".

5) Light grey clayish bioclastic limestone about 0.15 m thick. Individual layers of 2-4 cm thickness are separated by violet clay layers of 1-2 mm thickness. The fossil record includes graptilites, bryozoans, gastropods, cephalopods, brachiopods, echinoderms, ostracodes and trilobites (*Platillaenus jewensis* (Holm), *Otarozoum pahleri* (Schm.*),*

Toxochasmops (Schmidtops) proavus Rõõm., *Chasmops* gen. and sp. indet.).

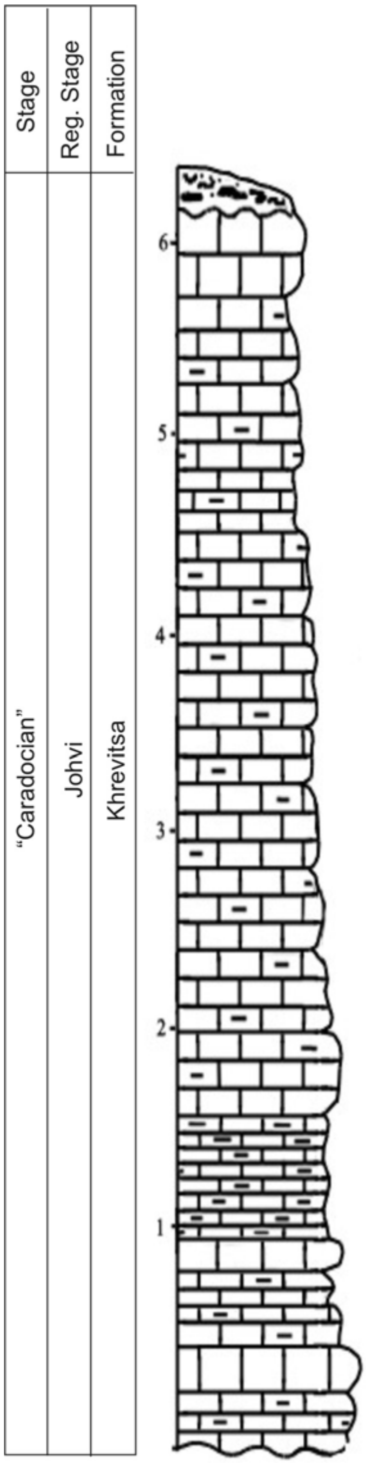

Fig. 23. The Khrevitsa River section.

6) Grey dense massive limestone slightly affected by dolomitization. The fossil record includes bryozoans, gastropods, cephalopods, brachiopods, echinoderms, ostracodes and trilobites (*Conolichas monticulosus* (Öpik), *Rollmops wenjukowi* (Schm.), *Stenopareia glaber* (Kjerulf), *Asaphina* gen. and sp. indet.). Thickness 0.13 m.

7) Grey clay-rich thin bedded marlstone with "jõhvilites". Thickness is 0.65 m. The fossil record includes brachiopods, bryozoans, cephalopods, echinoderms, gastropods, ostracodes, corals and abundant trilobites (*Amphilichas sp. indet., Asaphus (Postasaphus) jewensis* (Schm.), *Atractopyge dentate* (Esmark), *Platillaenus jewensis* (Holm), *Rollmops wenjukowi* (Schm.), *Toxochasmops (Schmidtops) proavus* Rõõm.).
8) Greenish grey clayish thin to medium bedded limestone intercalated with thin violet clay layers. Clay content diminishes upwards. Total thickness is 4.25 m. The fossil record includes brachiopods, bryozoans, conularians, cephalopods, graptolites, gastropods, ostracodes and trilobites (*Asaphus (Postasaphus) jewensis* (Schm.))

9) Yellowish grey dense massive bioclastic limestone affected by dolomitization. Thickness is 0.5 m. The most abundant fossils are crinoids. Brachiopods and bryozoans are rare. The only finding of a trilobite is *Asaphus (Postasaphus) jewensis* (Schm.).

Stop 13. "Kegel" dolomites of the Elisavetino Quarry.

The yellow "Kegel" dolomites are the most characteristic rock type for the upper part of the Izhorian plateau. They are widely used for road covering and as building stone. Many houses and palaces in Gatchina have been built from this rock. The main quarries for the "Kegel" dolomites are Elisavetino, Volosovo and Vruda. There are also many small quarries used for local purposes.
The old quarry in the outskirts of the village of Elisavetino is one of the deepest and most suitable for study. About 8 m of section can be seen (Fig. 24, Plate 4, F). The "Kegel" dolomites belong to the Elizavetino Formation of the Keila regional stage (Upper Ordovician). They represent facies specific for the easternmost part of the Ordovician Basin of Baltoscandia and its outcrops are restricted to the St. Petersburg Region. The dolomite of the Elisavetino Formation is interpreted as a shallow-water back-reef lagoon (sebkha) dolomite indicative for a tropical climate. The Vasalemma organic buildups in Estonia are

probably remnants of a “reef” or bar zone that separates the open shelf fore-reef clayish

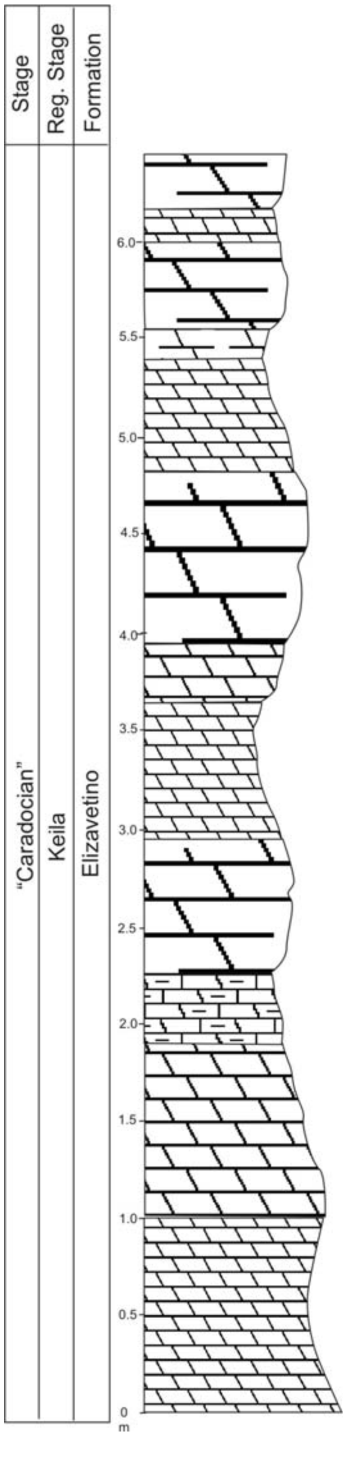

Fig. 24. The Elizavetino Quarry section (drawing by S. Terentiev).

facies of the Keila regional stage from back-reef dolomites.

In the section in Elisavetino Quarry we can see cycles consisting of relatively massive and bedded dolomites with thin laminations. The massive dolomites are interpreted as subtidal and thin laminated as tidal to supratidal, respectively. The subtidal part of the cycles is usually 0.6-1.0 m thick, whereas the tidal to supratidal part is about 0.1-0.4 m thick. Sometimes desiccation cracks (Plate 4, C) and bird’s-eye structures (Plate 4, B) can be seen on the rock surfaces. These structures are indicative for a shallow-water supratidal environment with occasional subaerial exposure. From sequence-stratigraphical point of view, the dolomites of the Elisavetino Formation represent the highstand system tract of the Kegel depositional sequence.

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