The Ordovician Billingen/Volkhov boundary interval (Arenig) at Lava River, northwestern Russia

Article *in* Norsk Geologisk Tidsskrift · January 2001

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Tolmacheva, T. & Fedorov, P. The Ordovician Billingen/Volkhov boundary interval (Arenig) at Lava River, northwestern Russia. *Norsk Geologisk Tidsskrift*, Vol. 81, pp. 161–168. Trondheim 2001. ISSN 0029-196X.

A detailed study of the conodont distribution within the condensed carbonate beds around the boundary of Billingen and Volkhov Stages (Lower Ordovician, Arenig) in northwestern Russia confirms the presence of a continuous succession of conodont biozones recognized in contemporaneous sequences in Scandinavia. The *Baltoniodus triangularis* and *Microzarkodina* sp. A zones are reported for the first time from East Baltica, where carbonates of this interval underwent extensive bioturbation and are characterized by a number of closely spaced and distinctive glauconitic hardground surfaces. It has been revealed that the distribution of conodont elements around the hardground surfaces is strongly affected by bioturbation.

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Introduction

In Baltica the boundary between the Billingen and Volkhov Stages (lower Arenig) coincides with the base of *Megistaspis polyphemus* trilobite Biozone (=*Megistaspis lata* Biozone of Männil & Meidla 1994). In practice, however, it is usually located at a distinctive relatively smooth hardground surface with characteristic borings and burrows. In Russia this level has been referred to the «Steklo» (glass) surface since Lamansky (1905), while in Estonia it has been described as the hardground surface with «amphora-like» borings (Orviku 1960). This hardground can be traced over a distance of almost 500 km along the Baltic-Ladoga Glint from the Syas River in the east to the Pakri Island in the west, and it represents a first order regional lithostratigraphic marker.

In some sections in the vicinity of St. Petersburg (e.g., at Izhora and Nazya rivers) a thin layer of quartzose sand further accentuates the «Steklo» surface. Fedorov & Dronov (1998) have recorded a flat pebble limestone conglomerate in one eastern locality, suggesting submarine erosion. However, at most localities in the eastern part of the glint it is accompanied by several closely spaced hardground surfaces covered by glauconitic veneers and containing numerous vertical borings. It is commonly difficult to determine which of these hardground surfaces represents the "real" «Steklo» surface (Dronov et al. 1996) since the trilobite and conodont zonation has not been determined across the Billingen-Volkhov boundary interval in most sections in Estonia and western Russia. The main object of this paper is to give the first detailed study of the conodont distribution and lithostratigraphy of this important interval.

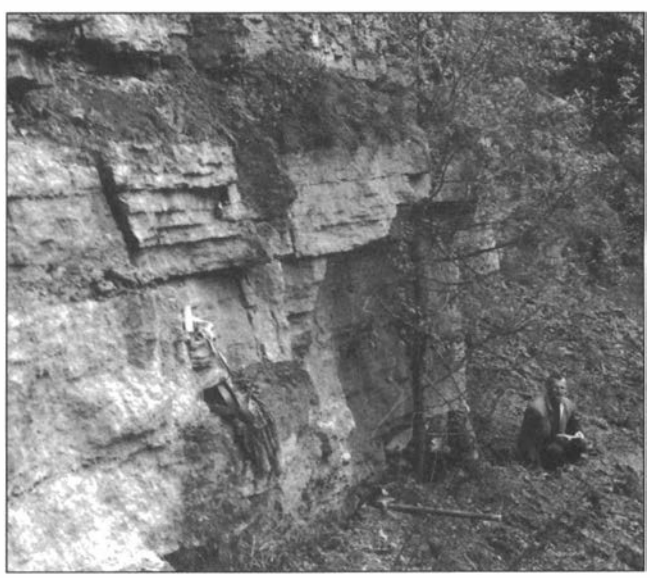


Fig. 1. Photo of the sampled section exposed on the left-hand side of the Lava River canyon, downstream of the Vasilkovo village (locality 6817 of Popov et al., 1989).

Geological setting, localities and methods

The lithostratigraphy of the Arenig deposits east of St. Petersburg was discussed recently by Dronov & Fedorov (1995) and Dronov et al. (1996). These authors noted that uppermost Billingen and lowermost Volkhov deposits in this region are represented by well-bedded bioclastic, glauconitic limestone that is informally called the "Dikari" (savages) Limestone. According to Dronov et al. (1996) this interval can be subdivided into 15 lithological units separated by hardground surfaces or thin clay beds. Each unit has a name given by local quarrymen, and most of the units can be traced over a distance of 200 km along the Baltic-Ladoga glint in Russia. The lowermost four and a half units approximately correspond to the Päite Member of the uppermost Billingen in Estonia, whereas the remaining 10 units correlate to the Saka Member of the lower Volkhov. The distinctive «Steklo» hardground surface is within the fifth unit, so-called Zelenyi (green) unit. Recent sedimentological studies (Dronov 1998) indicated that the bioclastic limestones of the "Dikari" beds

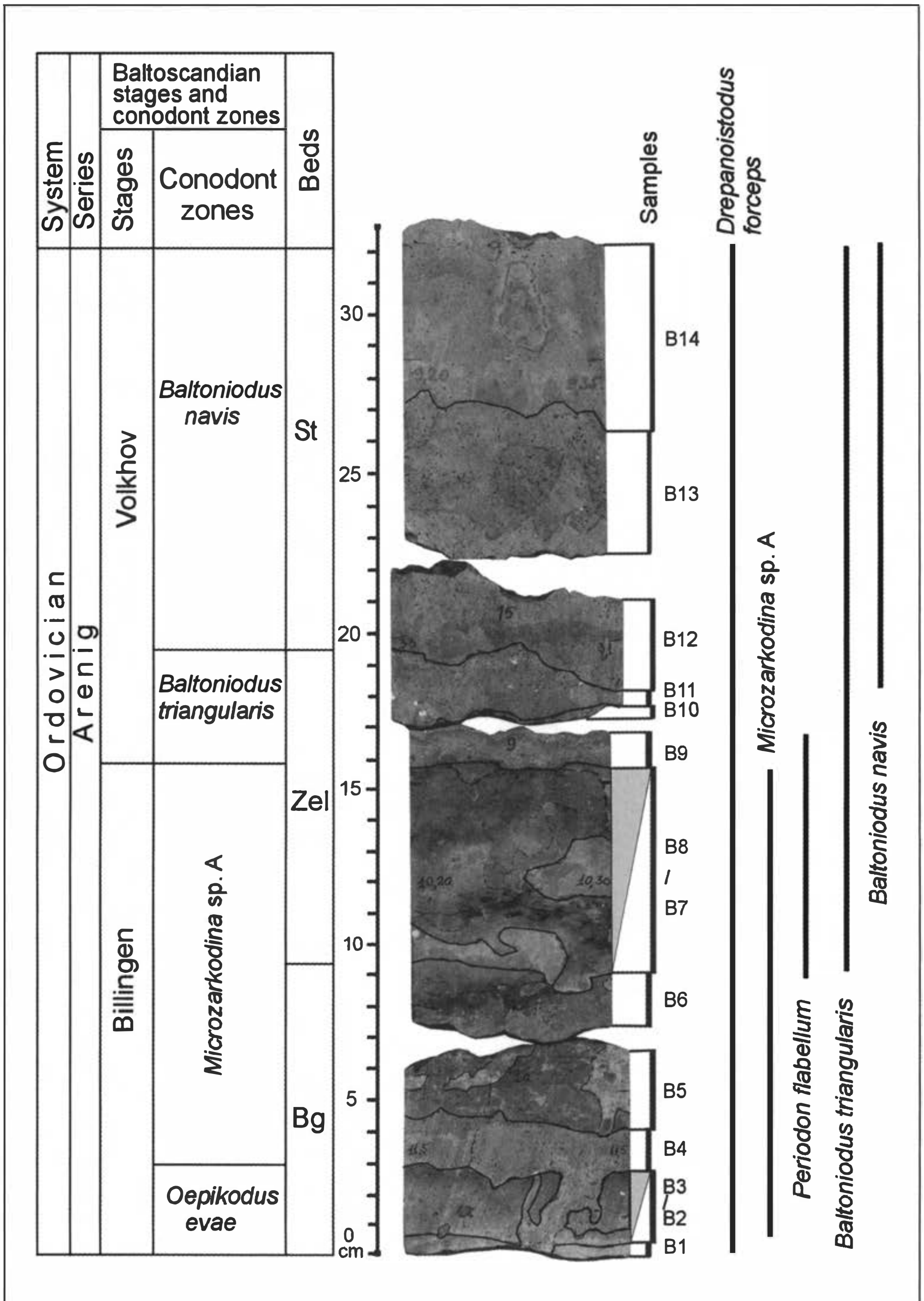


Fig. 2. Stratigraphic column composed by the photographed polished surfaces of the sampled successive levels from the boundary interval, showing biostratigraphic subdivision and distribution of selected conodonts. The darker grey in the column emphasizes the parts of the succession that is rich in glauconitic grains.

are mainly proximal tempestites, deposited somewhat below the seasonal storm wave base during unusually strong storms. The tempestites are separated by hard ground surfaces and sometimes covered by thin beds of silty clay, which probably represent the background deposits.

The present study is based on a suite of bed-by-bed samples from a succession approximately 33 cm thick through the Billingen-Volkhov boundary interval, which is exposed in a natural outcrop on the left-hand side of the Lava River canyon. (Figs. 1, 2, 5). This locality was mentioned and illustrated for the first time by Raymond (1916), and it represents a continuous exposure from the Upper Cambrian Ladoga Formation to the Middle Ordovician Obukhovo Formation (Kunda Stage). This outcrop has already been discussed in many papers (Mägi et al. 1989, Popov et al. 1989, Dronov et al. 1995, and Pushkin & Popov 1999), and furthermore proposed as a potential stratotype section of the Volkhov Formation (Fedorov, 2000).

Four large blocks of limestone from the boundary interval were cut into 0.7 cm thick slabs across the bedding surface (Fig. 2). The matrix between hardground surfaces was carefully separated from the rock infilling of vertical borings and sub-horizontal systems of burrows. In total, fourteen limestone samples from these slabs were dissolved in buffered 10 % acetic acid and the abundance of conodont elements in each sample was counted from the standard unit of residue (Table 1). One block (Zelenyi unit) was cut into 23 slabs, all surfaces of which were used for a three-dimensional reconstruction of the major sedimentological features including the shape of hardground surfaces and trace fossils (Fig. 3).

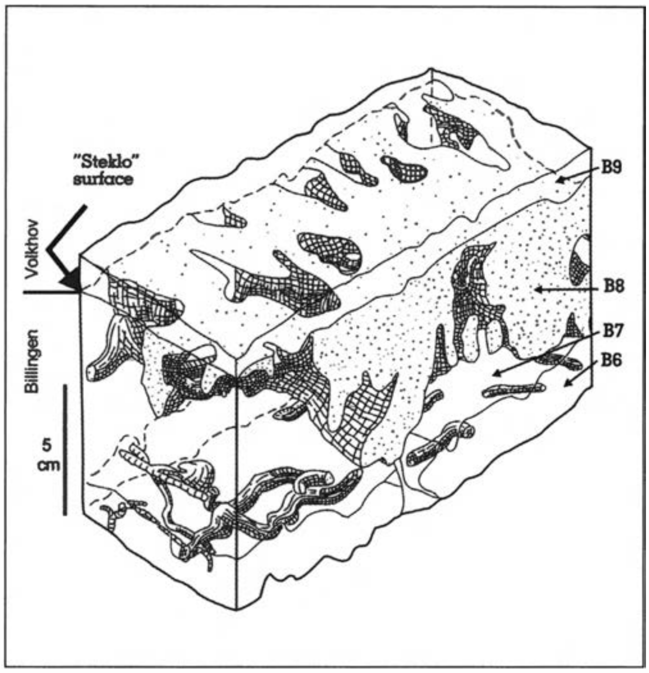


Fig. 3. Block diagram showing structures of bioturbation in the uppermost Billingen - basal Volkhov. «Steklo» surface indicated. Samples as in Fig. 2.

Litho- and biostratigraphy of the Billingen-Volkhov boundary interval at Lava river

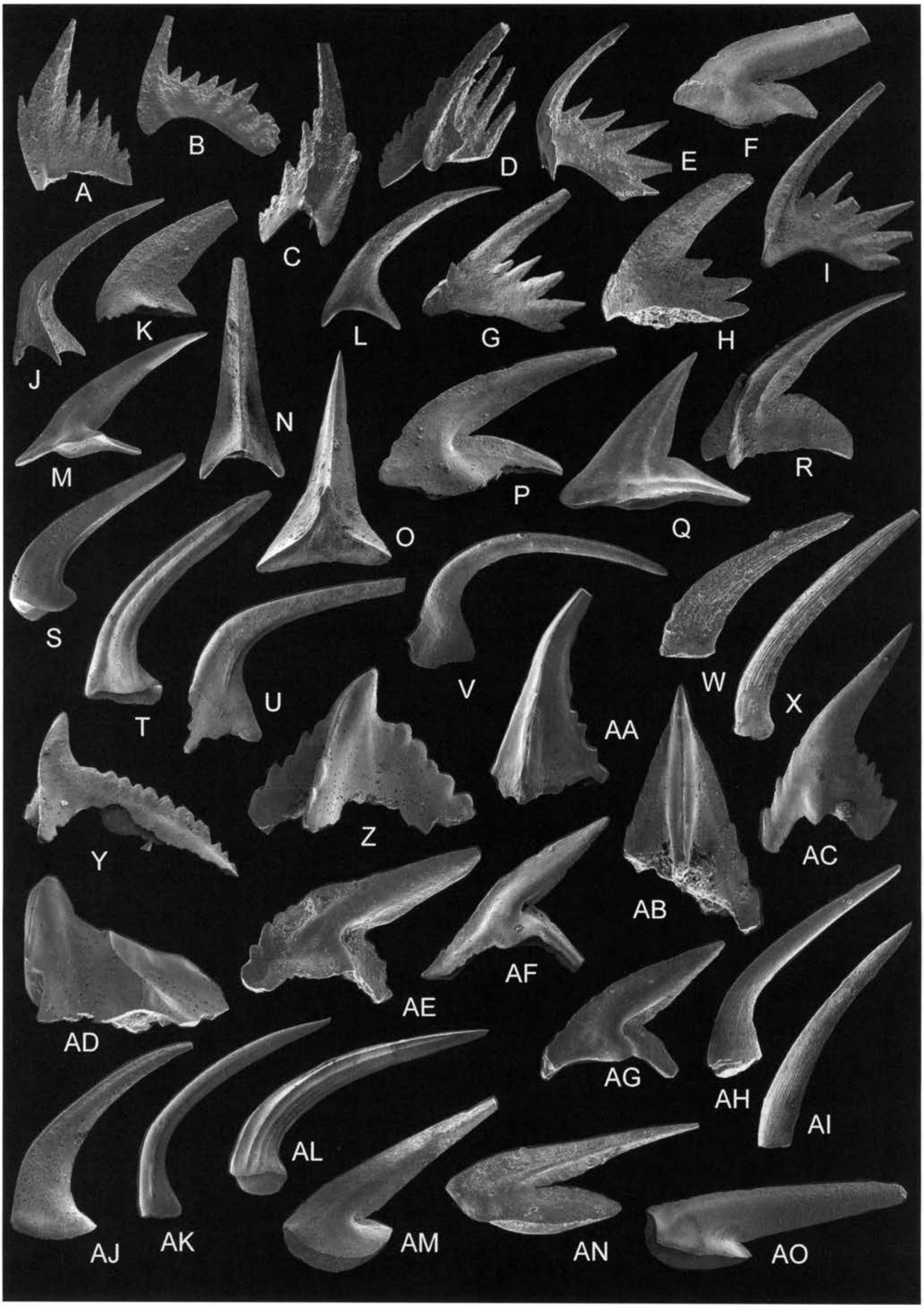
The studied samples cover three of the units recognized by Dronov at al. (1996) in the «Dikari» Limestone (Fig. 2). The taxonomic composition of conodont assemblages from these units is listed in Table 1. The following sequence was recognized from the base upward:

Lower Ordovician (Arenig), Billingen Stage, Lower Dikari Member

Beloglaz unit.— Only the upper part of this unit was sampled. This part consists of one bed of grey to yellow calcareous mudstone, about 3 cm thick, with rare glauconitic grains (samples B1, B2) and numerous *Trypanites*-type borings. The limestone infilling of the borings was sampled separately (sample B3). This is overlain by a 2 cm thick bed of grey calcareous packstone, with numerous large (up to 1.5 mm across) glauconitic grains (sample B4) and the uppermost bed of red calcareous mudstone, about 3-4 cm thick, lacking glauconite (samples B5, B6). The uppermost bed contains numerous trace fossils, which represented by thin (up to five millimetres across) sharp-walled, sub-horizontal burrows of *Thalassinoides*-type that were excavated in the semi-consolidated sediment. The rare bioclasts in the uppermost bed include abundant calcified spicules of hexactinellid sponges.

Zelenyi unit (lower part).— Yellowish-grey calcareous mudstone 8 cm thick with extensive bioturbation. Bioclasts are concentrated in the lowermost part of the unit and mostly represented by fragments of ostracodes, brachiopods and rare calcified spicules of hexactinellid sponges. This unit is characterized by the branching sub-horizontal systems of *Thalassinoides*–type, together with large excavations of other types of trace fossils (Fig. 3). There are also more obscure traces of bioturbation, indicated by slight colour changes. The samples were collected from the matrix (sample B7) as well as from the cavities, tunnels, and burrows (sample B8), which are filled with bioclastic wackstone or packstone rich in glauconite. The upper boundary of this bed coincides with a smooth hardground surface with a glauconitic veneer, which is identified here as the «Steklo» surface. The uppermost 3-5 cm below the hardground surface are stained by a yellow iron oxide. *Volkhov Stage, Upper Dikari Member*

Zelenyi unit (upper part).— One bed of yellowish grey, glauconitic packstone with obscure traces of bioturbation is about 3 cm thick (samples B9-B11). The lowermost part of the unit coincides with a poorly delineated hardground surface that is only some millimetres above the "Steklo" surface.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Staritskii unit.— One bed of greenish grey calcareous packstone, about 10 cm thick (samples B12-B14), with some poorly pronounced traces of bioturbation marked by a slight enrichment of glauconite.

The general succession of conodont biozones and stratigraphic ranges of the distinctive species (Table 1, Fig. 4) are closely comparable with those recorded from southern Sweden (Bagnoli, Stouge & Tongiorgi 1988), central Sweden (Löfgren 1993; 1994), and in particular with those from northern Öland (Bagnoli & Stouge 1997). The following four conodont assemblages are recognized in the Lava River section:

Oepikodus evae Zone.— The matrix of the Beloglaz unit (samples B1-B2) contains a low diversity conodont fauna dominated by *Drepanoistodus forceps* (Lindström). Other taxa are rare and represented mostly by long-range species, such as *Oistodus lanceolatus* Pander, *Scolopodus rex* Lindström, *Decoriconus peselephantis* Lindström and *Drepanodus arcuatus* Pander (Fig. 4). This interval is referred formally to the *Oepikodus evae* Zone although the assemblage recovered from the samples lacks the index species. The absence of the *O. evae* (Lindström) is also characteristic for the uppermost part of this zone in Sweden (Löfgren 1993). There is also no record of *Trapezognathus* in the studied interval. Thus the recognition of the *Trapezognathus diprion* Zone defined by the uppermost Billingen of northern Öland (Bagnoli & Stouge 1997) is hardly possible.

Microzarkodina sp. A Zone.— This biostratigraphical unit was recognized by Bagnoli & Stouge (1997) in the uppermost Billingen of northern Öland. In the section at Lava River *Microzarkodina* sp. A occurs in the uppermost part of the Beloglaz unit (Fig. 2, samples B4-B6) and in the lower part of the Zelenyi unit between two major hardground surfaces enclosing the lower part of the latter (Fig. 2, sample B7; Table 1). The most abundant conodont species in this assemblage is *D. forceps*, which comprises up to 50 % of the total number of counted elements. *Microzarkodina* sp. A (20 % of the total number of elements) is also common. *Periodon flabellum* (Lindström) is confined only to the uppermost part of the zone. This interval also contains some rare elements of *Tripodus* sp. and «*Semiacontiodus*» sp.. *Microzarkodina* sp. A occurs in the infillings of borings, which penetrate the hard ground surface at the lower boundary of the zone (sample B3). It suggests clearly that the underlying deposits have been contaminated due to the activity of boring organisms.

Baltoniodus triangularis Zone.— This conodont assemblage occurs only within a 2-3 cm narrow band above the "Steklo" hardground surface in the upper part of the Zelenyi unit (Fig. 2, samples B9-B11; Table 1). It is characterized by the first appearance of *B. triangularis* (Lindström), which co-occurs with numerous long-ranging species, like *D. forceps*, *Protopanderdus rectus* (Lindström), *S. rex* Lindström, *D. peselephantis* and *D. arcuatus*. Elements of *D. forceps* are the most abundant in this assemblage as well as in all other samples, however, the content of *P. rectus* increases in this zone and reaches up to 15 % of the total number of conodont elements in the samples. Again, it is evident that the underlying deposits have been contaminated by elements of *B. triangularis*, since it occurs sporadically in the vertical borings penetrating the "Steklo" hardground surface (sample B8), but is missing from the matrix of the underlying bed.

Baltoniodus navis Zone.— The lower boundary of this zone is defined in the section by the first appearance of *Baltoniodus navis* (Lindström). The assemblage of this zone is also strongly dominated by *D. forceps*, which comprises up to 70 % of the total number of elements in samples B12-B14 (Table 1). This zone ranges up to the top of "Dikari" Beds and it is more than 1.5 m thick in the Lava River section.

Fig. 4. Conodonts from the Lava section. Figured specimens are housed in the Central Research Geological Exploration Museum (prefixed CNIGR Museum), St. Petersburg.
A-D: Microzarkodina sp. A. A. P element, 13060/120, sample B6, x76. B. Sc element, 13060/121, sample B6, x78. C. Sd element, 13060/122, sample B6, x78. D. Sb element, 13060/123, sample B6, x100. E-I: Periodon flabellum (Lindström). E. Sa element, 13060/124, sample B7, x67. F. M element, 13060/125, sample B7, x53. G. P element, 13060/126, sample B7, x64. H. P element, 13060/127, sample B7, x66. I. Sb element, 13060/128, sample B7, x51. J-N: Tripodus sp. J. Sb element, 13060/129, sample B5, x43. K. P element, 13060/130, sample B5, x56. L. Sc element, 13060/131, sample B5, x33. M. M element, 13060/132, sample B5, x34. N. Sa element, 13060/133, sample B5, x42. O-R: Oistodus lanceolatus Pander. O. Sa element, 13060/134, sample B7, x59. P. M element, 13060/135, sample B7, x44. Q. P element, 13060/136, sample B7, x45. R. Sc element, 13060/137, sample B7, x43. S-U: Protopanderodus rectus (Lindström). S. Symmetrical element, 13060/138, sample B13, x68. T. Asymmetrical element, 13060/139, sample B13, x44. U. Symmetrical element, 13060/140, sample B13, x42. V. Drepanodus arcuatus Pander, arcuatiform element, 13060/141, sample B13, x55. W: Decoriconus cf. D. peselephantis (Lindström). W. Symmetrical element, 13060/142, sample B5, x92. X: Decoriconus peselephantis (Lindström). X. Asymmetrical element, 13060/143, sample B6, x94. Y, Z, AC, AF: Baltoniodus navis (Lindström). Y. Pb element, 13060/144, sample B13, x76. Z. Pb element, 13060/145, sample B13, x67. AC. Sc element, 13060/146, sample B13, x92. AF. M element, 13060/147, sample B13, x58. AA, AB, AG: Baltoniodus triangularis (Lindström). AA. Sb element, 13060/148, sample B13, x100. AB. Sa element, 13060/149, sample B13, x75. AG. M element, 13060/150, sample B13, x63. AD, AE. Trapezognathus quadrangulum Lindström. AD. Pb element, 13060/151, sample B13, x91. AE. M element, 13060/152, sample B13, x86. AH: "Semiacontiodus" sp. AH. Asymmetrical element, 13060/153, sample B7, x85. AI. Toxotodus gabriellae Löfgren. AI. 13060/154, sample B8, x85. AJ: Scalpellodus sp. AJ. 13060/155, sample B13, x93. AK: Scolopodus cf. S. rex. AK. Symmetrical element, 13060/156, sample B7, x56. AL: Scolopodus rex Lindström. AL. Asymmetrical element, 13060/157, sample B7, x54. AM: Drepanoistodus cf. D. basiovalis (Sergeeva). AM. Oistodiform element, 13060/158, sample B13, x62. AN: Drepanoistodus forceps (Lindström). AN. Oistodiform element, 13060/159, sample B13, x66. AO: Drepanoistodus contractus (Lindström). AO. Oistodiform element, 13060/160, sample B7, x43.

Table 1

Conodont element distribution in samples. A cross (+) marks rare species, which are recorded from the sample, but not included the counted conodonts. Grey indicates samples taken from the infilling of burrows, tunnels and cavities.

Stage	Samples	Drepanoistodus forceps	Drepanoistodus contractus	Drepanoistodus cf. D. basiovalis	Drepanodus arcuatus	Scolopodus rex	Oistodus lanceolatus	Cornuodus longibasis	Protopanderodus rectus	Decoriconus peselephantis	Tripodus sp.	"Semiacontiodus" sp.	Microzarkodina sp. A	Periodon flabellum	Baltoniodus triangularis	Baltoniodus navis	Scalpellodus sp.	Trapezognathus quadrangulum	Others	Total	Conodont zones
Volkhov	B14	154	+	+	+	2	2	+	13	2	+				+	8		1	2	184	*Baltoniodus navis*
	B13	315	1	5	4	6	+	+	26	9	+				11	10	2	3	2	394	
	B11	215	3	6	+	8	4	+	53	3	+				12				4	308	
	B12	170	3	6	5	3	+	+	16	4	+				6	6		1	1	221	*Baltoniodus triangularus*
	B10	178	0	5	+	+	+	3	24	7	+				8				2	227	
	B9	222	0	16	1	+	+	+	35	7	+			1	3				3	288	
Billingen	B8	96	+	+	2	1	14	1	6	7	+	1		3	3				2	136	*Microzarkodina sp. A*
	B7	93	8	+	+	8	38	1	8	7	4	2	1	26					1	197	
	B6	48	+	2	+	7	11	3	4	2	4	1	76							158	
	B5	125	5	7	+	8	23	4	10	8	4		52						2	248	
	B4	93	2	12	4	6	13	3	24	6	+		37							200	
	B3	49	3				11	3	10	5			1							82	*Oepikodus evae*
	B2	44	+			4	10	1	4	6		1								70	
	B1	36	3		1	5	7		2	5	2									61	

Discussion

In Sweden, the lower boundary of the *Megistaspis polyphemus* Biozone, as defined by Nielsen (1995), coincides with or is only slightly above the base of the *Baltoniodus triangularis* Zone (Löfgren 1994). However, in Estonia and the Russian part of the East Baltic the stratigraphic interval corresponding to the *B. triangularis* Zone has not previously been recognized at the base of the Volkhov Stage. Earlier studies indicated that *Baltoniodus navis* appears for the first time just below the distinctive "Steklo" hardground surface (Dronov et al. 1995, Fig. 2). This study undoubtedly showed that such early appearance of *B. navis* is connected with contamination of the underlying beds by active bioturbation.

B. triangularis Zone of the Swedish standard as well as «*Microzarkodina* sp. A» Zone recently defined by Bagnoli & Stouge (1997) in northern Öland is present also in the eastern part of the Baltoscandian Basin. The difficulty of their recognition in the East Baltic sections is mainly as a result of their negligible thickness, which does not exceed 10 cm in the examined section. This is the major difference from the Swedish sections, where the «*Microzarkodina* sp. A» Zone is up to 80 cm thick, and the *B. triangularis* Zone is almost 1 m in thickness (Bagnoli & Stouge 1997) (Fig. 5). It is possible that both zones are present in many sections west of St. Petersburg and in North Estonia, but remain unrecognized because of insufficient sampling.

In the Lower Allochton platform margin deposits within the Norwegian Caledonides, the upper boundary of the *O. evae* Zone has been defined by the first appearance of *Microzarkodina flabellum* (Lindström) while neither *Microzarkodina* sp. A nor *B. triangularis* Zone is observed (Rasmussen 1994). The first appearance of *M. flabellum* has been recorded below the first appearance of *B. navis* in the Horns Udde section of the northern Öland. This was used for the recognition of the *M. flabellum* interval Zone between the first appearance of the index species and the first appearance of *B. navis* (Bagnoli & Stouge 1997). However, it is impossible to recognize the proposed interval zone in the Lava section as *M. flabellum* was not recorded from the studied interval and undoubtedly appears somewhere above the first occurrence of *B. navis*. A similar pattern of distribution of these two species has been reported for central Sweden (Löfgren 1993; 1995).

In the Russian part of East Baltic «*Microzarkodina* sp. A» and *B. triangularis* zones only are preserved within extremely narrow intervals. The thickness of the remaining part of Billingen-Volkhov succession is comparable throughout Baltoscandia. For example, the *Oepikodus evae* and *Baltoniodus navis* zones have approximately the same thickness in the sections at Lava River and in the Horns Udde section of northern Öland.

The sediments within the investigated carbonate succession in the Arenig of the East Baltic consist mostly of bioclasts of suspension feeding organisms including brachiopods, pelmatozoans, bryozoans, and ostracodes, and this faunal assemblage persisted more or less unchanged during the interval under consideration. The boundary interval is characterized by numerous hardground surfaces that do not show any traces of major erosion or subaerial exposure. The absence of erosion is also confirmed by the rare clay lenses more than 1.5 m thick that accumulated within the *B. triangularis* Zone just on top of the "Steklo" hardground. These clay lenses represent the basal part of organic mud mounds developed in several locations along the Russian part of Baltic-Ladoga Glint

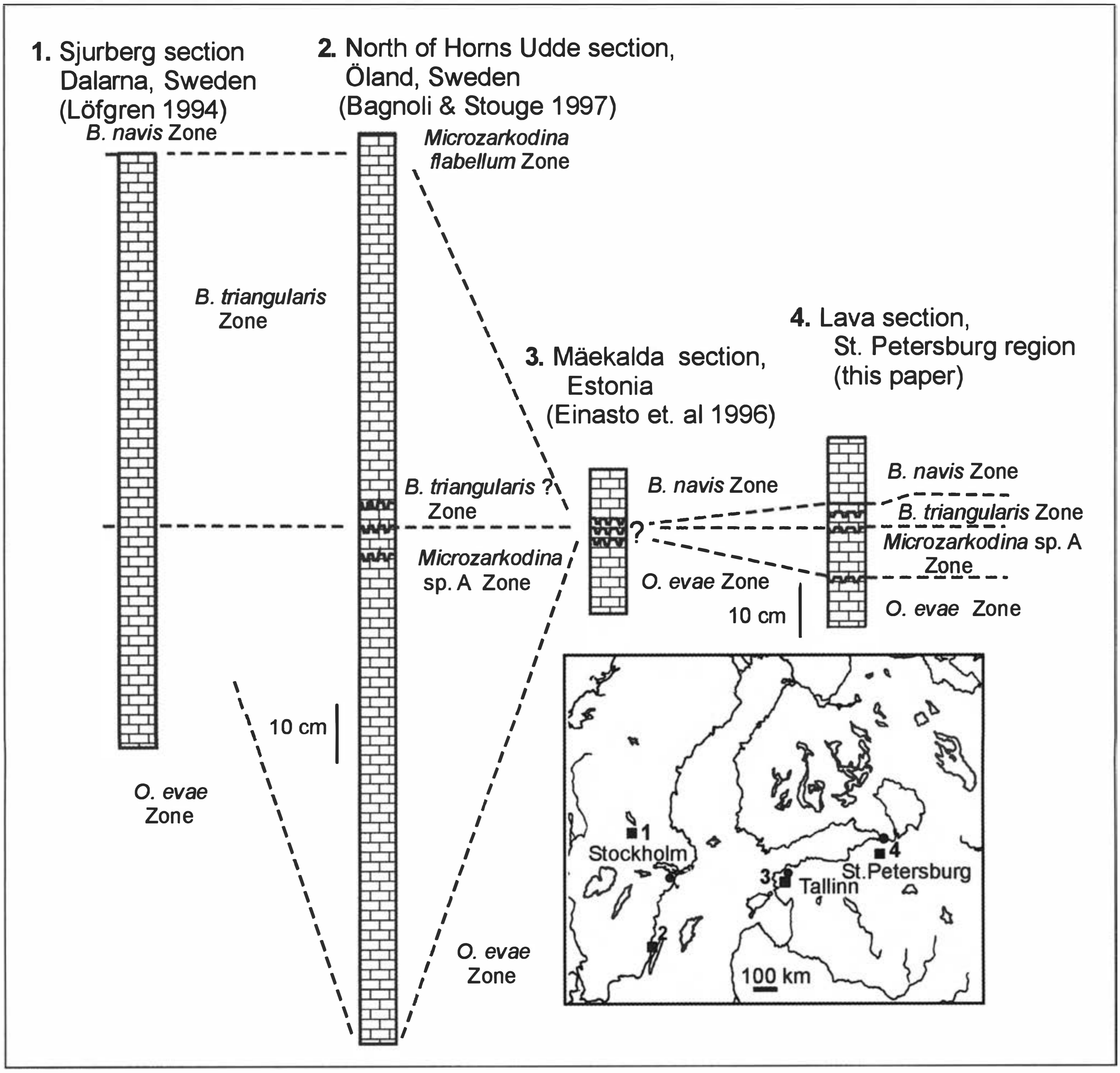

Fig. 5. Correlation of the upper Billingen and lower Volkhov interval across Baltoscandia with schematic map, showing the location of the illustrated sections.

(Fedorov & Dronov 1998). The data presented provide direct evidence for a significant period of non-deposition in the East Baltic near the boundary of the Billingen and Volkhov Stages.

Unfortunately, now it is impossible to correlate the conodont zonation with the local trilobite zonation, because the key trilobite taxa have not yet been found from this extremely condensed interval.

Acknowledgements. - T. Tolmacheva acknowledges grants (to Lars E. Holmer) from the Swedish Natural Science Research Council (NFR) and the Royal Swedish Academy of Sciences (KVA) that supported the work in Uppsala. In Russia, T. Tolmacheva's studies were supported by the Russian Foundation of Fundamental Sciences (grant no. 99-05-65-290). P. Fedorov was supported by the Russian Foundation of Fundamental Sciences (grant 98-05-65-065) and by a grant (to Lars E. Holmer) from the Royal Swedish Academy of Sciences (KVA). We are grateful to Lars E. Holmer (University of Uppsala) and Leonid Popov (National Museum and Galleries of Wales, Cardiff) for helpful comments on earlier versions of the manuscript. This paper is a contribution to the IGCP project no. 410, «The great Ordovician Biodiversification event: Temporal and spatial patterns, implications for global correlation and resources».

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