

EXCURSION
guidebook

PALEOZOIC
ICHTHOLOGY
OF ST. PETERSBURG
REGION

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PALEOZOIC ICHNOLOGY OF ST. PETERSBURG REGION

Excursion Guidebook

ANDREI DRONOV & RADEK MIKULÁŠ



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INTRODUCTION TO THE GEOLOGY OF THE ST. PETERSBURG REGION

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 Palaeozoic 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.



Fig. 1. Geological map of St. Petersburg Region with the localities visited during the field excursion. Legend:
1. Precambrian basement; 2. Vendian (Eldiacarian); 3. Cambrian; 4. Ordovician; 5. Devonian; 6. Localities:
1 – Sablino, 2 – Putilovo, 3 – Lava, 4 – Babino, 5 – Lynna and Syas; 7. Baltic-Ladoga Glint line.

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 sedimen-

tation. 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.

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. Männil (1966). 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 Geological and Palaeontological Institutes of the Russian Academy of Sciences (Moscow). Contrary to the body fossils, however, the trace fossils until recently have never received systematic investigation.

CAMBRIAN OF ST. PETERSBURG REGION

■ The **LOWER CAMBRIAN** in the St. Petersburg Region is represented by the Sivverskaya 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. loutova* 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), *Problematonites 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 (Kallio and Nestor, 1990). However, the uppermost Ordovician deposits are absent in the St. Petersburg region (Fig. 2).

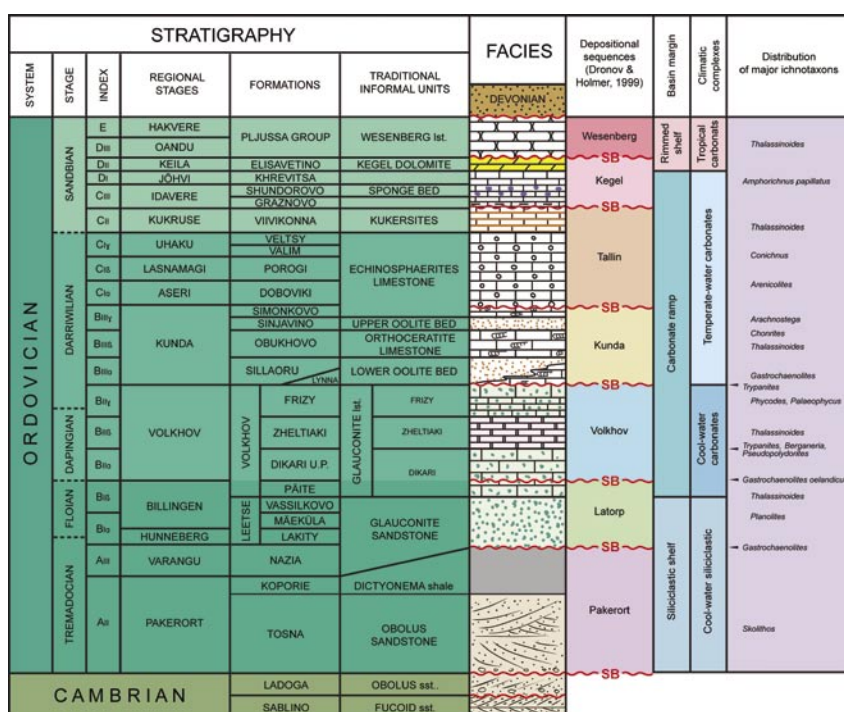


Fig. 2. Stratigraphic chart for the Ordovician of St. Petersburg Region showing facies, sequences, climatic complexes and distribution of major ichnotaxons.

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, 1966a). 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 deltiifer* Zone and rare organophosphatic brachiopods.

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 “Glauconitic 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” (BII α) of Lamansky (1905); (2) the “Zheltiaki Limestone” (BII β); and (3) the “Frizy Limestone” (BII γ).

The **Volkhovian part of the Dikari Limestone (BII α)** 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 than 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 *Baltioniodus 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 (BII β)** 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 (BII γ)** 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** (BIII α 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** (BIII α + β SL) (“Lower Oolite Bed”) consists of calcareous clay and highly argillaceous limestone with numerous iron ooids. It can be subdivided into the Nikolskoe (BIII α NK) and Lopukhinka (BIII β LP) Members (Ivantsov, 1990).

The **Obukhovo Formation** (BIII β + 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** (BIII γ SN) (“Upper Oolite Bed”) consists of argillaceous limestone with iron ooids. It corresponds with the upper part of the *Asaphus* (*Neosaphus*) *pachyophthalmus* – *A.* (*A.*) *minor*, *A.* (*Neosaphus*) *ingrianus* – *A.* (*A.*) *sulevi* and *A.* (*Neosaphus*) *laevissimus* local trilobites zones.

The **Simankovo Formation** (B_{III} γ SM) consists of highly argillaceous limestone with clay intercalations and is about 2m thick.

The **ASERI REGIONAL STAGE (C₁A)** 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* (*Neosaphus*) *laevissimus* Schmidt that is replaced by *Asaphus* (*Neosaphus*) *platyrurus* Angelin just above the non-deposition surface. The upper part of the Duboviki Formation corresponds to the *Asaphus* (*Neosaphus*) *punctatus* – *Asaphus* (*Neosaphus*) *kotlukovi* and *Asaphus* (*Neosaphus*) *kovalevskii* – *Asaphus* (*Neosaphus*) *intermedius* local trilobite zones (Ivantsov, 1993). In terms of the conodont biostratigraphy of Baltoscandia, the Duboviki Formation corresponds to the *Eoplacognathus suecicus* Zone.

The **LASNAMAGI REGIONAL STAGE (C₁B)** 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* (*Neosaphus*) *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 (C₁C)** 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 (*Echinospaerites aurantium suprum* Haeckel), as well as various bryozoans, trilobites, ostracodes, bivalves, gastropods and hyoliths.

The **IDAVERE REGIONAL STAGE (C_{III})** 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 (D_I)** 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 Jastremino 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 schmidtii 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), *Iliaenus 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

There is a consensus of opinions that during the Ordovician, the Baltic palaeocontinent migrated from a subpolar to subequatorial position in the southern hemisphere (Cocks and Torsvik, 2005), (Fig. 3). Latitudinal migration is reflected in the succession of facies from subpolar, predominantly siliciclastic, sands and black shale in the Tremadoc, through temperate bioclastic wackestones in the Floian-Sandbian, to tropical sabkha dolomites and pelmicrites in the Katian-Hirnantian, which is well documented in the Ordovician basin of Baltoscandia. The large-scale lithofacies zonation of the basin has been described by Männil (1966a) and Jaanusson (1976, 1982, 1995). Passing from relatively deep-water to shallow-water settings, the zones are as follows (in ascending order): (1) Scanian Confacies Belt; (2) Central Baltoscandian Confacies Belt; and (3) North Estonian Confacies Belt (Fig. 4). For the most shallow-water facies of the North Estonian Confacies Belt in northern Estonia and northwestern Russia (St. Petersburg Region), four climatically dependent lithological complexes have been distinguished: (1) cool-water siliciclastites; (2) cool-water carbonates; (3) temperate-water carbonates; and (4) warm-water tropical carbonates (Dronov and Rozhnov, 2007).

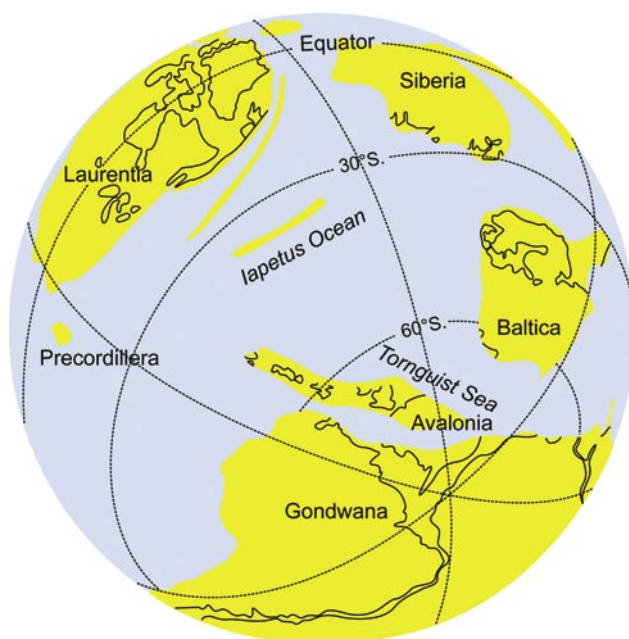


Fig. 3. Palaeogeographical position of the Baltic paleocontinent in the Middle Ordovician; modified from Christiansen and Stouge (1999).

The lowermost (Cambrian and Tremadocian) complex is predominantly represented by siliciclastic sediments. Formation of the cool-water carbonate ramp in the East Baltic began in the terminal Hunneberg and continued until Billingen and Volkhov time. This stratigraphic interval was usually referred to in previous publications as “Glaconite limestone” because of the abundant scattered glauconite grains and hardground surfaces impregnated by glauconite. The uppermost Billingen and Volkhov bioclastic limestones of the St. Petersburg region have been interpreted as cool-water calcareous tempestites, which were deposited in a storm-dominated, shallow-marine environment (Fig. 5). Storms produced characteristic sheet-like skeletal sand beds of considerable

Fig.4.

Generalized facies zones of the Ordovician basin of Baltoscandia during the Middle and Late Ordovician; modified from Männil (1966a), Jaanusson (1976, 1995) and Nielsen (2004).

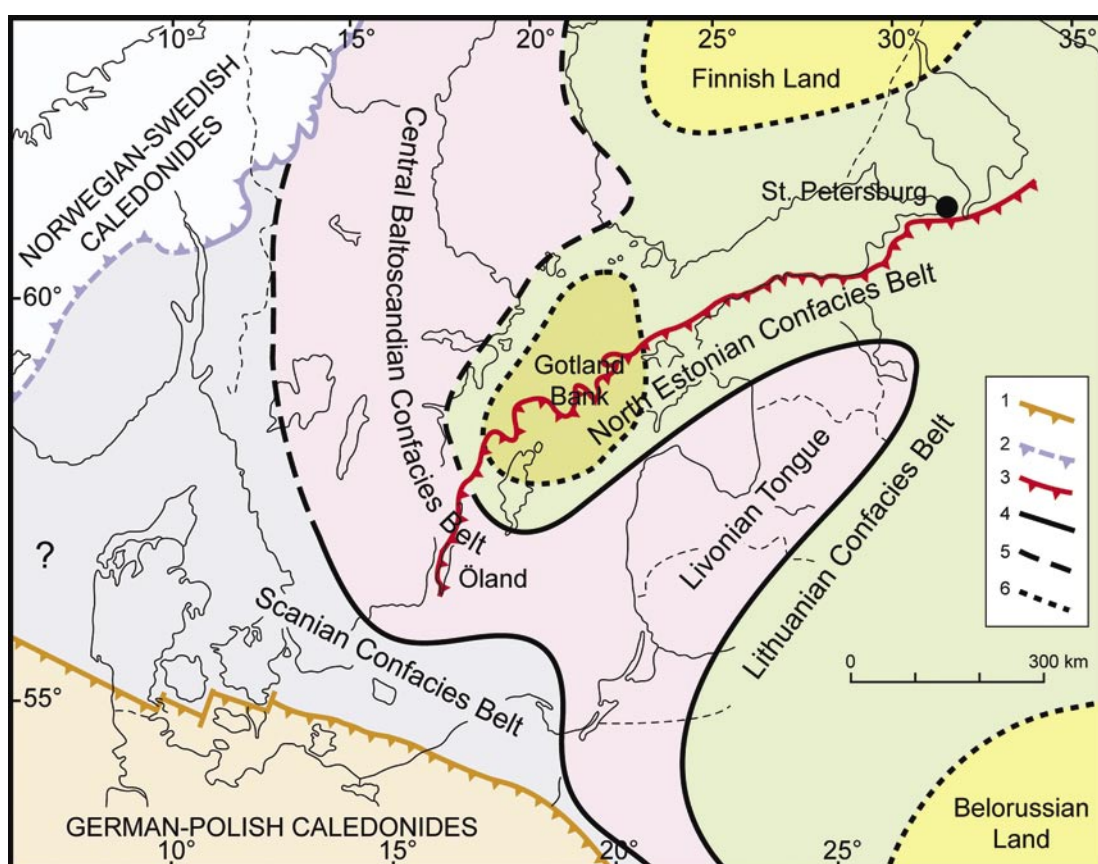
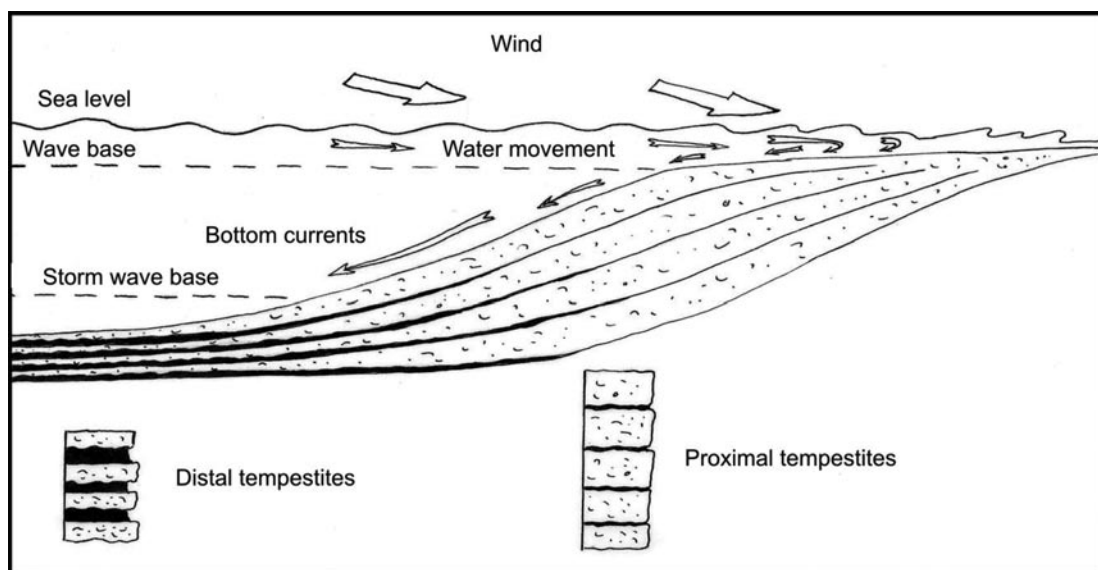


Fig.5.

Simplified model for the Volkhovian and Kundan carbonate tempestites.



lateral extent. About 30 composite beds and bed packages of storm origin can be traced in the upper Billingen–Volkhov deposits over a distance of more than 300 km along the eastern part of the Baltic–Ladoga Glint. These beds provide a precise time framework for high-resolution regional correlation. Most of the beds are distinctly graded and consist predominantly of coarse-grained shell debris. The carbonates of the Billingen–Volkhov interval are extremely condensed due to low productivity of the homoclinal ramp “carbonate factory”. Abundance of discontinuity surfaces, which are typical

for the Billingen and Volkhov regional stages, is probably a result of carbonate dissolution (Dronov and Rozhnov, 2007).

The shallow-water carbonates from the base of the Kunda regional stage up to the base of the Keila regional stage are related to a temperate sedimentation province. In contrast to overlying warm-water carbonates they contain little or no lime mud, no calcium carbonate pellets and ooids as well as no micritized skeletal grains. There is clay material between calcite bioclasts instead of lime mud. Depositional processes resulted in the formation of a distally steepened carbonate ramp. The thickness of stratigraphic units of the same duration is greater there than in the underlying cool-water carbonates and less than in the overlying warm-water carbonates, which probably reflect changes in productivity of the “carbonate factory”. The most characteristic shallow-water facies comprises iron oolites and organic-rich shales called kukersite. In contrast to the underlying cool-water carbonates, deposits of this stratigraphic interval contain neither glauconite grains nor glauconite-impregnated hardground surfaces in the shallow water settings. This suggests that the water temperature was not favourable for glauconite formation, i.e., that it was above 15° C. The annual mean temperature of the surface water at that time falls probably into the interval between 15° C and 22° C (Dronov and Rozhnov, 2007).

Another interesting aspect of the Ordovician geology of the St. Petersburg region is the enigmatic organic buildups of mud mound type (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 Dapingian age and the largest ones extend approximately 3–4 m in height and are about 100–200 m 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 these enigmatic buildups is summarized by P. Fedorov (2003).

All trace fossils displayed in the Field Guide originated in a relatively shallow (near storm wave base and shallower), cold- to temperate-water environment on a tide- to storm-dominated shelf. The trace fossil assemblages in the region are rich and diverse. Some of the specific trace fossils have already been used as diagnostic fossils for some regional stages and stratigraphic levels. This is the case, for example, with the so-called “Jõhvilites” (subvertical burrows from the Jõhvi regional stage, mainly *Amphorichnus pappilatus* (Männil, 1966b) and “Amphora-like” borings (Orviku, 1960), which have been used to mark the base of the Volkhov regional stage (Männil, 1966a). Detailed ichnostratigraphy has been elaborated for the Volkhov stage interval of the St. Petersburg region, with precise bed-by-bed correlation based on the distribution of specific trace fossils and ichnofabrics, which allows individual beds, bedsets and bedding planes to be recognized and traced for a distance of more than 300 km (Dronov et al., 1993; 1996).

SEQUENCE STRATIGRAPHY AND SEA-LEVEL CHANGES

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 stratigraphic 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. 6). 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 Pakerort, 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, 1966a). The lower boundary of the Volkhov sequence is interpreted as a 2nd-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).

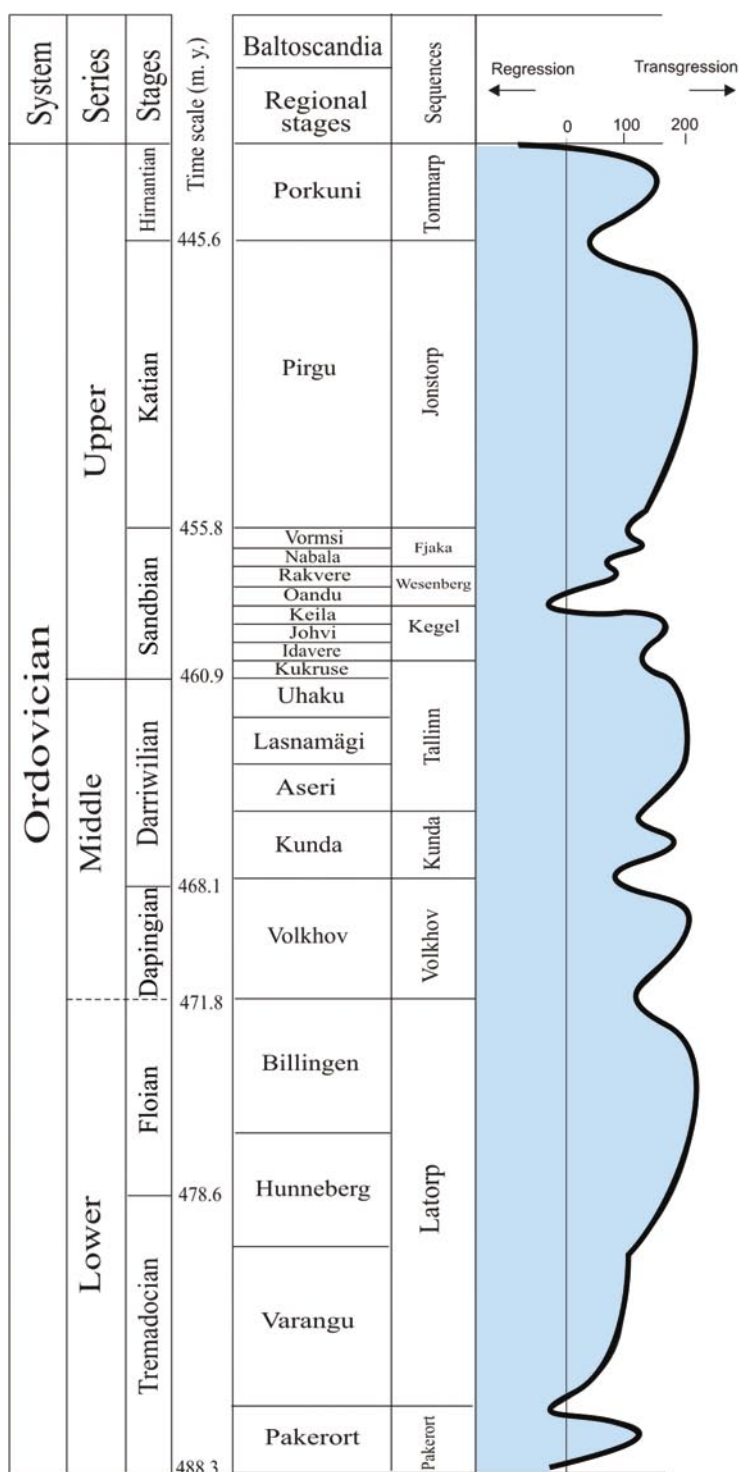
There is no evidence of prominent erosion at the base of the Tallinn sequence and it is represented by more shallow water deposits as compared with the underlying Kunda and Volkhov sequences. The shallowing of the basin was not a result of forced regression but rather a consequence of an increasing sediment 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 north-eastern Estonia and north-western 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

Fig. 6.
Sea-level changes in
the Ordovician of
Baltoscandia.



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.

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 stratigraphic interval in St. Petersburg region were deposited on a siliciclastic-carbonate ramp within a shallow-marine, storm-dominated environment. These conditions were favorable 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 litho-facies can be identified in the Volkhovian succession of the region. All the litho-facies 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 tempestites 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. 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.

TRACE FOSSILS

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) were 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 (Vishniakov and Hecker, 1937; Männil, 1966b) or borings (Orviku, 1940) were the only ichnotaxa 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. 7). 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. *Amphorichnus* 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., Aceñolaza and Aceñolaza 2003). In the Ordovician of the St Petersburg Region, *Arachnostega gastrochaenae* is common through the Kunda regional stage.

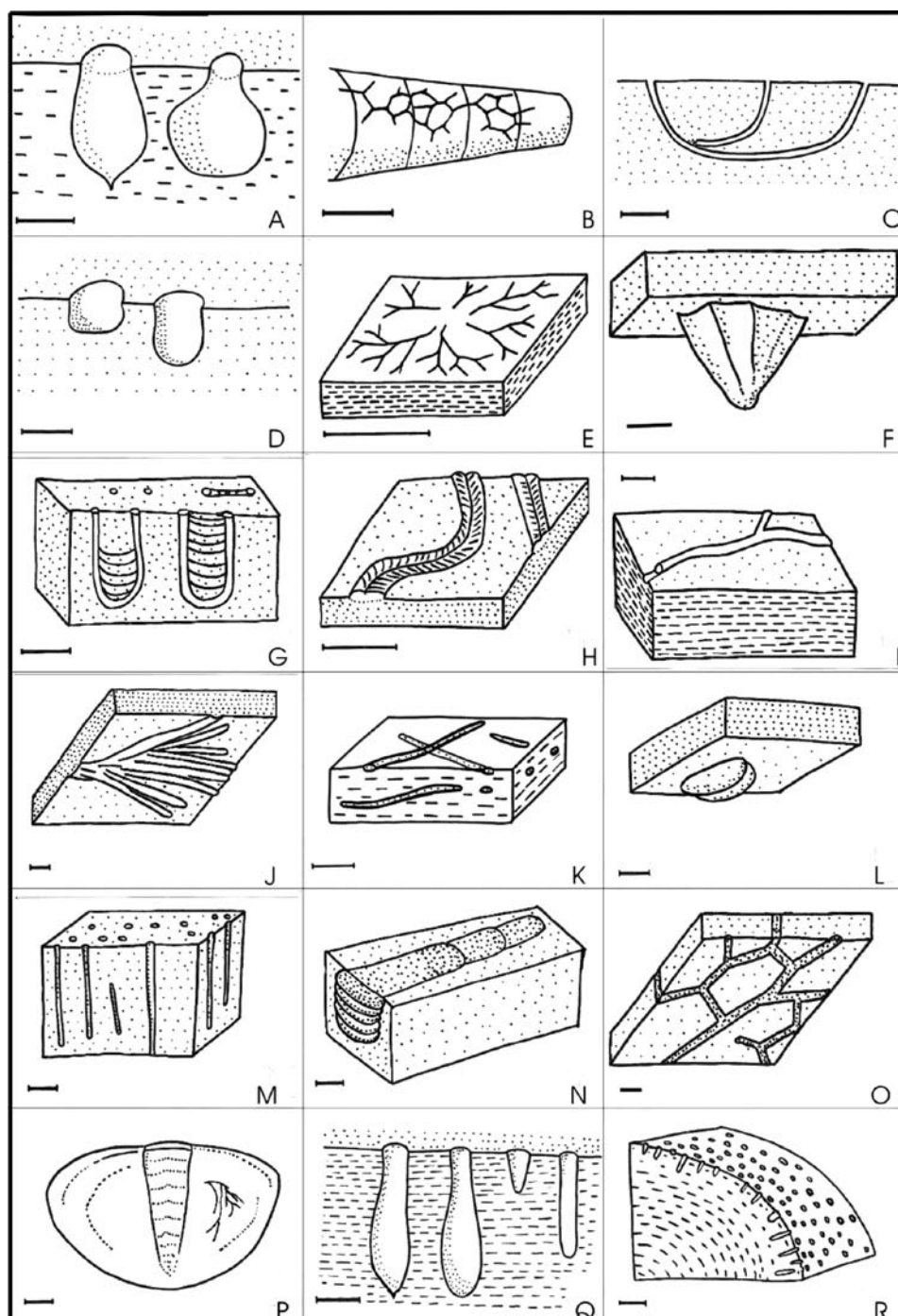


Fig. 7.

Schematic drawings of the Ordovician ichnogenera mentioned in the Field Guide:

- A – *Amphorichnus*;
- B – *Arachnostega*;
- C – *Arenicolites*;
- D – *Bergaueria*;
- E – *Chondrites*;
- 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 *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 (B_{II}β) 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 biotrititic 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. Occasionally 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 ichnofabrics; it often re-burrows tunnels of *Thalassinoides*. *Chondrites* is very common in certain layers of Leetse Formation and in Zheltenky Bed of the Zheltiaki 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). 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 pair 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). In 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).

The ichnogenus *Teichichnus* Seilacher, 1955 is the morphologically simplest spreiten-structure, consisting of wall-shaped, approximately vertical 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 *Teichichnus* come from the basal beds of the Kunda sequence, i.e. the basal oolitic 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 horizontal 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 Members; Putilovo, Sablino, Lava, Lynna and other localities).

BORINGS

“Bryozoan borings.” Richly fossiliferous layers of the highstand system tract of the Volkhov sequence (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 ichnogenetic 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 frequent 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 bioclasts 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).

PALEOZOIC ICHTHOLOGY OF ST. PETERSBURG REGION

field excursion

DAY 1. Thursday, 24th of June 2010: Sablino, Lava, Putilovo

Sablino

- STOP 1.** Right bank of the Tosna River Canyon near the bridge
- STOP 2.** Sablino caves
- STOP 3.** Sablinka waterfall.
- STOP 4.** Left bank of the Tosna River Canyon 300 m downstream from the Tosna waterfall

Lava River Canyon

- STOP 5.** Old quarry on the left bank of the Lava River Canyon and the natural outcrop on the opposite side of the valley

Putilovo Quarry

- STOP 6.** Mining field of the “Dikari Limestone” in the Putilovo Quarry
- STOP 7.** Hecker-type mud mound in the Putilovo Quarry
- STOP 8.** Kunda in the southern part of the Putilovo Quarry

Leaving St. Petersburg early in the morning we drive towards the south-east on the St. Petersburg – Moscow highway. This flat area is a territory of Lower Cambrian rocks (“Blue clays”) covered by a blanket of Pleistocene glacial and post-glacial deposits. We pass the turn to the town of Kolpino and cross the Izhora River. Shortly after that we climb the Baltic-Ladoga Glint and enter the Ordovician (Izhorian) Plateau. Passing Popovka village we then turning left to cross the Sablinka River at the Uljanovka village.

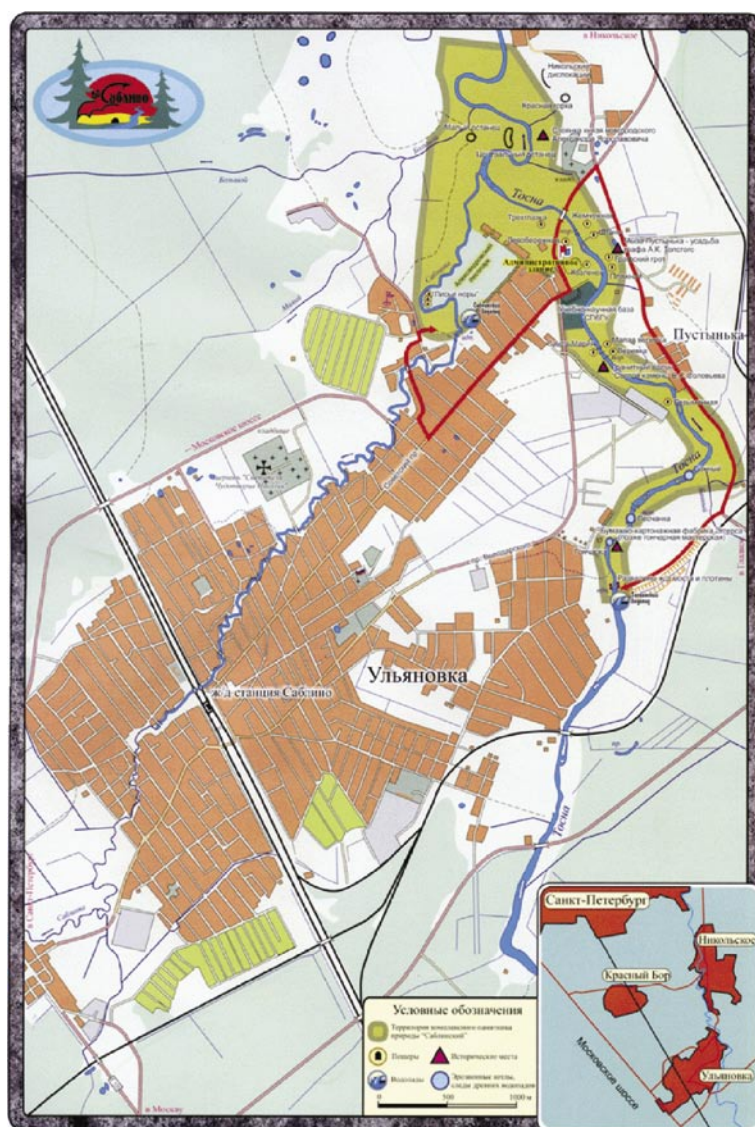


Fig. 8.
Schematic map for the vicinity of
Sablino railway station.

STOP 1.

THE RIGHT BANK OF THE TOSNA RIVER

NEAR THE BRIDGE

■ We cross the Tosna River at the bridge on the road to the village of Nikolskoe and stop on the right bank of the Tosna Canyon. Here in a small sand quarry we have an opportunity to study Middle Cambrian, Upper Cambrian and Lower Ordovician (Tremadocian) siliciclastic deposits (Fig. 9) containing typical *Skolithos* and less clearly preserved possibly drop-like vertical trace fossils. The section is as follows (from the base to top), (Fig. 10):

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 (Fig. 11. A, B). The colour pattern of the quarry wall is given by recent precipitates of iron oxides and hydroxides, which visually augmented the sedimentary structures; but in the same time, the ichnofossils were partly “deformed” by the precipitates that (similarly as, e.g., flintstone nodules in chalk) only roughly “copy” the original structures. 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.

Trace fossils, placed tentatively to *Gastrochaenolites* or to the “Skolithos Group”, are represented by vertical shafts up to 5–6 cm deep and about 1-2 cm in diameter (Fig. 11. A, B), some of them suggests presence of a drop-like chamber in the base. The burrows are filled with quartz sand identical to the sand of the surrounding host sediments, and they have unsharp walls and no wall lining. Actually, the structures become visible on the outcrop wall because of colour contrast due to weathering that occurred in Quaternary time. Iron oxide/hydroxide transported by ground water is concentrated inside the burrows and along the former bedding planes, which represent more permeable zones than the surrounding sediments. Emphasized by this iron oxide/hydroxide distribution alone, extracted from water, the burrows become visible. Within the Sablino caves, where oxygenation of the ground-water does not occur, there is no colour contrast between quartz sands inside and outside burrows. Under these conditions, the ichnofabric is difficult to recognize. The described trace fossil occurs very densely at some places, as typical for the Cambrian “pipe rocks”. The burrows are usually associated with herringbone cross-stratification. The proximal (upper) end of the burrows is usually truncated by erosion and the real morphology of its uppermost part remains unknown. The trace is typical for the Middle Cambrian Sablinka formation and it is absent in the Upper Cambrian Ladoga formation and the Lower Ordovician Tosna formation.

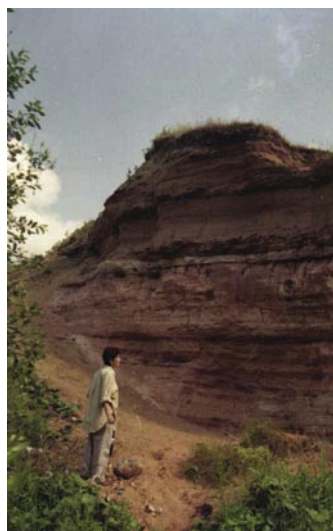


Fig. 9.
Sabino, Ladoga and Tosna
Formations in a small quarry on
the right bank of the Tosna River
near the bridge.

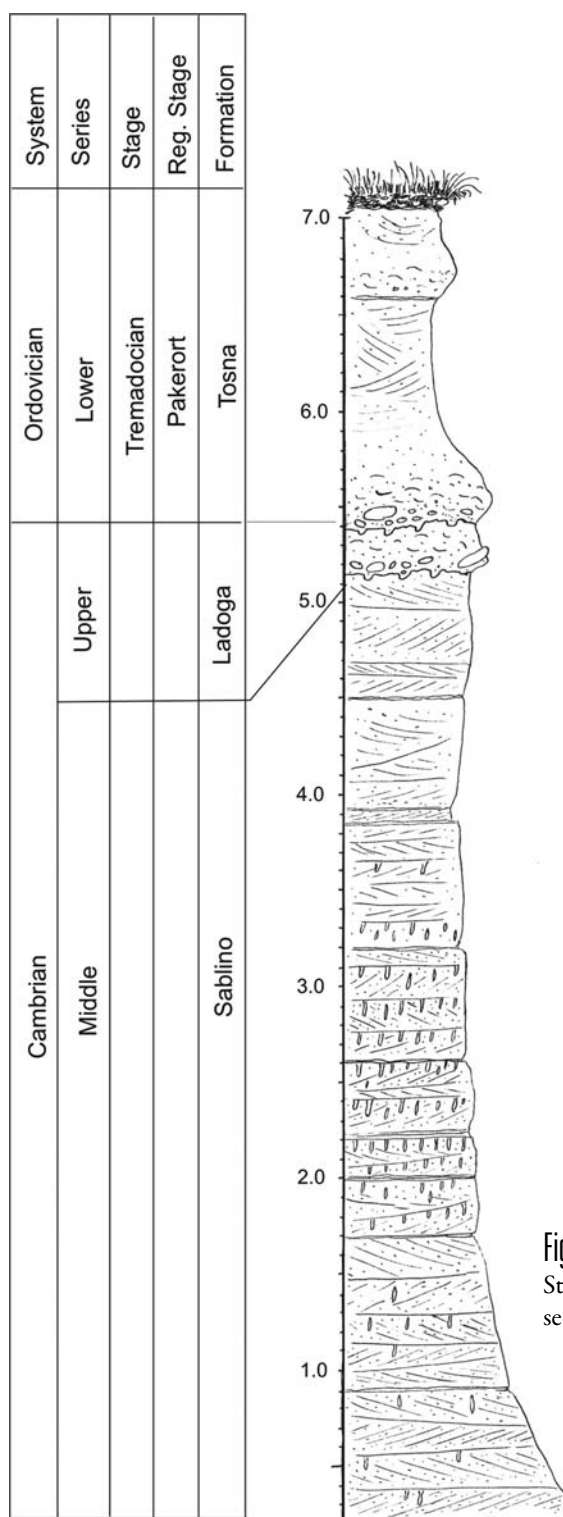


Fig. 10.
Stratigraphic
section for Stop 1.

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



Fig. 11.

Trace fossils:

A, B – *Gastrochaenolites?* from the Middle Cambrian Sablino Formation;

C, D, E, F – *Skolithos* from the Lower Ordovician Tosna Formation.

amount of brachiopod shells. The lower boundary of the formation represents an uneven erosional surface with cavities 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 upper boundary also coincides with regional unconformity (Fig. 9, 10).

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 (Fig. 9). 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 cavities and pockets up to 0.15 m deep. Pebbles of hard quartz sandstone can be seen on this surface.

In this locality we have an opportunity to observe also trace fossils which we refer here to *Skolithos* with the yet unsolved ichnospecific status. The trace is represented by thin and relatively deep burrow with well-defined walls (Fig. 11. C, D, E, F). The length varies from 6 cm to 16 cm; diameter is 2–3 mm. Because of the strongly cemented filling, the tubes of *Skolithos* are easily washed out from the loose surrounding sands by rain on the outcrop surface. This process makes them visible and easy recognizable in the outcrops exposed to wind and rain. The tubes are filled with the same quartz sand as surrounding sediments. *Skolithos* forms a monospecific ichnoassemblage in quartz sands with numerous scattered fragments of phosphatic brachiopod shells attributed to the Lower Ordovician Tosna formation (“*Obolus* sandstone” in older terminology). It characterizes high-energy subtidal nearshore environments.

Koporie Formation

Black, bituminous shale up to 0.18 m thick. Traditional informal name is “Dictyonema Shale”. 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.

STOP 2.

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 Tremadocian/Dapingian boundaries (Fig. 12 A). 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 Tremadocian/Dapingian 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 laminae deposited on the surface of an ancient tidal flat during a period of subaerial exposure (Dronov and Popov, 2004). Taking into account the position of the Baltica paleocontinent in the Middle Cambrian (Cocks and Thorsvik, 2005) it seems natural to have traces of sinsedimentary freezing in sub-aerially 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).

The ichnologic content of the uppermost 60 cm of the Sablino Formation consists both of indeterminate bioturbation structures (spots, disturbed laminae) and of distinguishable or identifiable trace fossils. The ichnofabric index ranges from 1 (= no bioturbation) to 2 (= few percent of the bioturbated substrate); the index usually increases upwards. Individual colonisation horizons can be seen in only a few places (Fig. 12 B), showing, however, very limited lateral extent.

Among distinguishable/identifiable trace fossils, the ichnogenera *Diplocraterion* Torell, 1870 and *Skolithos* Haldeman, 1840 were recognized (Fig. 12 C, D, E).

Diplocraterion (Fig. 12 D, E) is represented by vertical U-shaped tubes showing a reworked lamina (spreite) between the limbs of the U. The spreite is in some cases deflected, ladle-like. The

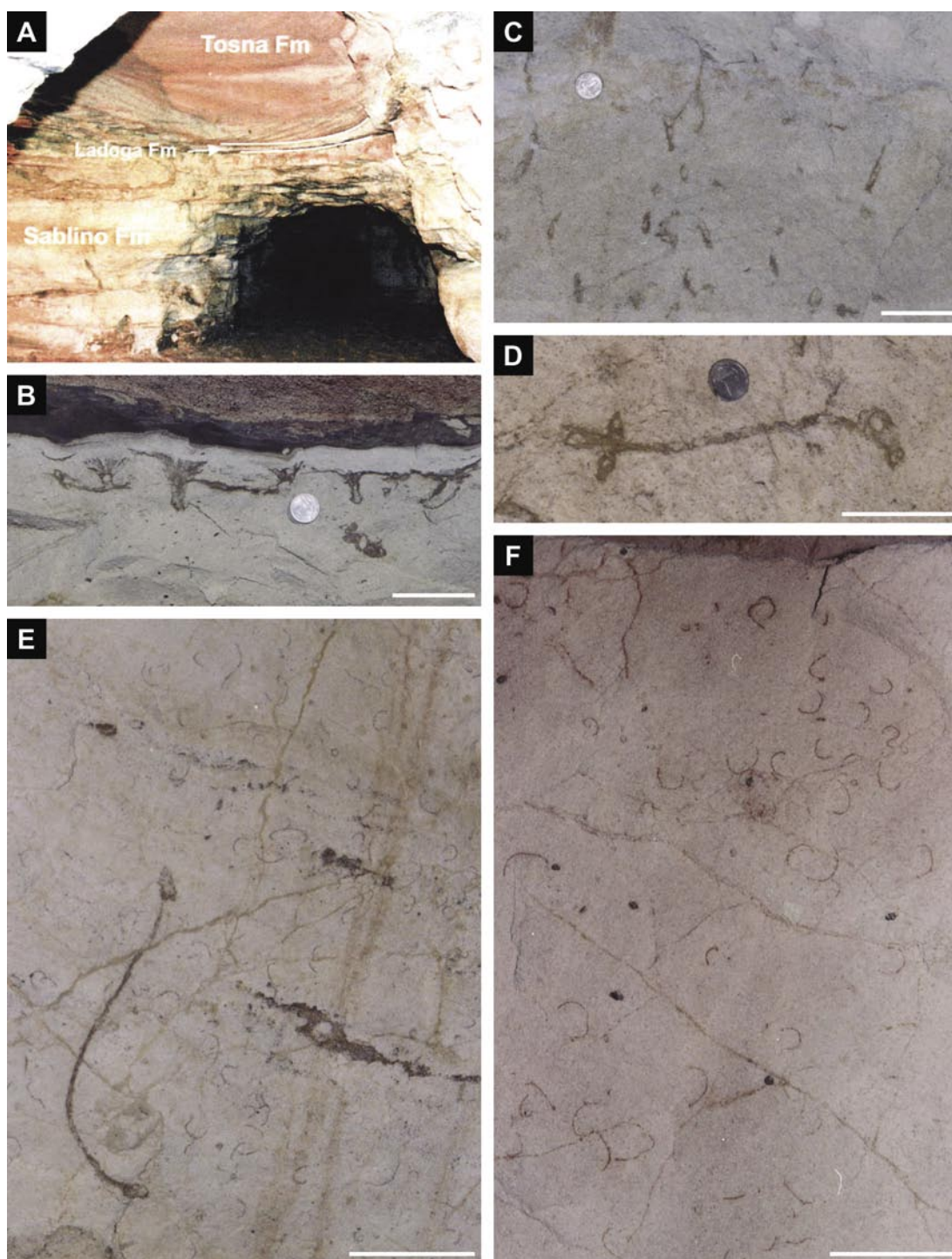


Fig. 12.

Levoberezhnaya cave in Sablino:

A – View of a gallery at the Levoberezhnaya cave showing rocks of the Sablino, Ladoga and Tosna Formations;

B – Shafts of undetermined trace fossils with “flame-like” structures in their upper parts, top of the Sablino Fm.;

C – *Skolithos* isp., top of the Sablino Fm.;

D – *Diplocraterion* isp. (horizontal cross section), top of the Sablino Fm.;

E–F – Horizontal and oblique cross sections of body fossils, top of the Sablino Fm.

Scale bars = 5 cm for all figures.

From Natal'in et al. (2010).

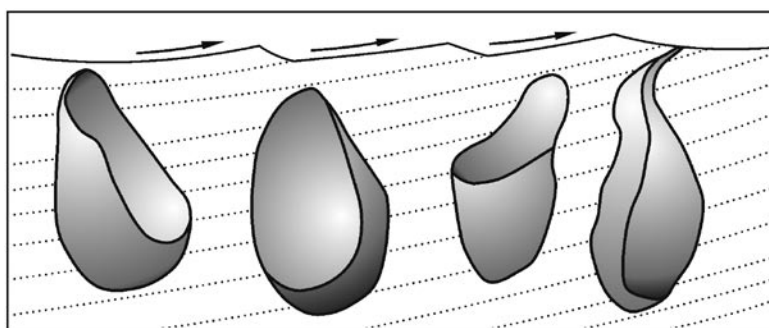
tube is up to 10 mm in diameter, smooth, unlined; with maximum depth of the structure 50 mm. Cross-cutting relationships show that *Diplocraterion* can disturb the cup-like bodies as described below. According to these authors, *Diplocraterion* is the dwelling burrow of a suspension feeder, characteristic of settings with relatively strong wave and current energy. The specimens from Sablino cannot be, according to the section observed, identified on the ichnospecific level.

The ichnogenus *Skolithos* (Fig. 12 C) displays vertical and steeply oblique shafts, 2–8 mm in diameter, up to 60 mm in depth. The shafts are solitary or in widely spaced groups (usual spacing

Fig. 13.

Three-dimensional reconstruction of the “cup-like” body fossils from the top of the Middle Cambrian at Salbino and their presumed position in the substrate. Presumed mechanism of shifting the substrate (i.e. current ripples) is also marked.

From Natal'in et al., 2010.



1–5 cm). Walls of the shafts are probably always smooth, probably unlined but made visible by dark (? manganiferous) precipitates. *Skolithos* is typically a dwelling burrow; in the described material, some vertical shafts might represent also escape structures, as chevron-like patterns can be observed on their top parts.

Another kind of biogenic structure is represented by shallow, relatively wide shafts with “flame-like” structures in their upper parts (Fig. 12 B). These structures, purely on a morphological basis, resemble body fossils of sea anemones. They can be explained by the collapse of hollow dwelling burrows; the “flames” possibly originated from the collapse of a thin mud drape (? algal mat) covering the sea bottom.

The morphological analogues of Ediacaran-like fossils are the most interesting feature of the sequence. They display thin (up to 0.5 mm) cross-sections in the form of a regular to slightly irregular C, U or J. Circular cross-sections are rare; exceptionally, the cross-section is an asymmetrical S (Fig. 12 E, F). Cross-sections resembling broad Us or Cs are typically observed in vertical cross sections up to 20 mm deep and 10–15 mm of horizontal extent. The resulting shapes, reconstructed on the basis of the cross sections, are irregular, minute cups (Fig. 13). Walls of the cups are smooth, with no preserved inner structure. Only a division crack filled with clay substance and poor ferruginous/manganiferous cement is observed. These structures resemble “cup-shaped” Ediacaran animals, among which the genus *Ernietta* is closest by its general body-plan; some similarities can be found also to *Ediacaria*, *Cyclomedusa* and *Nemiana*.

Crosscuttings between trace fossils and the cup-like forms are rare, but in all observed cases burrows of the ichnogenus *Diplocraterion* crosscut the cup-like structures. The cup-like bodies do not crosscut mutually, but may touch; usually they are arranged in weakly bordered clusters, where the average distance of the individuals reaches 5–10 mm; outside the clusters, the distance may be 20 or more cm. (Cf. Natal'in, Mikuláš and Dronov 2010.)

STOP 3.

SABLINKA WATERFALL

■ In the outcrop near Sablinka waterfall (Fig. 14) we have an opportunity to study stratigraphical interval from the quartz sandstone (“Obolus Sandstone”) of the Tosno Formation (Tremadoc) till the top of the “Dikari” Unit of the Volkhov Formation (Dapingian), (Fig. 15). Tosno and Kopirie Formations have been described in the outcrop on Stop 1. Here we continue upward the section.

BILLINGEN REGIONAL STAGE

Nazia Formation, Leetse Formation Mäekula and Vassilkovo 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). It is interpreted as a transgressive lag of the Latorp depositional sequence (Dronov and Holmer, 1999).

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. Vassilkovo Beds consists of three units: 1) about 0.04 m of bluish green clay with a thin red band in the middle. 2) About 0.06-0.08 m of bluish green argillaceous limestone with rare glauconite grains. 3) About 0.16 m of argillaceous limestone with glauconite grains interbedded with greenish grey clay.

The basal quartz sand layer (Nazia Formation) this outcrop is full of phosphatized burrows which we intend to describe as a new ichnospecies of *Gastrochaenolites*, *G. variabilis* (Dronov, Mikuláš and Bromley in review; a *nomen nudum* herein). Some of them are very similar in morphology with *Gastrochaenolites oelandicus* but have much more variable morphotypes. They are represented by subvertical conical or amphora-like burrows occurring at the erosional surface on top the Varangu Regional stage in St. Petersburg region and Estonia. Originally these burrows were reported by K. Stumbur (1962), who suggested that they mark a single erosional surface that cuts different lithofacies. He actually used these trace fossils as a regional stratigraphic marker.

The burrows are usually 5–6 cm deep (rarely up to 12 cm) and infilled with glauconite sand. At some places (Luga River, Putilovo) the burrows penetrate black bituminous argillites of the Koporie formation (“Dictyonema Shales”). In Varangu and other places in Estonia similar burrows have been reported from the surface on top of the Varangu clays (Stumbur, 1962). In the vicinity of St. Petersburg in the Tosna and Sablinka River valleys these burrows are known as “phosphatized burrows” from the Nazia Formation (Ershova et al, 2006). The Nazia Formation of Varangu age is represented in this region by a thin (only 15–20 cm) bed of quartz sand resting directly on the “Dictyonema Shale” (Fig. 16B, C). Within this sandstone bed one can easily find rather large burrows filled with the same quartz sand material or quartz sand enriched with glauconite grains. These burrows open at the top surface of the bed, which is overlain by the bed of glauconite sand, usually enriched by glauconite grains. The sand within the burrows is cemented by phosphatic material and because of this they can be easily washed out from the loose sand and their morphology can be studied (Figs. 16 A, 17).

The size and general morphology of the burrows are variable. The length varies from 2 cm to 11 cm (usually 4–6 cm). Horizontal cut is semicircular or elliptical with diameter of about 2–3.5

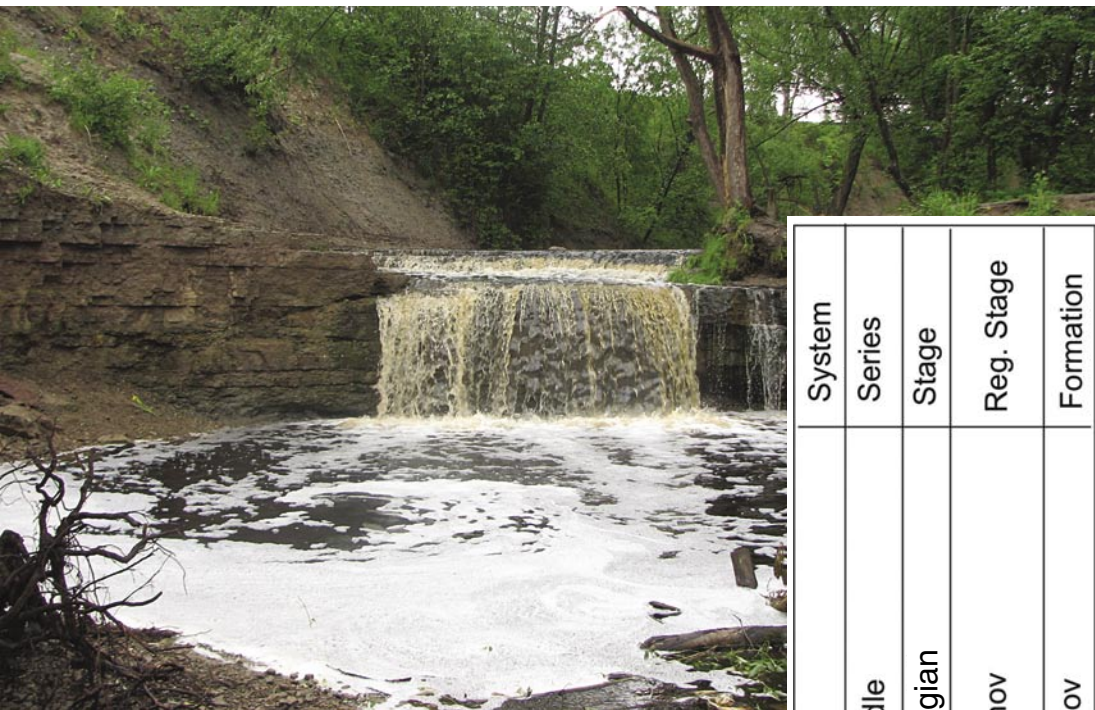


Fig. 14.
View on Sablinka waterfall.
The hard rock unit is Dikari
Limestone.

System	Series	Stage	Reg. Stage	Formation
Ordovician	Middle	Dapingian	Volkhov	Volkhov
	Lower	Floian	Pakerort	Koporie
		Latorp		
		Billingen		
				Leetse
				Tosna

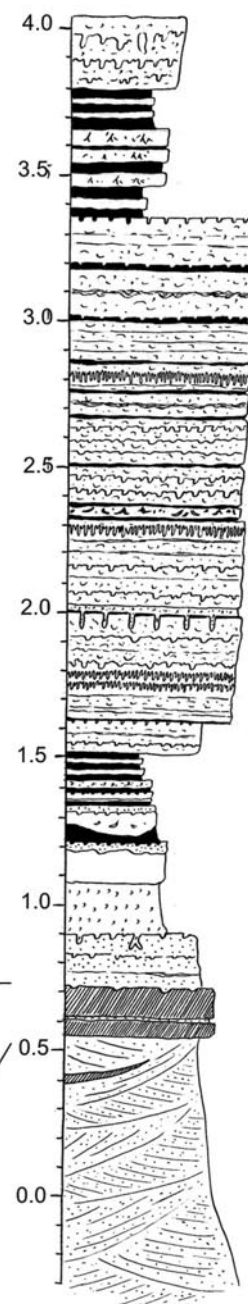


Fig. 15.
The Sablinka River section
near the Sablinka waterfall.

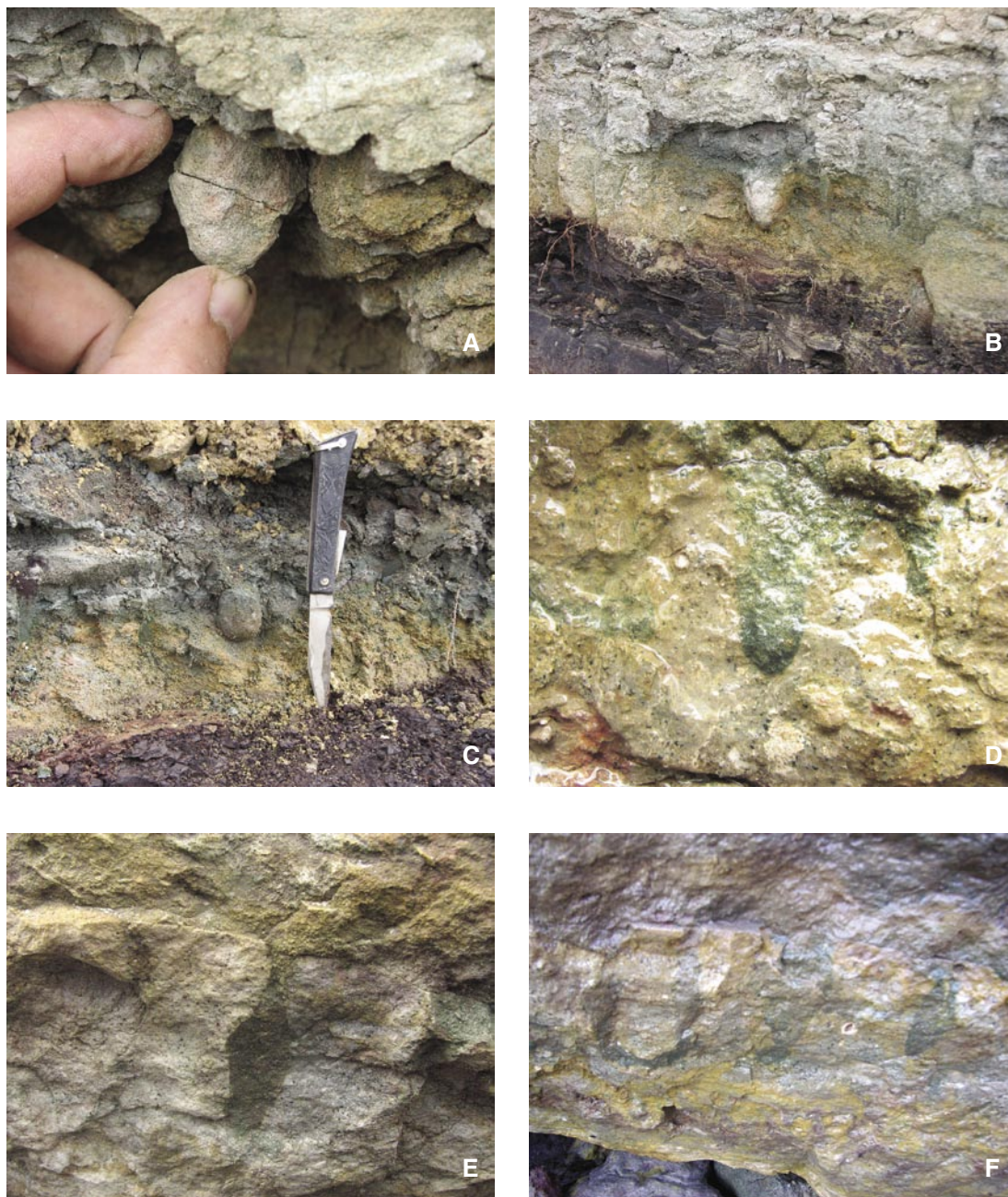


Fig. 16.

Trace fossils:

A, B, C – *Gastrochaenolites variabilis* from the Nazia Fm.;

D, E – *G. oelandicus* from the “Steklo” surface at the base of the Volkhov Regional Stage.

F – Two borings of *G. oelandicus* connected by posterior burrow in a U-shaped structure (“Steklo” surface under the waterfall).

cm. The burrows are drop-like (Fig. 17 A, H, K), conical (Fig. 17 B, C, D), bulbous (Fig. 17 F, I), amphora-like (Fig. 17 E, J) and even boot-like (Fig. 17 G, L). When two or more burrows spaced too close to each other or they cut each other, the morphology of the compound structure can be more complicated.

The conical morpho-type is very close to ichnogenus *Conichnus* whereas the others are reminiscent of *Amphorichnus* and *Gastrochaenolites* but in the case of “phosphatized burrows” it is obvious that all the morphological variations have been made by the same producer during the equal kind of behaviour. The variation itself has to be used with caution as the ichnotaxobase, otherwise we get a non-realistic picture of the manifold exploitation of the substrate through the longer list of ichnotaxa, if the variability is not taken into account.

The topmost part of the structures was sometimes cut by erosion or just not cemented enough to survive when it is washed out from surrounding sands. But in some cases (Fig. 17 J, E) one can see a

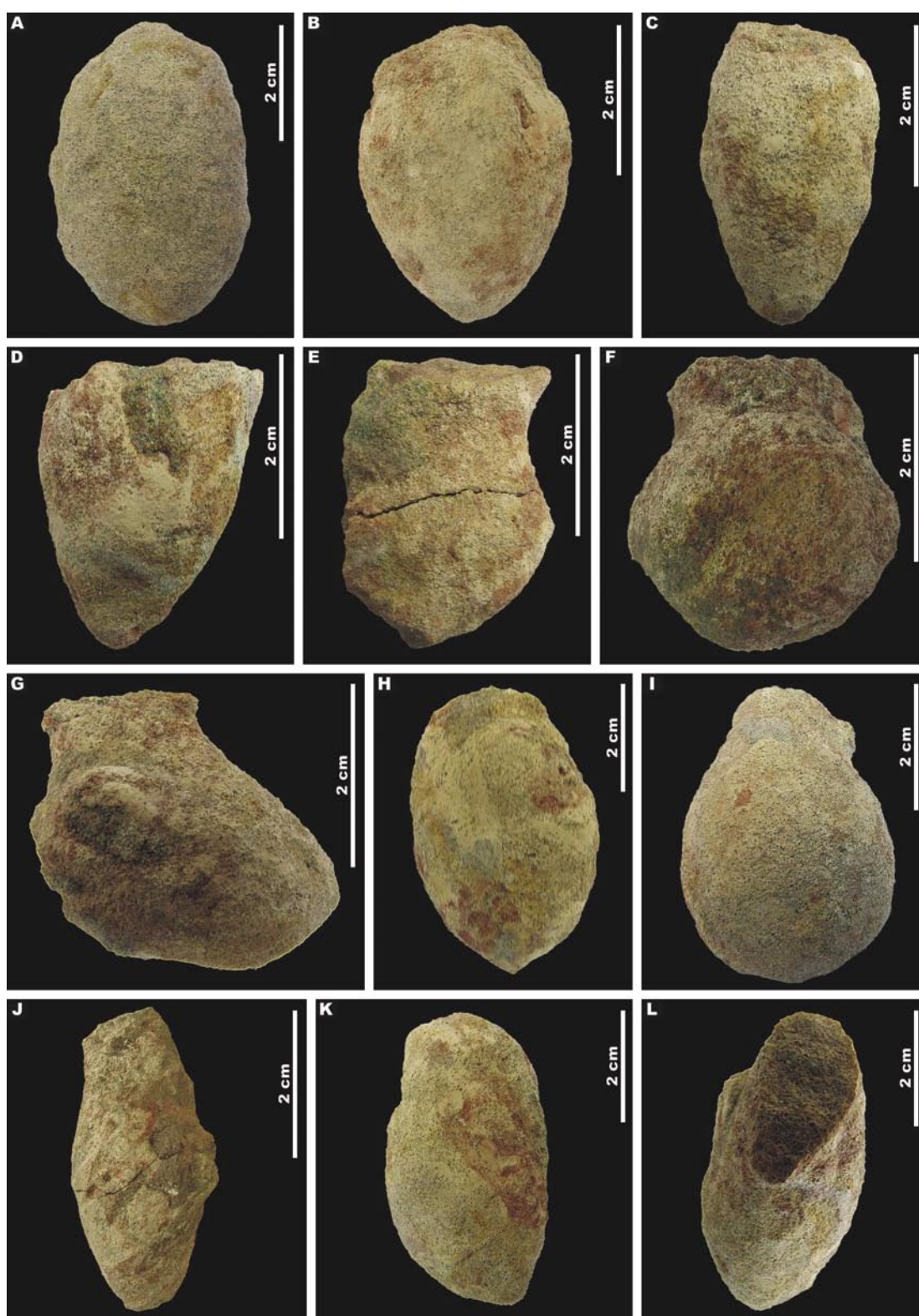


Fig. 17.
Morphotypes of *G. variabilis* from the Nazia Fm. near the Sablinka waterfall:
A, H, K – drop-like burrows;
B, C, D – conical burrows;
F, I – bulbous burrows;
E, J – amphora-like burrows;
G, L – boot-like burrows.

kind of neck and widening upward aperture that is reminiscent of the classical amphora-like borings, *Gastrochaenolites oelandicus*.

Not all of the structures are symmetrical. In some of them the lowermost terminus does not lie on the axis but is shifted to one side of the structure (see Fig. 17 K). In extreme cases it leads to

boot-like shape of the structure (Fig. 17 G, L). This example demonstrates that the animal was able to change direction of burrowing from subvertical to subhorizontal.

The phosphatized burrows are dwelling structures and probably the shape of the burrow depends on how long the animal lived in it. If the producer left the burrow during a process of active burrowing, the shape would be conical with a relatively sharp, angular distal (lower) termination; but if it rested there for a longer time the shape of the burrow changes. The bottom becomes more rounded (Fig. 17 A) and even bulbous-like (Fig. 17 F, I).

When the burrows are abandoned by the producer and filled by sediment, other smaller burrowers may have occupied them. In some cases (Fig. 17 D, J) these later burrows are easily recognizable because they are filled with glauconite grains, more darkly coloured against the background of the light-coloured quartz grains filling the main burrow. The subsequent burrowers probably preferred to use the softer sediments inside the large burrows than to penetrate the firm substrate of the surrounding sediments.

The variable shape and size of the “phosphatized” burrows is a reason for naming them *Gastrochaenolites variabilis*. They exist in a single bed and show a continuous transition between end-member morphological types. The subvertical burrows that were described by Stumbur (1962) and which penetrate “Dictyonema Shale” and Varangu clays in the St. Petersburg region and Estonia belong to the same ichnogenus. It is obvious that they penetrate the same erosional surface at the top of Varangu regional stage. At some places this surface cuts “Dictyonema Shale”, while in the others it cuts Varangu clays or quartz sands of the Nazia Formation. The shape of the burrows slightly differs depending on the substrate. In sands they are thicker, cone-like, vase-like or bulbous-like while in black shale they are much narrower and in clays are something in between. Clearly the burrow morphology depends on the consistency of the substrate. But again it seems to be unwise to name all these substrate-dependant variations as separate ichnogenera.

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 m) with a prominent flat hardground surface covered by a thin glauconite veneer. The surface is pitted by so-called “Amphora-like borings” (*Gastrochaenolites oelandicus*), (Fig. 16 D, E, F). 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 9. Ichnological characteristic of the Dikari Limestone will be presented in detail in the Putilovo Quarry (Stop 6).

STOP 4.

OUTCROP ON THE LEFT BANK

OF THE TOSNA RIVER 300 M DOWNSTREAM

FROM THE TOSNA WATERFALL

■ Leaving the Sablinka waterfall we return to the bus and drive backward to 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 (Fig. 18). 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:



Fig. 18.
Outcrop on the left
bank of the Tosna
River 300m down-
stream from Tosna
waterfall.

MIDDLE CAMBRIAN

Sablino Formation

About 2 m of pink or white medium to fine grained quartz sand with multidirectional cross-stratification.

UPPER CAMBRIAN

Ladoga Formation

Up to 0.20 m of medium to coarse grained quartz sand with a coquina of the organo-phosphatic brachiopods. The lower and upper boundaries of the formation represent regional unconformities and sequence boundaries. In this outcrop we have an opportunity to observe *Skolithos* trace fossils in the Upper Cambrian Ladoga Formation (Fig.19 A, B). Burrows are up to 7 cm long and about 4 mm in diameter. Usually they are filled with fragments of phosphatic brachiopod shells. Morphologically they are similar to the *Skolithos* from the Lower Ordovician Tosna Formation but differ in size.

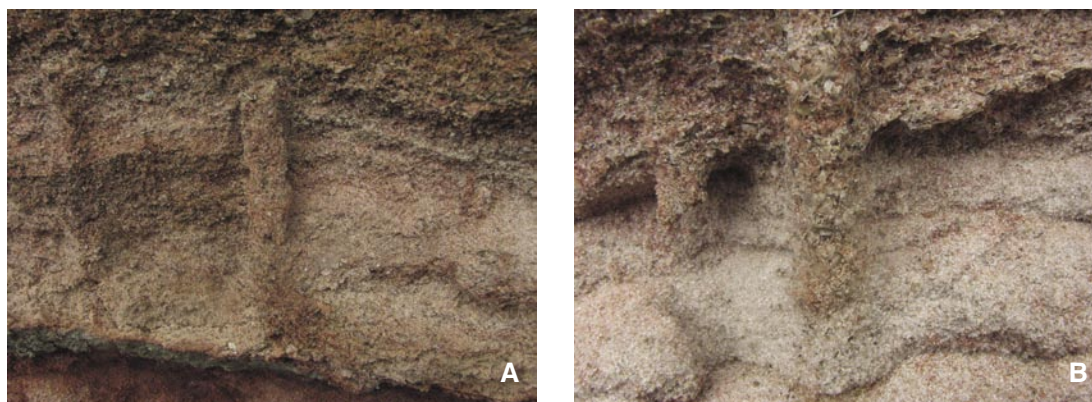


Fig. 19.
Skolithos isp., Upper Cambrian Ladoga Fm. Left bank of the Tosna River 300 m downstream from the waterfall.
A – *Skolithos* burrows;
B – Fragments of phosphatic brachiopod shells inside of *Skolithos* burrow.

LOWER ORDOVICIAN

Tosna Formation

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

MIDDLE ORDOVICIAN

In the main outcrop on the left bank of the Tosna River, the carbonate succession of the Volkhov Formation can be studied in great detail. The thickness of all units (beds and bedsets) in the Tosna and Sablinka River valleys is less than in Putilovo quarry. It diminishes westwards. But all beds are recognizable due to specific ichnofabric and/or characteristic trace fossils. The succession looks as follows:

Volkhov Formation, Dikari Limestone, Red Dikari

In contrast to the section that will be shown in Putilovo quarry, there is no basal layer of clay underlying the Dikari Limestone in the Tosna Canyon. 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 Melkovetsvet 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 Melkovetsvet beds, which 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 colors. The bed contains up to four nondepositional surfaces with a yellow, iron-enriched impregnation. The surfaces are pitted by U-shaped burrows corresponding in morphology to *Arenicolites*. Borings of similar morphology usually assigned to

Pseudopolydorites. But in a case of Krasnenkij bed it is difficult to make a clear distinction between borings and burrows. Glauconite grains are rare or absent. Thickness is 0.12 m.

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 (Fig. 20 A, B) (*Gastrochaenolites oelandicus*) is well developed (Fig. 20 C). The borings, filled with glauconite grains, protrude deep into the underlying Beloglaz Bed (Fig. 20 D, E, F). This surface marks the base of the Middle Ordovician Series and the lower boundary of the Volkhov depositional sequence. It is interpreted as a transgressive surface that coincides with a sequence boundary (Fig. 21).



Fig. 20.

Gastrochaenolites oelandicus borings:
A, B – first published images of “Amphora-like holes” (Kupffer, 1870);
C – hardground surface at the base of the Volkhov Regional Stage (“Steklo” surface) with “Amphora-like borings” (*G. oelandicus*);
D – vertical cross section of *G. oelandicus*;
E – Typical “Amphora-like boring” (*G. oelandicus*) filled from above with glauconite enriched material;
F – “Steklo” hardground surface pitted by *G. oelandicus* borings.

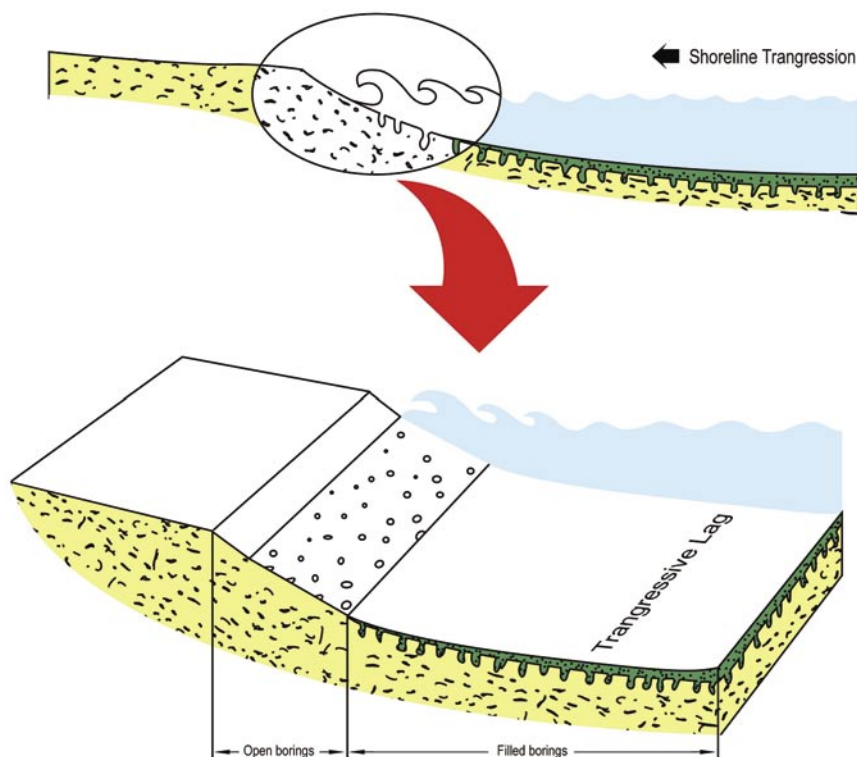


Fig. 21.
Development of the
“Steklo” transgres-
sive surface.

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”). In some sections the lower end of the borings is curving that suggests U-shaped morphology. These structures can be assigned to the ichnogenus *Pseudopolydorites*; this determination is, however, problematized by the fact that “Karandashi” structures from some other layers localities are simple shafts resembling *Trypanites*. A mixture of the “I”-shaped and “U”-shaped burrows/borings is a challenge for ichnotaxonomy (Dronov-Mikulash-Bromley in review).

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 with a hardground bearing *Trypanites* isp. (isp. nov.; Dronov – Mikuláš – Bromley in review) which are better exposed at the Putilovo Quarry (next set of stops). 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 subvertical burrows that remind “Amphora-like borings” but their depth and diameter is usually less. These structures will be better exposed in the Lava River Canyon (Stop 5). 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 (Fig. 22). It creates a magnificent view on this part of the valley. The height of the waterfall is about 2.0 m.

Fig. 22.
View on Tosna
waterfall.



STOP 5.

OLD QUARRY ON THE LEFT BANK OF THE LAVA RIVER AND NATURAL OUTCROPS ON THE OPPOSITE SIDE OF THE VALLEY

■ Leaving Sablino we follow to road to Nikolskoe and Kirovsk along the Tosna River valley till the Neva River and then along the left bank of the Neva till crossroad with a St. Petersburg – Murmansk Highway. About 78 km from St. Petersburg we turn right and climb the Baltic-Ladoga Glint (Fig. 23). In this place it is crossed by the Lava River which forms a deep canyon. In the 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. It is a best place to study an icnofossils from the “Lower Oolite bed” (Sillaoru Formation). The quality of the exposures here is much better than in Putilovo Quarry for this particular stratigraphic interval. 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 (Fig. 24).

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 SI)

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), (Fig.25). The formation consists of two members.

Nikolskoe Member (BIII α 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 similar to “Amphora-like borings” (Gastochaenolites) but slightly different in size and filling material. 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 (BIII β LP) – 0.18 m of clay, calcareous clay and bioclastic limestone intercalations, both containing numerous large (about 2 mm across), well-developed iron ooids. Layers of clay 0.02-0.05 m thick are present at the base, at the top and in the middle of this unit. The

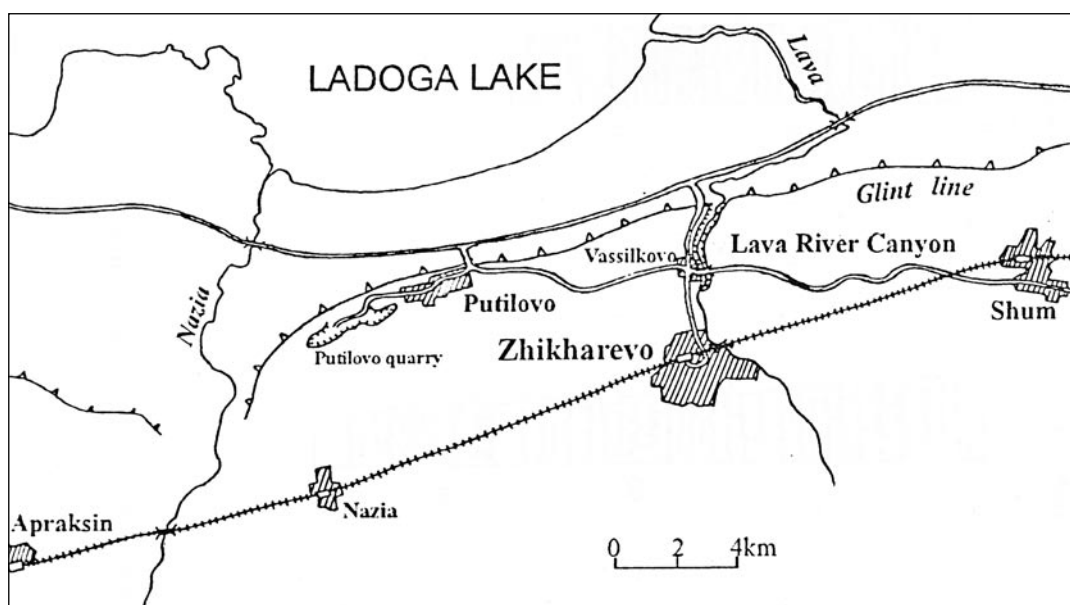


Fig. 23.
Schematic map for
the vicinity of Puti-
lovo village.

trilobites *Asaphus* (*A.*) "*raniceps*" Dalman are relatively common. The whole Sillaoru sequence demonstrates a shallowing upward succession.

Subvertical burrows filled with iron ooids or ferruginized bioclasts (pseudo-ooids) are very common in the clayish limestone of the "Lower Oolite bed" (Sillaoru Formation). The surrounding sediment is represented by bioclastic wackestones, locally containing scattered iron ooids. Carbonate sediment within burrows is enriched with iron ooids, which makes these structures visible and easily recognizable on cut rock surfaces. General morphology and also a size of some burrows (those having preserved the chamber and thinner neck) are comparable to *Gastrochaenolites*, namely *G. oelandicus* and *G. variabilis* (nomen nudum). If we do not consider the probable truncation of the burrows, three basic morphological types can be distinguished: (1) straight vertical burrow resembling *Skolithos*, up to 6 cm deep (Fig. 26 A, E); (2) amphora-like burrow reminiscent to *G. oelandicus* (Fig. 26 B, C, F); and (3) bulbous burrow that fit to the diagnosis of *G. variabilis* (Fig. 26 D). At the outcrop, several colonization horizons can be recognized; high dynamism of sedimentation and erosion is evident. We presume that the uppermost part of the structures has rarely survived; in most cases it is removed by erosion. It is possible that all these structures had a funnel-shaped aperture and a neck before the truncation. But it is also likely that part of the variability comes from biologic/behavioral reasons; some bulbous-like structures can also be observed in the section (Fig. 26 D) but they are not very common. Probably, as in the case with *G. variabilis*, the differences in shape may represent the individual growth pattern of a (probably soft-bodied) tracemaker and varieties in strategies of the utilization of the dwelling space in the substrate. All the morphotypes are connected with each other by transitional forms.

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. 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. The most common trace fossils are *Thalassinoides* burrows.



Fig. 24.
View on the Ordovician rocks exposed in the high cliff on the right bank of the Lava River Canyon beneath the village of Gorodishche.



Fig. 25.
General view on the "Lower Oolite bed" (Sillaoru Fm.).

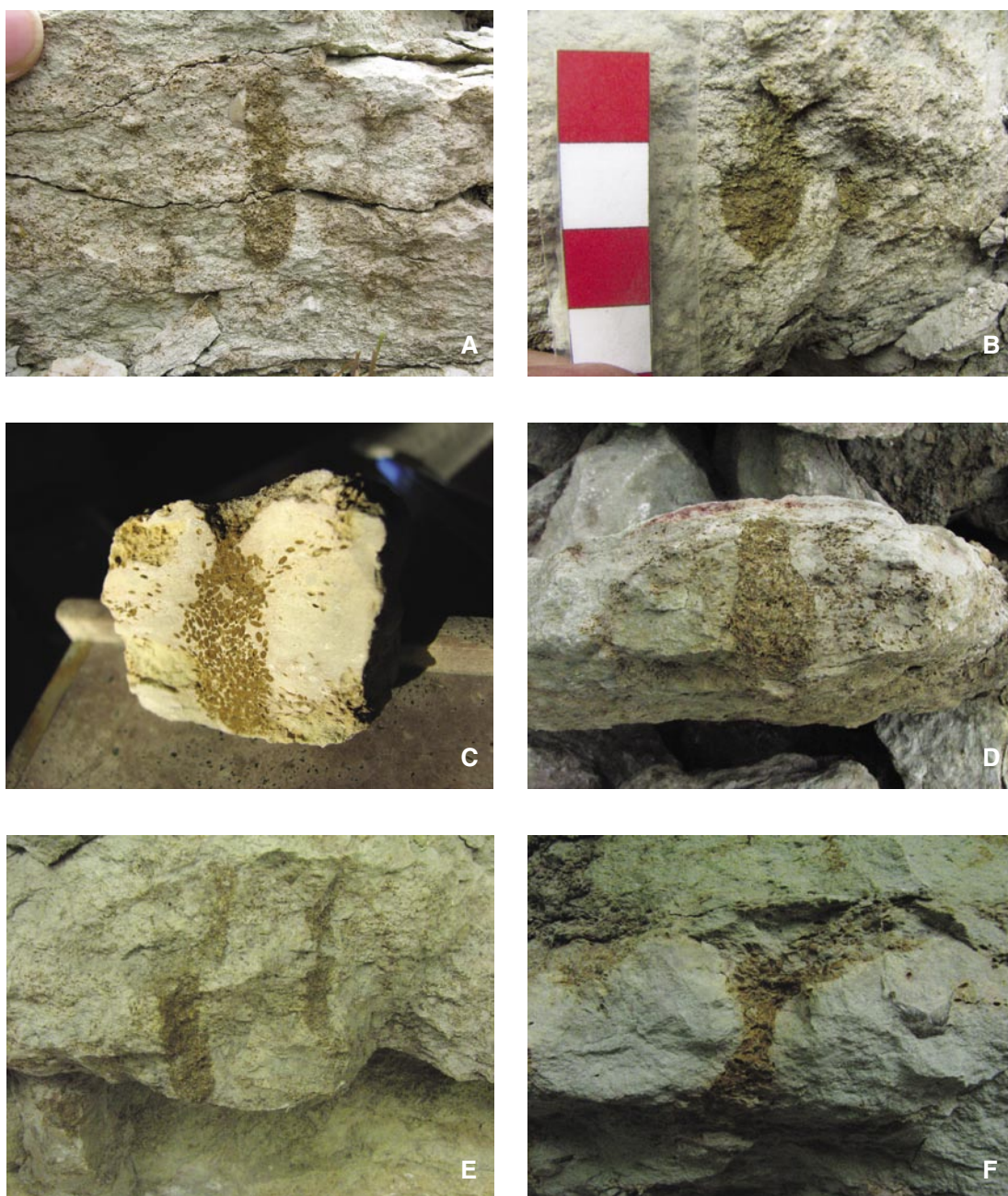


Fig. 26.

Gastrochaenolites? burrows in the “Lower oolite bed”:
A, E – straight vertical burrows resembling *Skolithos*;
B, C, F – amphora-like burrow reminiscent of *G. oelandicus*;
D – bulbous burrow that fit to the diagnosis of *G. variabilis*.

STOP 6.

MINING FIELD OF THE "DIKARI LIMESTONE", 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. Stability of this nomenclature reflects the lateral persistence of these lithologic units. Objectively, this informal terminology reflects some distinctive lithological and ichnological features, such as hardness and homogeneity of the rock, mode of intercalation, distribution of colors as well as intensity of bioturbation and specific list of ichnotaxa typical for each bed. 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. 27). The active mining field in Putilovo Quarry provides a good opportunity to look more precisely at this informal litho- and ichno-stratigraphic subdivision of the Volkhov Formation.

Putilovo Quarry

Putilovo Quarry is situated about 15 km westward from the Lava River Canyon. After 20 minutes drive we enter the village of Putilovo, passing through the village and moving in a westerly direction to enter the Putilovo Quarry (Fig. 23).

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.

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 (Fig. 27).

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.

VOLKHOV STAGE

Volkhov Formation, Dikari Limestone (BIIa)

The lower part of the Dikari Limestone terminated by the "Steklo" surface with *Gastrochaenolites oelandicus* developed on the base of the "Zeliony" Bed was studied in more detail at the Stop

Fig. 27.

Bed-by-bed correlation of the sections of Volkhov Fm. along the Baltic-Ladoga Glint Line.

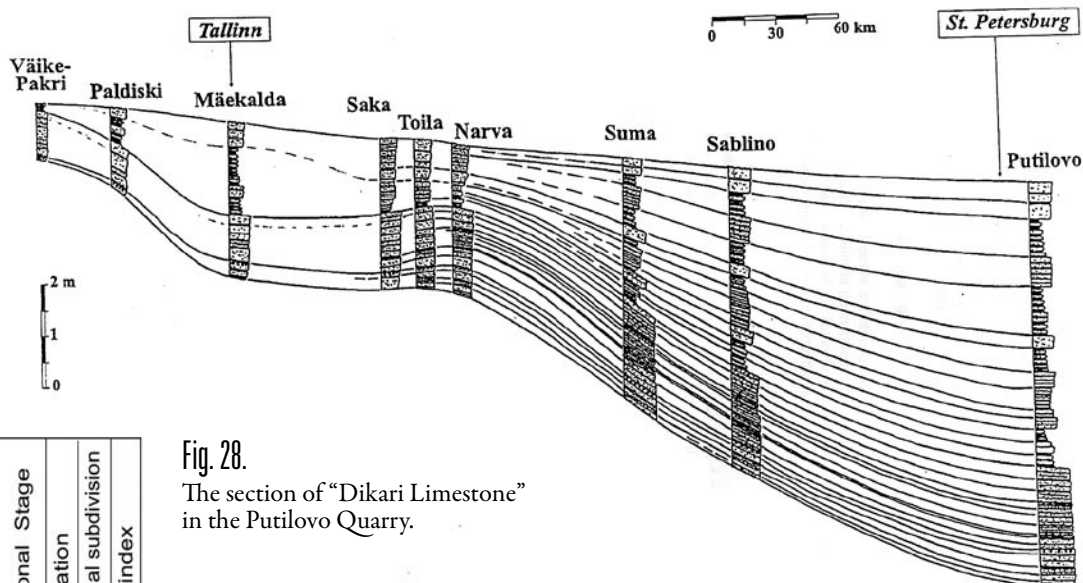
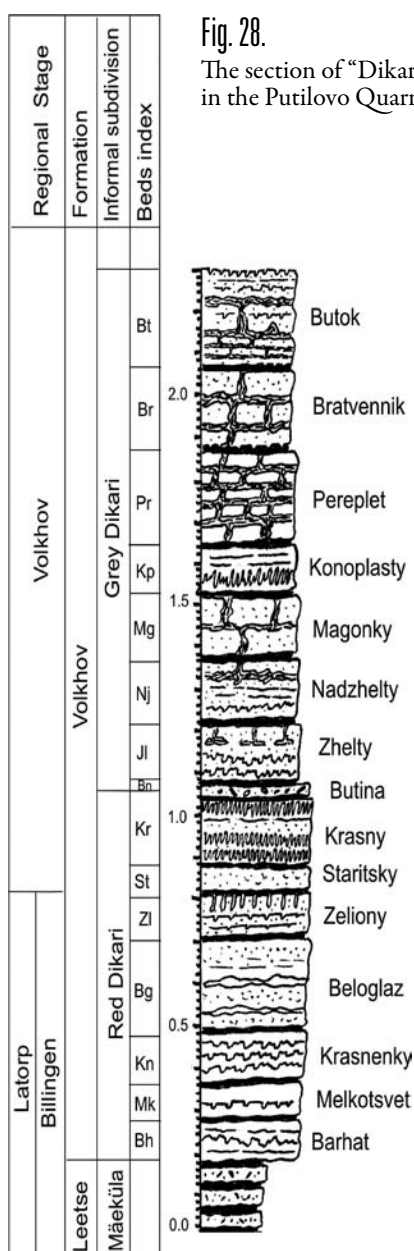


Fig. 28.

The section of "Dikari Limestone" in the Putilovo Quarry.



4. 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. 28). The most remarkable of these is the Butina unit, comprising 0.01–0.05 m of relatively soft red marlstone with thin *Thalassinoides* network typical for Central Baltoscandian Confacies belt. 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. Ichologically, the hardground is marked by (1) shallow vertical borings attributable to *Trypanites* (*Trypanites heckeri* by Dronov, Mikuláš and Bromley in review; *nomen nudum* herein; Fig. 29 A, B), and (2) remnants of the *Thalassinoides* ichnofabric augmented by the weathering/dissolution of the surface prior its hardening. The hardground is interpreted as a transgressive surface and evidence for an abrupt increase of water depth.

The upper part of the Dikari Limestone is very variable from ichnological point of view: each of the individual

beds shows its own ichnofabric. Basic ichnologic patterns were described by Mikuláš, Dronov and Logvinova (2002). The bed-by-bed description of the ichnofabrics exceeds the scope of this guidebook, and some of the beds are better exposed at the Babino Quarry (Stop 9). Ichnotaxonomically, the ichnogenera *Thalassinoides*, *Arenicolites*, *Pseudopolydorites* (Fig. 29), *Trypanites* and *Bergaueria* dominate; *Palaeophycus* (lined) and *Planolites* (unlined) are also common. Especially intriguing is the occurrence of *Bergaueria* cf. *B. perata* Prantl, 1946; in the Putilovo Quarry, it is very frequent in a bedding plane inside the “Butok” unit. The approximately hemispherical pits, some with flat bottoms and/or central knobs on the bases, show a strict, “geometrical” symmetry, which is more typical for borings (e.g., most of the ichnospecies of *Gastrochaenolites* except *G. oelandicus*) than for burrows. Nevertheless, *Bergaueria* is not developed on a hardground (but a partial compaction/initial lithification is probable as the burrow clearly intersects slightly compacted tunnels of *Thalassinoides*). Moreover, few of the specimens of *Bergaueria* are quite deep, resembling in the diameter/ratio the ichnogenera *Conichnus* or *Conostichus*, and several specimens were recognized to have a narrow “neck”. We presume that this neck is a partly collapsed remain of the escape structure, which is a pattern not yet recognized for *Bergaueria*.

The *Trypanites heckeri* (nonem nudum) is an extremely “shallow” trypanites, with a rather high ratio diameter/depth (1.1 to 1:5). It was tentatively placed to *Circolichnus* by Mikuš et al. (2002) but later we suggested its treatment inside the ichnogenus *Trypanites*. The high ratio diameter/depth cannot be explained merely by truncation as the evidence exists that it was in some places negligible (cf. Mikuláš et al. 2002).

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. 30). These units are traceable over a distance of more than 200 km along the Baltic-Ladoga Glint line.

Ichnologically, the Zheltiaki bear rich ichnofabrics with *Thalassinoides* and *Chondrites*. Rarely, also washed-out surface trace fossils were found (*Rusophycus*; Mikuláš et al. 2002).

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 (Fig. 32). 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. 31). 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.

The individual units of Frizy contain, in specific colonization horizons, *Thalassinoides* isp. (various patterns and sizes of networks and boxworks), *Palaeophycus* (lined simple/rarely branched tunnels), *Gastrochaenolites oelandicus* and rarely also *Bergaueria*. Inside the Upper Unit of Intercalation, a “patchy hardground” composed of hardened tunnels of *Thalassinoides* isp. bears *Trypanites heckeri* (see Fig. 29 and 33).

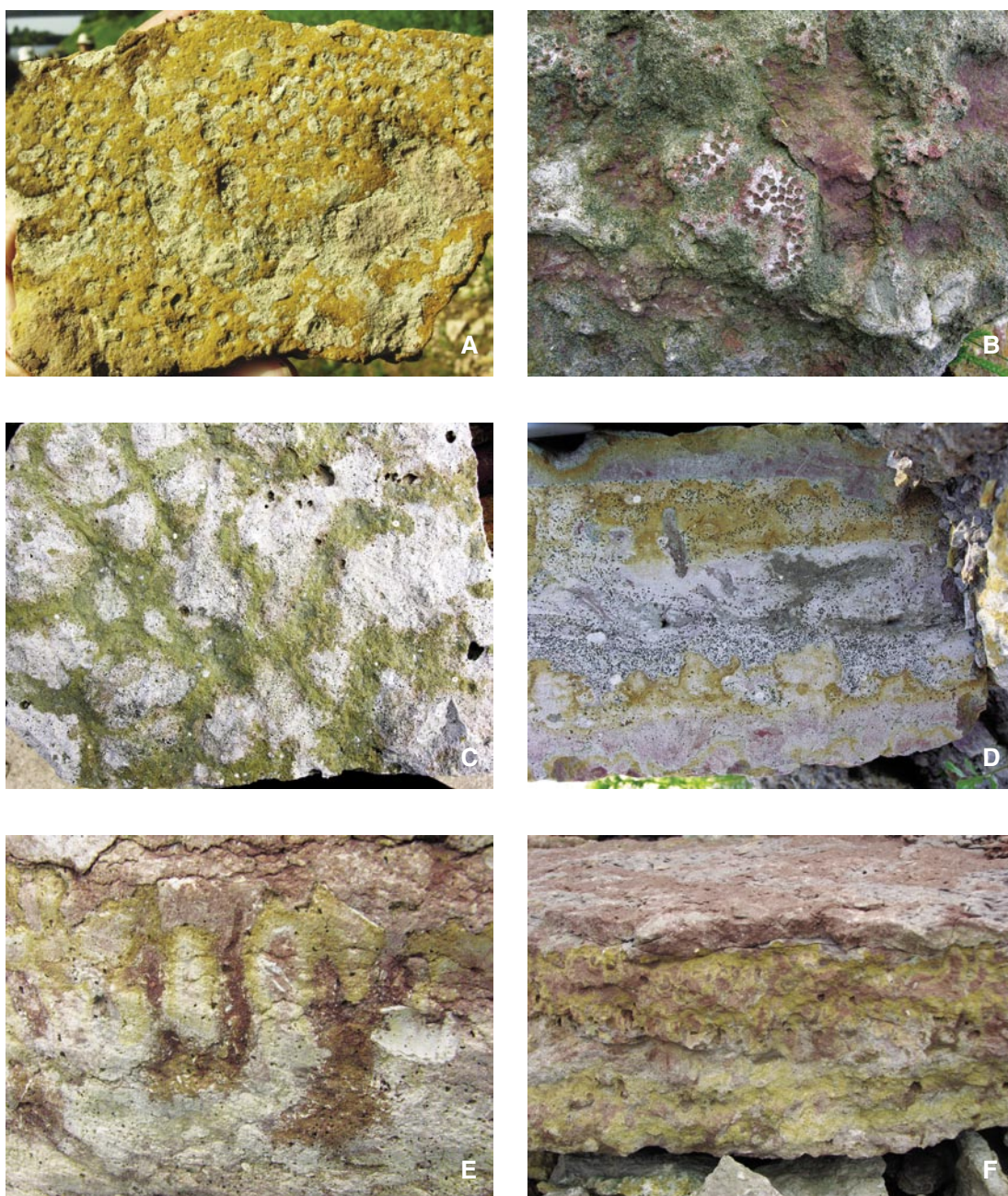


Fig. 29. Trace fossils from Putilovo Quarry:
A – *Trypanites beckeri* from the transgressive hardground surface on top of the Butok bed;
B – *Trypanites beckeri* on the patch hardground inside the Frizy unit;
C – *Thalassinoides* network from the Pereplet bed;
D – *Thalassinoides* from the Beloglaz bed;
E – *Arenicolites* from the Krasnenky bed;
F – Ichnofabric dominated by *Arenicolites* from the Krasny bed.

Fig. 30.
Section of the “Zheltiaki” Limestone in the Putilovo Quarry.

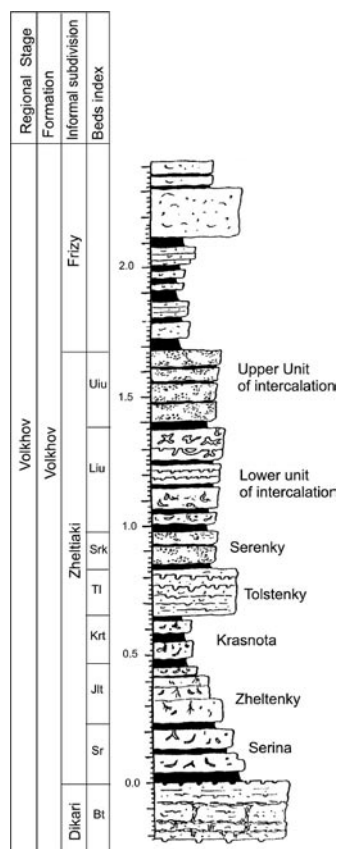


Fig. 31.
Section of the Frizy Limestone in Putilovo Quarry.

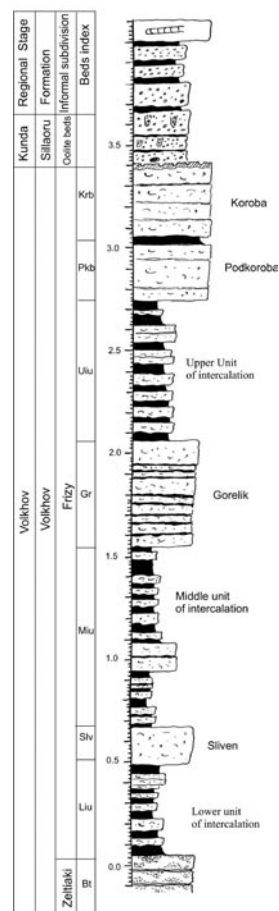


Fig. 32.
View on the upper part of the Zheltiaki and Frizy Units in Putilovo Quarry.





Fig. 33.

Trace fossils from Putilovo Quarry:

- A – *Bergaueria* penetrating *Thalassinoides* (Frizy);
- B – *Bergaueria* penetrating *Phycodes* (Frizy);
- C – *Bergaueria* from the Zheltiaki Limestone;
- D – *Thalassinoides* from the Zheltiaki Limestone;
- E – *Palaeophycus* from the Butok bed (Dikari);
- F – *Thalassinoides* from Frizy Limestone.

STOP 7.

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 syndimentary 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 (Fig. 34). 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. 35). 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. The clay hump is covered by a yellow micritic crust up to 0.5 m thick in the upper part of the mound (Fig. 36). The outer surface of the crust is accentuated by a hardground surface usually pitted by *Tripanites heckeri* (*nomen nudum*; see the comment to the previous stop) 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).

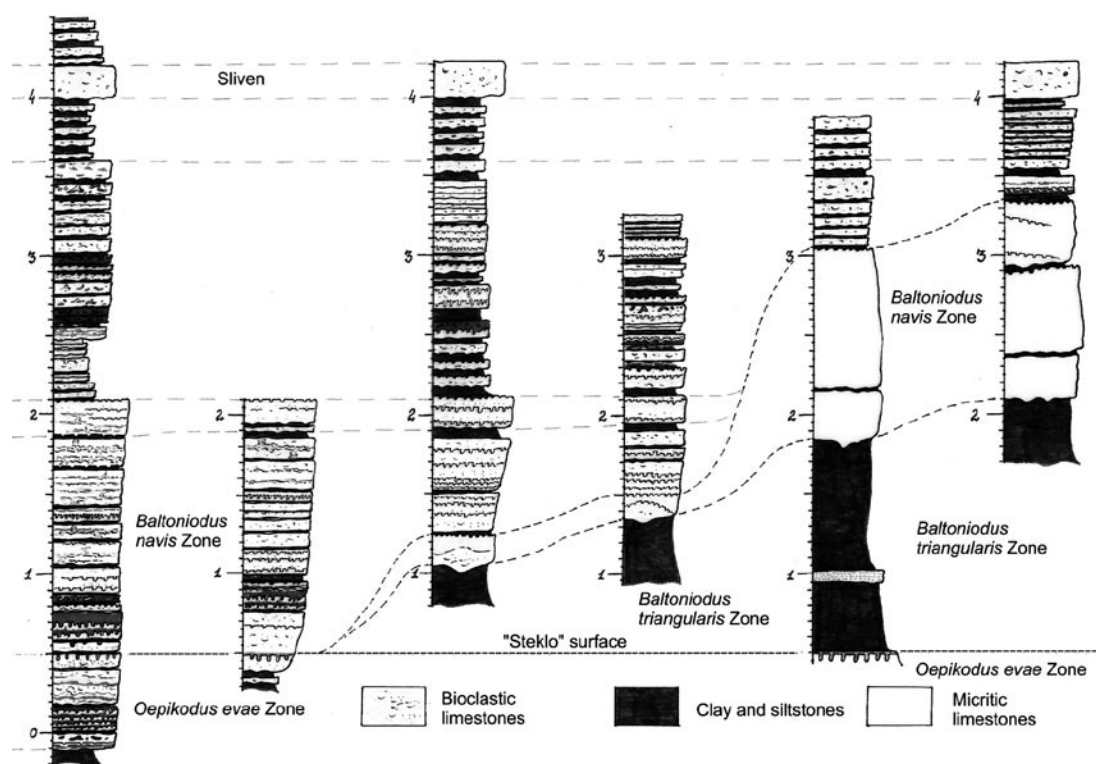


Fig. 34.
Schematic drawing
of the Putilovo mud
mound.



Fig. 35.
Clay core of
the Putilovo
mud mound.



Fig. 36.
General view on
the Putilovo mud
mound.

STOP 8.

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. 37).

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 belongs to the BIII α whereas the other belongs to the BIII β “subhorizons”. Besides vertical borings Planolites trace fossils are very abundant in the “Lower Oolite bed” (Fig. 38)

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. 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 BII β /BII γ boundary. Asaphid trilobites are very common.

Sinjavino Formation (BIII γ 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 (BIII γ 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 0.02–0.04 m 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.

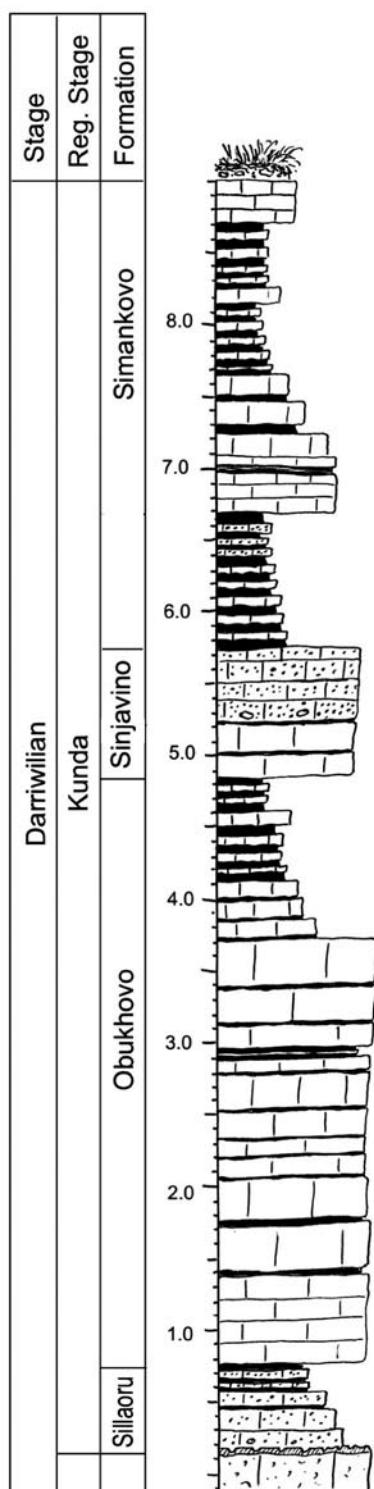


Fig. 37.
The Kunda Stage section in
the Putilovo Quarry.



Fig. 38.
Trace fossils from the
"Lower Oolite bed":
A – *Planolites*;
B – *Planolites*,
Thalassinoides and
Gastrochaenolites?

PALEOZOIC ICHTHOLOGY OF ST. PETERSBURG REGION

*field
excursion*

DAY 2.

Thursday, 25th of June 2010:
Babino, Lynna, Syas

STOP 9. Babino Quarry

STOP 10. Lynna River Canyon

STOP 11. Right bank of the Syas River 1 km upstream
of the village of Kolchanovo

STOP 9.

BABINO QUARRY

Leaving the town of Volkhov in the morning we drive about 7 km to the north along the right bank of the Volkhov River till the village of Babino where a big limestone quarry is operating since the early 60th of XX century (Fig. 39). In this quarry we will have an opportunity to study trace fossils from the Volkhovian (Dapingian) stratigraphic interval and a little bit from the underlying Latorpian and overlying Kundan rocks. The Dikari Limestone is especially well exposed here (Fig. 40) and each of its 15 individual beds can be examined and compared to the beds from Putilovo quarry (Stop 6). The distance between Babino and Putilovo quarries is about 70 km.

From the top to the bottom the succession of the Dikari beds is as follows:

Butok bed. It is the uppermost bed of the Dikari succession. Usually it consists of 5–6 elementary layers reworked by various generations of *Thalassinoides* burrows. The upper boundary is represented by a hardground surface marked by an extensive yellow goetic impregnation and numerous vertical borings of *Trypanites heckeri* (nomen nudum). One of the bedding planes inside the Butok bed contains well preserved *Bergaueria*.

Bratvennik bed. It is a more coarse grained bed that can be subdivided into 3–4 elementary layers. There is a level of extremely intensive *Thalassinoides* reworking in the middle part of the bed. The lower surface of the bed is covered by numerous isometric *Bergaueria* pits (knobs in hyporelief), about 1–2 cm in height and 1.5–2 cm in diameter, filled by glauconitic sediment. Rarely, we can observe the double of vertically connected bergauerians on two different levels, suggesting the escape behavior of the tracemaker.

Pereplet bed. It consists of between four and seven elementary layers, which are difficult to trace laterally because of strong bioturbation. *Thalassinoides* burrowing system increase the distinctness of the bedding planes as the tracemaker obviously used a welcome possibility of easier burrowing. On the other hand, the *Thalassinoides* boxworks frequently pass from one level within the bed to another and similar bioturbation patterns cannot be mechanically correlated. The deepest directly measured *Thalassinoides* is 8 cm in Babino, but in Putilovo, the maximum depth of the boxwork ascertained (in Zheltiaki) was 22 cm.

Konoplasty bed. It is characterized by hardground surface penetrated by numerous closely spaced vertical borings about 1.5–2.5 cm deep filled with sediment rich in glauconite. Most of the borings demonstrate double openings in horizontal plane and some display U-shaped morphology in vertical cross-sections. These structures are known under the informal name of ‘Karandashi’ (pencils). They can be assigned to the ichnogenus *Pseudopolydorites* as the evidence for boring is rather straightforward; provided *Arenicolites* is considered a potentially ‘substrate crossing’ ichnogenus, similarly as *Gastrochaenolites*, also this name can be taken into account (Fig. 41).

Miagonky bed. This bed usually consists of two individual layers of about equal thickness. The bedding surfaces are commonly marked by *Thalassinoides* horizontal burrowing systems.

Nadzhelty bed. This bed may be subdivided into 5 elementary layers each about 2–3 cm thick. *Thalassinoides* burrows dominate. The bed contains several patchy hardground surfaces usually bright yellow in color and pitted by *Trypanites heckeri* and *Pseudopolydorites* boring.

Zhelty bed is similar to Nadzhelty in petrographical and ichnological characteristics; therefore, outside the outcrop, it is usually undistinguishable from the overlying Nadzhelty bed.

Butina bed. This bed is composed of a red, friable, extensively bioturbated marlstone with *Thalassinoides* burrowing system.

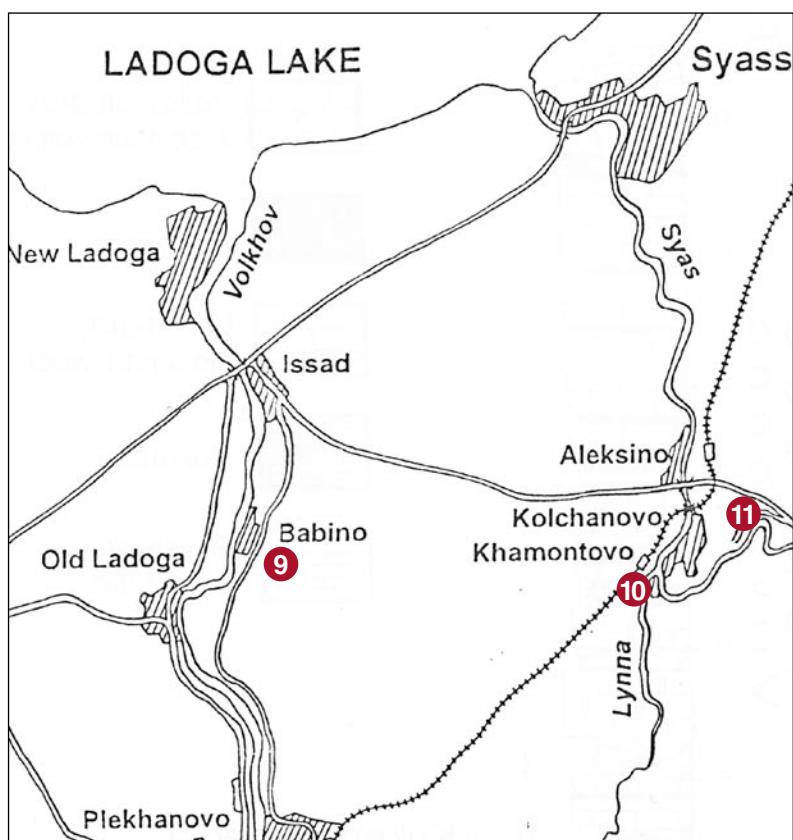


Fig. 39.
Schematic map of the
Volkhov Region.

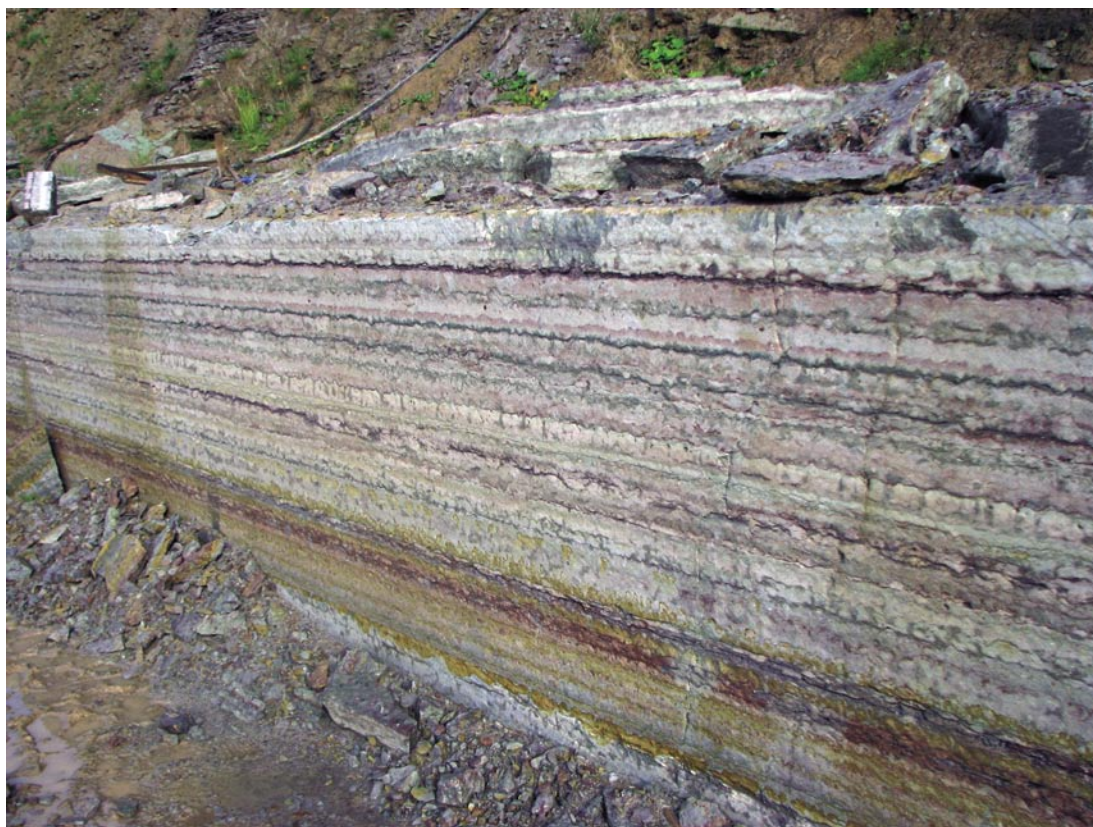


Fig. 40.
View on a Dikari
succession in Babino
Quarry.

Fig. 41.

Borings in the Dikari limestone of the Babino Quarry:

A, B, C – *Pseudopolydorites* (*Arenicolites*?) from the Konopliasty bed;

D – *Pseudopolydorites* (*Arenicolites*?) from the Pereplet bed;

E – *Pseudopolydorites* *ichnofabric* from the Krasny bed;

F – *Trypanites heckeri* from the top of the Butok bed.



Krasny bed. The bed is characterized by red color and contains several hardground surfaces penetrated by numerous narrow, vertically oriented borings of about 3–5 cm in height and with diameter of 2–3 mm. This is the same “Karandashi” borings (*Pseudopolydorites* and/or *Arenicolites*) as in the Konopliasty bed (Fig. 41). At some places, the bed contains flattened pebbles of light brown or yellow micritic limestone, which are penetrated from both sides by *Trypanites heckeri*.

Staritsky bed. This bed can be distinguished mostly by its stratigraphical position between the Krasny and Zeleny beds. *Thalassinoides* burrows and *Pseudopolydorites* borings are typical.

Zeleny bed. This bed is enriched by glauconite which is the reason why this bed is called “zeleny” (green in Russian). Within this bed, several smooth hardground surfaces covered by bright green glauconite veneer and pitted by *Gastrochaenolites oelandicus* can commonly be recognized (Fig. 42).

Beloglaz bed. Light colored to white bioclastic wackestone and packstone with well developed *Thalassinoides* burrow system.

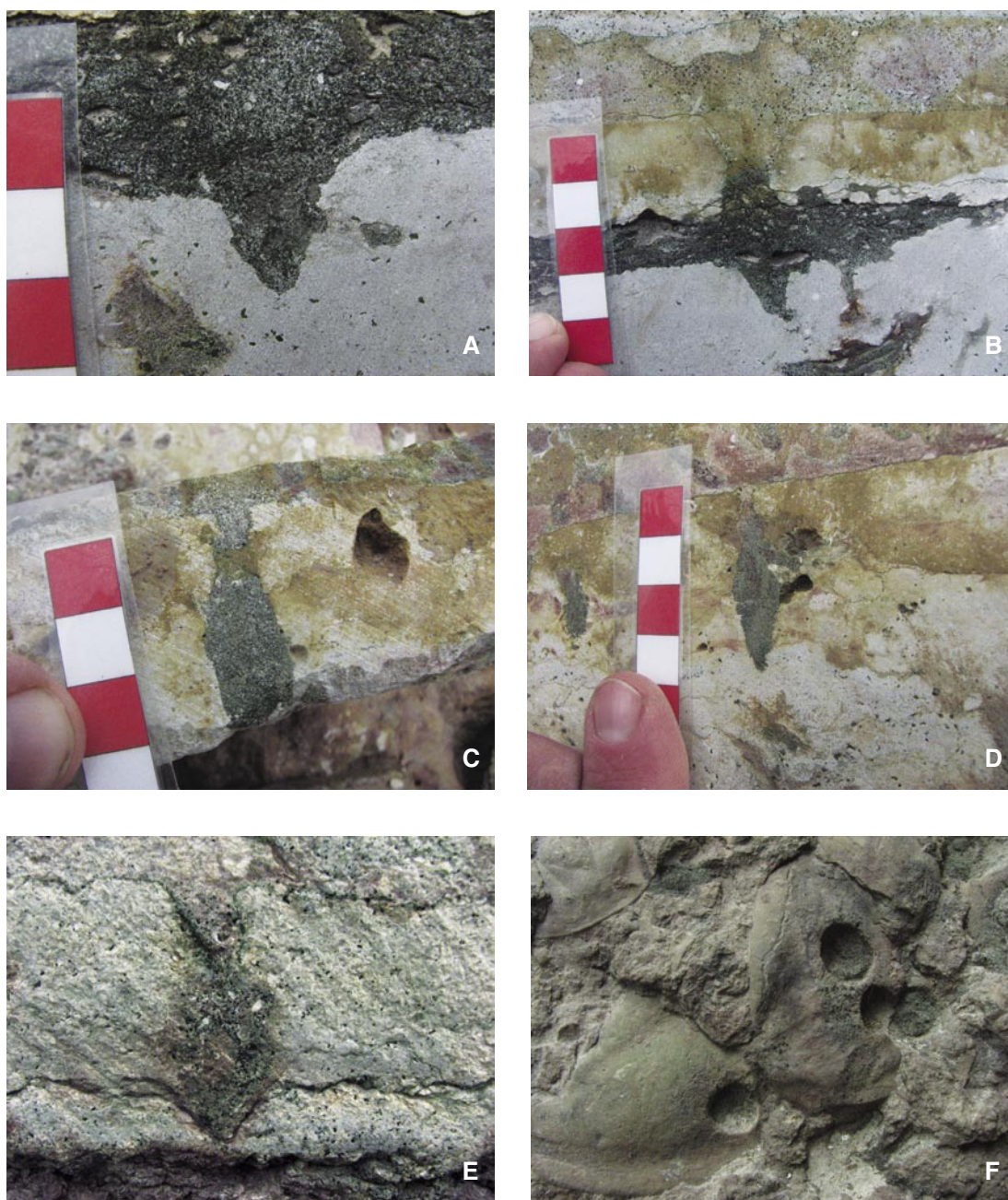


Fig. 42.
Borings in the Dikari limestone of the Babino Quarry:
A, B, C, D – *Gastrochaenolites oelandicus* borings on the Billingen/Volkhov boundary;
E – *G. oelandicus* in the Pereplet bed;
F – *G. oelandicus* penetrating trilobite *Megistaspis estonica* carapaces. Billingen/Volkhov boundary. Kingisepp Quarry.

Krasnenky bed. This bed can be easily recognized by its strong red and yellow colors. It contains up to four non-depositional (early diagenetic?) surfaces with a yellow, iron-enriched impregnation. These surfaces are usually penetrated by *Pseudopolydorites* borings.

The lowermost beds of the Dikari succession (Melkotsvet and Barkhat) are usually undistinguishable in the Babino quarry.

The Dikari beds mined in the quarry are cut nearby in grinding works, which enables us to study fresh and very large cut/polished sections of each of the beds either in the works directly, or on the waste dumps. As stated above, not all of the beds can be recognized in certainty outside the outcrop, but most of them can be. Thus, the cut/polished sections, often tens of square decimeters in areal extent, give very informative views of ichnofabrics and ichnofossils of the Dikari beds.

STOP 10.

MOUTH OF THE LYNNA RIVER

Leaving Babino quarry we drive north till the St. Petersburg – Tikhvin highway and follow it in southeast direction. After 30 minutes drive we reach Syas River valley and drive upstream along its left bank till the Lynna River. We stop on the west side of the Lynna River about 500 m from its mouth. The river valley here forms a canyon up to 15 m deep. On the left bank of the river the Volkhov and Kunda stages are exposed continuously for several hundred meters. The Volkhov Formation is represented by the uppermost part of the Zheltiaky Beds (BII β) and Frizy Beds (BII γ) with total thickness of 3, 45 m. Kunda stage is represented by the Lynna Formation (BIII α), Sillaoru Formation (BIII β) and Obukhovo Formation (BIII β + γ). The following section was described from the cliff on the left bank of the Lynna river about 300–400 m upstream from the mouth (Fig. 43).

VOLKHOV STAGE

Volkhov Formation (BII VL)

Only the middle and upper subdivisions of the Volkhov Formation (Zheltiaki and Frizy Members respectively) can be seen in the outcrop.

The *Zheltjaki Member (BII β)* is represented by its uppermost unit (BII β Pp2) which is easy to recognize in the shallow water of the river due to the yellow colour of the limestones and presence of hardground surfaces. Visible thickness is about 0.3 m. Ichnofabric is not easily accessible to study, but the most characteristic trace fossils of the unit, i.e. *Thalassinoides* and *Chondrites*, were recognized here.

The *Frizy Member (BII γ)* is represented by rhythmically alternating limestone beds and clay intercalations. The layers of bioclastic limestone (usually wackestone or packstone) as well as clay layers contain numerous scattered glauconite grains. As everywhere in the eastern part of the region, the Frizy Member consists here of seven informal lithostratigraphical units (from the base to the top):

Lower unit of intercalation (BII γ Pp1) - Five layers of light grey or greenish grey bioclastic wackestone intercalated with layers of bluish grey clays (0.40 m).

Sliven (BII γ Sl) - Relatively thick (0.25 m) bed of light grey hard bioclastic limestone which consists of several layers amalgamated together almost without clay intercalations. The bed contains numerous *Bergaueria*.

Middle unit of intercalation (BII γ Pp2) – The same limestone and clay intercalation as in the Lower unit of intercalation.

Gorelik (BII γ Gr) – Seven beds of bioclastic limestone rich in glauconite grains separated by thin layers of clay. The unit differs from the underlying and overlying units by the reduced thickness of clay layers. The total thickness is about 0.50–0.52 m.

Upper unit of intercalation (BII γ Pp3) – The same intercalation of limestones and clays as in the previous cases. A distinctive hardground non-deposition surface with *Trypanites heckeri* (n.n.) borings and an accumulation of glauconite grains are present in the base of the unit. Total thickness is about 1.50–1.52 m.

Podkoroba (BII γ Pb) – Relatively massive bed of hard light grey bioclastic limestone with rare glauconite grains.

Koroba (BII γ Kb) – Massive light grey bioclastic limestone with hardground discontinuity surfaces covered by glauconite skins about 0.15 m and 0.25 m up from the base and also at the top of the unit (0.40m).



Fig. 43.
View on the outcrop
on the Lynna River.

In Frizy member in this outcrop *Palaeophycus*, *Thalassinoides* and *Bergaueria* burrows as well as *Trypanites beckeri* borings could be observed. *Bergaueria* (Fig. 44 C, D, E) often penetrates passively filled tunnels of *Thalassinoides*, or it occurs on preserved basal parts of the washed-out tunnels of *Thalassinoides*.

KUNDA STAGE

Lynna Formation (BIII α LN)

The Lynna Formation is represented by flysch-like limestone and clay intercalations but unlike the underlying Frizy unit it does not contain glauconite grains. Among the different types of limestones, mudstones and wackestones dominate. The Lynna Formation represents a complete cycle of sedimentation which begins with a drowning event and shallows upwards. The trilobite *Asaphus* (*Asaphus*) *expansus* makes its first occurrence about 0.1 m above the base of the unit. The upper part of the formation consists of four beds of bluish grey argillaceous limestone, varying in structure from mudstone to wackestone. Hardground non-deposition surfaces with *Trypanites beckeri* (n.n.) occur about 0.05 m and 0.15 m above the base and at the top of this unit. Total thickness of the formation is about 2.8 m.

Sillaoru Formation, Lopukhinka Member? (BIII β SI)

The Sillaoru Formation which represents the “Lower Oolite Bed” is difficult to identify precisely in this locality because of the almost complete absence of iron ooids in the rocks. It seems reasonable to infer, however, that a thick (0.10 m) clay bed, red in the lower part and grey in the upper part, with a lens-like layer of limestone in the middle, represents the lowermost part of this formation. Lenses of strongly argillaceous limestone with small iron ooids fill the cavities on the top of the underlying unit. The light grey, argillaceous limestone with rare, fine glauconite grains near the base seems to represent the upper part of the formation (0.40m).



Fig. 44.

Trace fossils from The Lynna River:

A – *Arachnostega* under the cephalopod shell, Obukhovo Formation;

B – *Arachnostega* under the trilobite shield, Obukhovo Formation;

C, D, E – *Bergaueria* from the Frizy Limestone of Volkhov Formation;

F – *Chondrites* from Lynna Formation.

Obukhovo Formation (BIII β + γ Ob)

At this outcrop, only the lower part of the Obukhovo Formation, from the top of the equivalent of the “Lower Oolite Bed” to the so-called “White bed” as defined by Lamansky (1905), is exposed. The formation is represented by a rather monotonous succession of limestone and clay intercalations and is about 2.70 m thick. The colour of both types of rock are grey or bluish grey without glauconite grains. For the purpose of correlation in the Volkhov region, it is practical to place the base of the Obukhovo Formation to the base of a prominent, thick (0.12 m) clay bed varying from grey to red in colour, having a thin intercalation of nodular limestone in the middle part. At the very top of the section, the so-called “White bed” of Lamansky (1905) can be seen. It is represented by hard light grey bioclastic limestone of about 0.25 m thick; during its weathering, characteristic caverns originate. The bed can be easily identified in the Volkhov River valley as well as in the Lava River Canyon. According to Lamansky (1905), the base of the “White bed” coincides with the base of the BIII γ “substage”. Kundan rocks contain numerous cephalopod shells; for this reason, they were informally called “*Orthoceras* Limestone”. On some of the shells, well preserved specimens of the trace fossil *Arachnostega* were found (Fig. 44 A). *Arachnostega* burrows can be also developed under trilobite carapaces (Fig. 44 B). For the Kundan deposits, the trace fossil *Chondrites* (“large” forms with diameter of tunnels of few millimeters) is also typical in this locality (Fig. 44 F).

STOP 11.

RIGHT BANK OF THE SYAS RIVER

1 KM UPSTREAM OF THE VILLAGE OF KOLCHANOVO

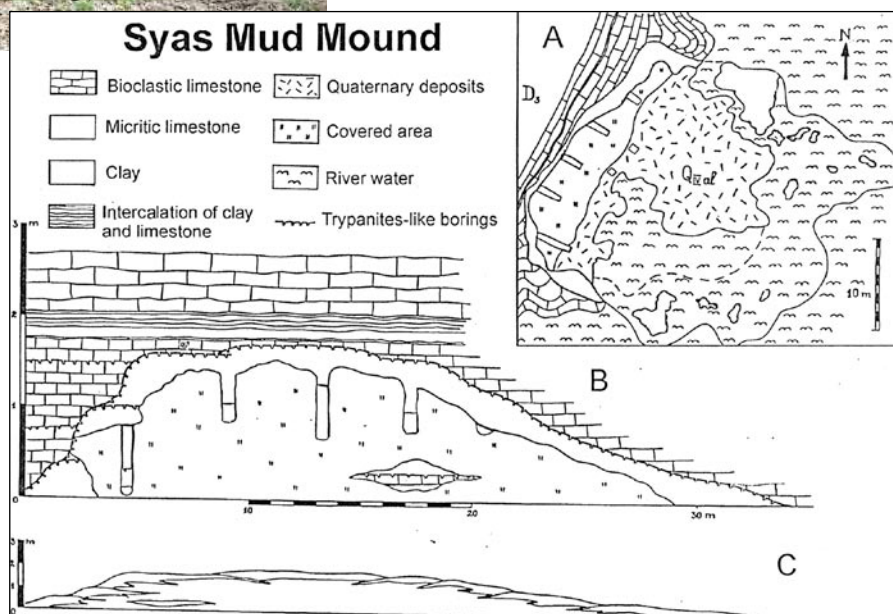
Leaving Lynna River we drive back to the bridge across the Syas River and follow St. Petersburg – Tikhvin highway towards Tikhvin for about 5 km. Then we turn to the right and stop on the right bank of the Syas River 1 km upstream of the village of Kolchanovo. In this locality we have an opportunity to see again the Upper part of the Volkhov Formation (Frizy member) which contains here an organic buildup, the so called “Syas hump”. From ichnological point of view this locality is interesting for its *Thalassinoides*, *Palaeophycus*, *Bergaueria*, *Trypanites heckeri* and some Devonian trace fossils including borings *Palaeosabella*.

The Syas mud mound or «Syas hump» was first discovered and described by S. Vishniakov and R. Hecker (1937) who interpreted it as a syndedimentary fold of tectonic origin. Later R. Manuil (1966) made an assumption that the «Syas hump» might be interpreted as an organic buildup of uncertain origin. New information about the inner structure of the hump has been collected by Dronov & Ivantsov 1994 and Dronov & Fedorov 1994 (Fig. 45).



Fig. 45.

View on the Syas hump.



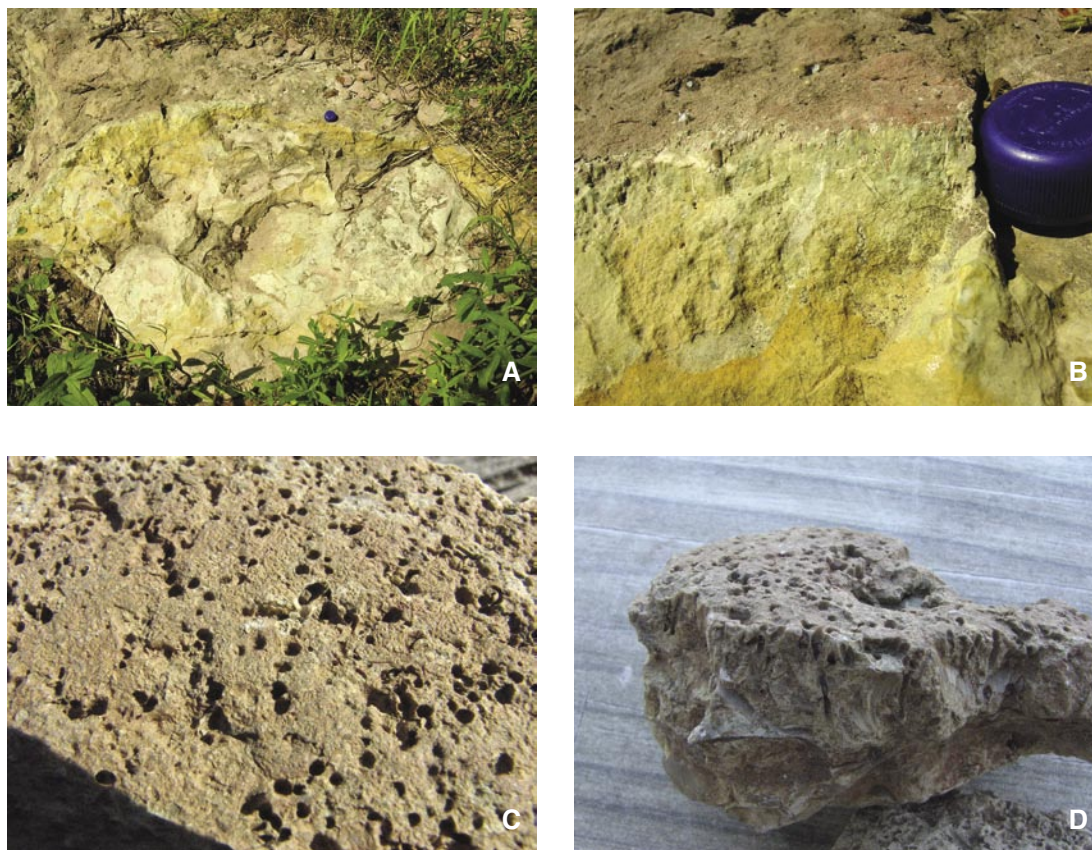


Fig. 46.
Ordovician and
Devonian borings:
A – micritic crust of
the Syas hump;
B – *Trypanites*
heckeri borings on the
surface of the Syas
hump;
C – Devonian
hardground pitted by
Palaeosabella borings;
D – Vertical section
with *Palaeosabella*
borings.

The «Syas hump» along with other similar structures in the Lower Ordovician of the St Petersburg region represent a new, very specific type of organic buildup of mud mound type, that were named «Hecker-type mud mounds» commemorating the name of one of their first investigators (Dronov & Fedorov 1994). The most intriguing feature of these mud mounds is the presence of a thinly laminated non-carbonate clay core in the middle of the buildups.

In the Syas mud mound one can easily recognize the clay core and the micritic crust facies. The clay core facies which forms the inner part of the “reef” is represented by grey or yellow clays intercalated with layers of bioclastic wackestone. Brachiopods, ostracods, bryozoans, echinoderms, trilobites and even graptolites are quite common in these facies. The clay hump is covered by a carbonate crust which is represented by 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 that can be interpreted as the sponge spicules can be found in these crust facies. The outer surface of the crust is densely pitted by *Trypanites heckeri* (n.n.) borings.

In this locality, we can observe an unconformity between the Ordovician and Devonian Systems. Devonian rocks contain numerous trace fossils including borings *Palaeosabella* (Hecker, 1983) which is interesting to compare with *Trypanites heckeri* (Fig. 46).

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