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Lower and Middle Ordovician conodonts from the subsurface of SE Estonia and adjacent Russia

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Abstract. The distribution of conodonts in the Lower–Middle Ordovician beds was studied in five drill core sections of southeastern Estonia. Ten conodont zones and six subzones, from the *Paroistodus proteus* Zone to the *Eoplacognathus lindstroemi* Subzone, were established. The peculiarity of the studied sequence is that the Volkhov Stage is notably poor in conodonts, in particular *Baltoniodus* species. Large specimens of *Drepanodus arcuatus* and *Protopanderodus rectus*, however, are found in great numbers in the uppermost Volkhov and lower Kunda stages. The deeper shelf conodont faunas recognized in SE Estonia (Central Baltoscandian confacies belt) are compared with shallow shelf faunas of northern Estonia (North Estonian confacies belt).

Key words: conodonts, biostratigraphy, Lower Ordovician, Middle Ordovician, Estonia.

INTRODUCTION

The first summary on the subsurface geology of SE Estonia, based on data from deep boreholes, was published by Kajak (1962). A general overview of the stratigraphy, lithofacies and palaeogeography of the region was given in the monograph by Männil (1966). According to the latter and the following publications (Gailite & Ulst 1975; Ulst 1976; Ulst et al. 1982), southeastern Estonia is located in the deeper part of the Baltic Basin. However, the most detailed data are available in unpublished reports of the Geological Survey of Estonia (Väärsi et al. 1964; Kajak et al. 1975). New supplementary data on the Ordovician geology of southeastern Estonia were lately presented in special publications of the series *Estonian Geological Sections* (Põldvere 2001, 2005, 2007). Lower–Middle Ordovician conodonts have been identified in the Mehikoorma-421 drill core (Männik & Viira 2005) and upper Middle Ordovician conodonts in the Valga-10 drill core (Männik 2001).

In the present paper the Lower and Middle Ordovician conodont biostratigraphy and diversity changes in the deep-water facies are considered on the basis of the drill core material from SE Estonia. Preliminary results were presented at the Seventh Baltic Stratigraphical Conference in Tallinn, Estonia (Viira & Löfgren 2008).

GEOLOGICAL SETTING

Männil (1966) and Jaanusson (1976) divided the Ordovician of the Baltoscandian Basin into confacies belts with specific sedimentological and palaeontological features (Fig. 1). The North Estonian confacies is represented by shallow-water carbonate rocks, while the Central Baltoscandian confacies extending to South Estonia and Latvia has more argillaceous sediments of the deeper shelf settings (Fig. 1). In the latter area the boundary of the lower and upper Tremadoc is connected with the development of a maximal submersion of the Jelgava depression, with continuous deepening up to the end of Kunda time (Männil 1966; Ulst et al. 1982). Red-coloured calcareous sediments accumulated in the depression and on its slopes. The present study area in SE Estonia embraces the northeastern end of the Jelgava depression.

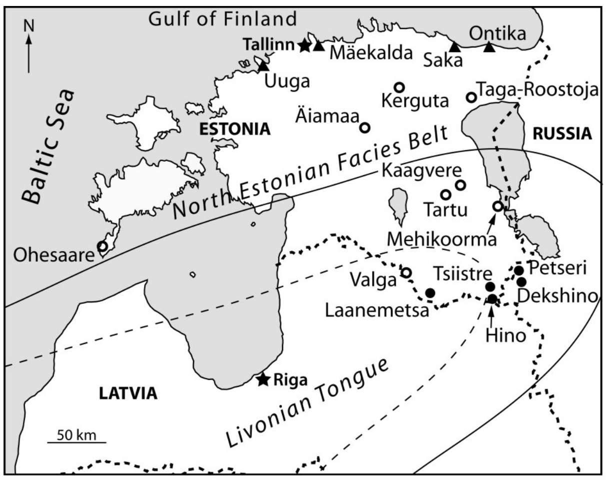


Fig. 1. Location of the studied core sections (filled circles), other drill cores (empty circles) and outcrops (triangles) mentioned in text. Solid line – approximate boundary between the North Estonian Facies Belt and the Livonian Tongue of the Central Baltoscandian Facies Belt (Männil 1966; Jaanusson 1976); dotted line – limits of the Jelgava depression (Ulst et al. 1982).

The sedimentary bedrock strata of Estonia have a gentle southward dip (6–19′), so that the rocks exposed in North Estonia are in South Estonia available for study only in drill core sections. This regularity was disturbed tectonically in southeastern Estonia where the crystalline basement was uplifted in the late Silurian and Early Devonian, and the younger Ordovician and Silurian sedimentary rocks were eroded.

The lithology and fauna of the eastern part of the Central Baltoscandian confacies belt have mainly been studied in Latvia where a system of formations and members has been established (Männil 1963; Springis 1974; Ulst & Gailite 1976; Ulst et al. 1984). The lithological units first distinguished in Latvia were introduced for southern Estonia by Männil (1990) and Männil & Meidla (1994).

The Ordovician sequence in southern Estonia begins with the Zebre Formation which belongs to the Varangu, Hunneberg and Billingen stages (Fig. 2). In SE Estonia the sediments of the Zebre Formation are represented by greenish-grey and reddish-brown glauconitic argillaceous dolomite with a thickness up to 4 m. A series of discontinuity surfaces occurs in the lower and upper parts of the formation. The succeeding Kriukai Formation corresponds to the Volkhov Stage and consists of reddish-brown argillaceous dolomite with dolomitic marlstone interbeds. The thickness of the unit is 9.1–17.6 m, with a maximum in the Dekshino-328 core section. The Šakyna Formation consists mainly of greenish-grey argillaceous dolomite with dolomitic marlstone interbeds, commonly 3–9 m thick. The lower boundary of the formation is marked by discontinuity surfaces in the Petseri-330 and Dekshino-328 core sections. The formation is of early to middle Kunda age. The Baldone Formation is represented by up to 12.6 m thick reddish-brown and greenish-grey argillaceous limestone and dolomite with marlstone interbeds, and is of late Kunda age. Ten discontinuity surfaces are found in the Petseri-330 section in the

GLOBAL STAGE	REGIONAL STAGE	FORMATION		CONODONT	
		N Estonia	SE Estonia	ZONE	SUBZONE
DARRIWILIAN	UHAKU	Kõrgekallas	Taurupe	*Pygodus serra*	*Eopl. lindstroemi*
		Väo			(*Yangtzepl. protoramosus*)
					Baltopl. robustus
	LASNA-MÄGI		Stirnas		(*Baltopl. reclinatus*)
					Yangtzepl. foliaceus
	ASERI	Kandle	Segerstad	*Eoplacognathus suecicus*	
	KUNDA	Napa	Baldone	*Eoplacognathus pseudoplanus*	*Microzark. ozarkodella*
		Loobu			(*Microzark. hagetiana*)
				Yangtzeplacognathus crassus	
				Lenodus variabilis	
		Sillaoru	Šakyna		
	VOLKHOV	Toila	Kriukai	(*Baltoniodus norrlandicus*)	(*Lenodus antivariabilis*)
DAPINGIAN					(*Trapezogn. quadrangulum*)
				Paroistodus originalis	
				Baltoniodus navis	
				Baltoniodus triangularis	
FLOIAN	BILLINGEN	Leetse	Zebre	*Oepikodus evae*	
				(*Prioniodus elegans*)	
	HUNNE-BERG			*Paroistodus proteus*	(*Oelandodus elongatus - Acodus deltatus*)
TREMADOCIAN					(*Paracordylodus gracilis*)
					Tripodus
					Drepanoistodus aff. *D. amoenus*
	VARANGU	Varangu		(*Paltodus deltifer*)	

Fig. 2. Stratigraphical scheme and conodont zonation of the Lower and Middle Ordovician used in Estonia (according to Nõlvak et al. 2006, modified). Subzones of the *Paroistodus proteus* Zone after Löfgren (1994, 2000). Conodont zones and subzones in brackets are not found in SE Estonia.

interval 418.8–423.3 m. The Segerstad Formation corresponds to the Aseri Stage and consists of up to 5.2 m thick reddish-brown argillaceous limestone and dolomite. In the lowermost part of the formation one or two discontinuity surfaces occur in the Dekshino-328 and Hino-452 core sections. The Stirnas Formation consists of thick greenish-grey mottled reddish-brown argillaceous limestone and dolomite with marl interbeds. The unit is about 3 m thick in the Dekshino-328 section and is of Lasnamägi age. The uppermost Middle Ordovician Taurupe Formation of Uhaku age is about 10 m thick in the Dekshino-328 section. It is represented by grey nodular limestone and argillaceous dolomite with grey limestone and marl interbeds.

MATERIAL

Conodonts were studied in the Tsiistre-327, Hino-452, Laanemetsa-70, Petseri-330 and Dekshino-328 core sections, situated in the most southeastern corner of Estonia and adjacent Russia, on the northern slope of the Lokno–Mõniste uplift (Puura & Vaher 1997) (Fig. 1). The conodonts from these sections were preliminarily identified during the geological mapping in the 1960s–1970s. The sampling interval in these cores varied depending on the lithology and necessity of defining the stage boundaries. All together 73 samples were investigated. The samples were small, with a maximum weight of ~300 g. The smallest sample of 30 g came from the Zebre Formation. For this paper some residues were picked additionally, all conodonts were re-examined and identified in the multielement taxonomy. The illustrated specimens of conodonts belong to the collection No. 594, which is housed in the Institute of Geology at Tallinn University of Technology (institutional abbreviation GIT).

DISTRIBUTION OF CONODONTS

Petseri-330 core section

Twenty-one samples from the Lower and Middle Ordovician part of the section were studied (Fig. 3). The

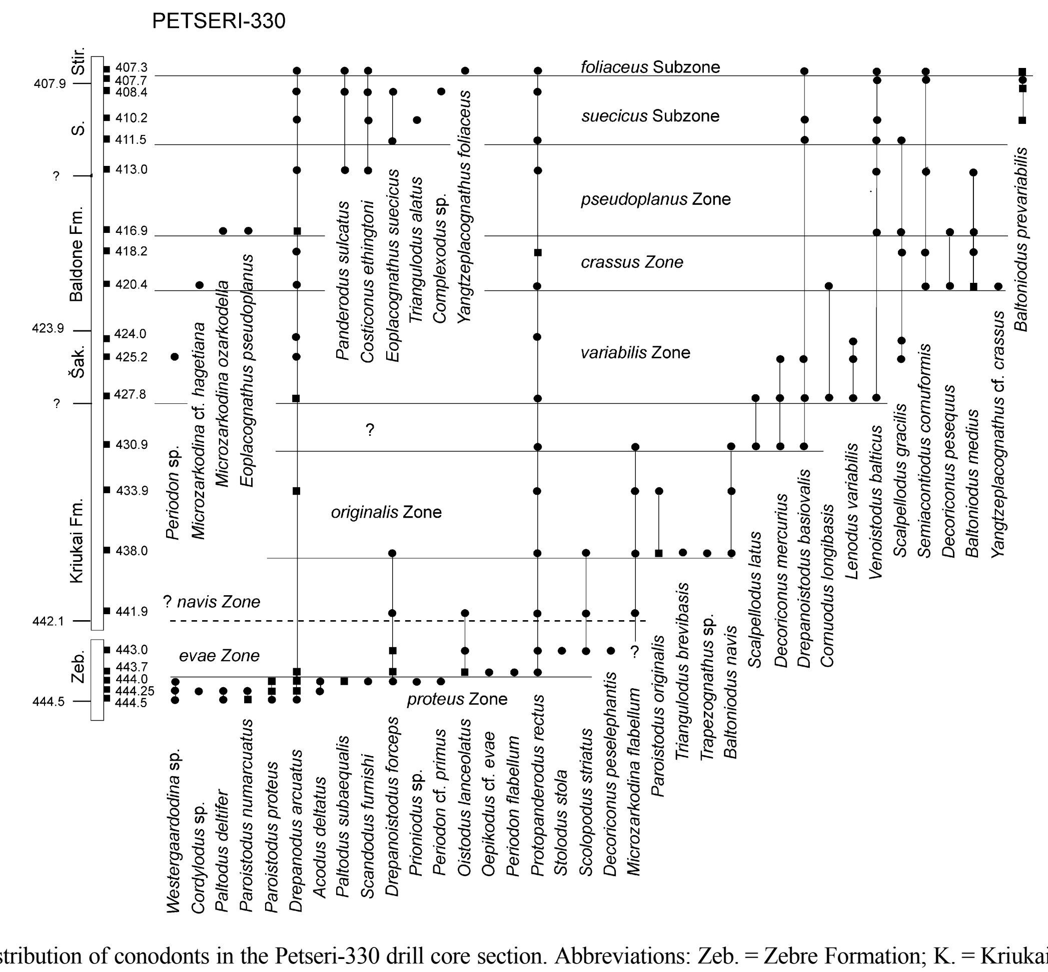


Fig. 3. Distribution of conodonts in the Petseri-330 drill core section. Abbreviations: Zeb. = Zebre Formation; K. = Kriukai Formation; Šak. = Šakyna Formation; S. = Segerstad Formation; Stir. = Stirnas Formation; D = Devonian. Circle – 1–20 specimens, square – more than 20 specimens. Depth in metres.

zonal species *Paroistodus proteus* was identified in three samples, but the complexes of species in these samples were somewhat different. The lowest sample of greenish-grey glauconitic argillaceous dolomite from 444.5 m contains mixed fauna, rare *Paltodus deltifer* – the index species of the underlying zone, *Paroistodus numarcuatus* and rare *Paroistodus proteus*. The sample of reddish-brown dolomite with glauconite grains from 444.25 m yielded numerous *P. proteus* and *Drepanodus arcuatus*, and rare specimens of an early form of *Acodus deltatus* (Fig. 4E, G). The third sample of violet-brown argillaceous dolomite from 444.0 m with large glauconite grains contains a more diverse conodont fauna, besides numerous *P. proteus* (Fig. 4A–C), *D. arcuatus* and *A. deltatus* (Fig. 4F), the first representatives of the genera: *Periodon* cf. *primus* (Fig. 4M, N), *Prioniodus* sp. (Fig. 4O, S), *Scandodus furnishi* (Fig. 4K) and *Drepanoistodus forceps*.

The Kriukai Formation in the interval from 442.1 m up to about 428.0 m includes reddish-brown argillaceous limestone in the upper and dolomite in the lower part. Two samples, from 438.0 and 433.9 m, belong to the *Paroistodus originalis* Zone where rare and fragmentary *Baltoniodus navis* occur. Almost complete Pa specimens of *Lenodus variabilis* (Fig. 5B, C) are found in the sample at 424.0 m, from the grey argillaceous dolomite of the Šakyna Formation.

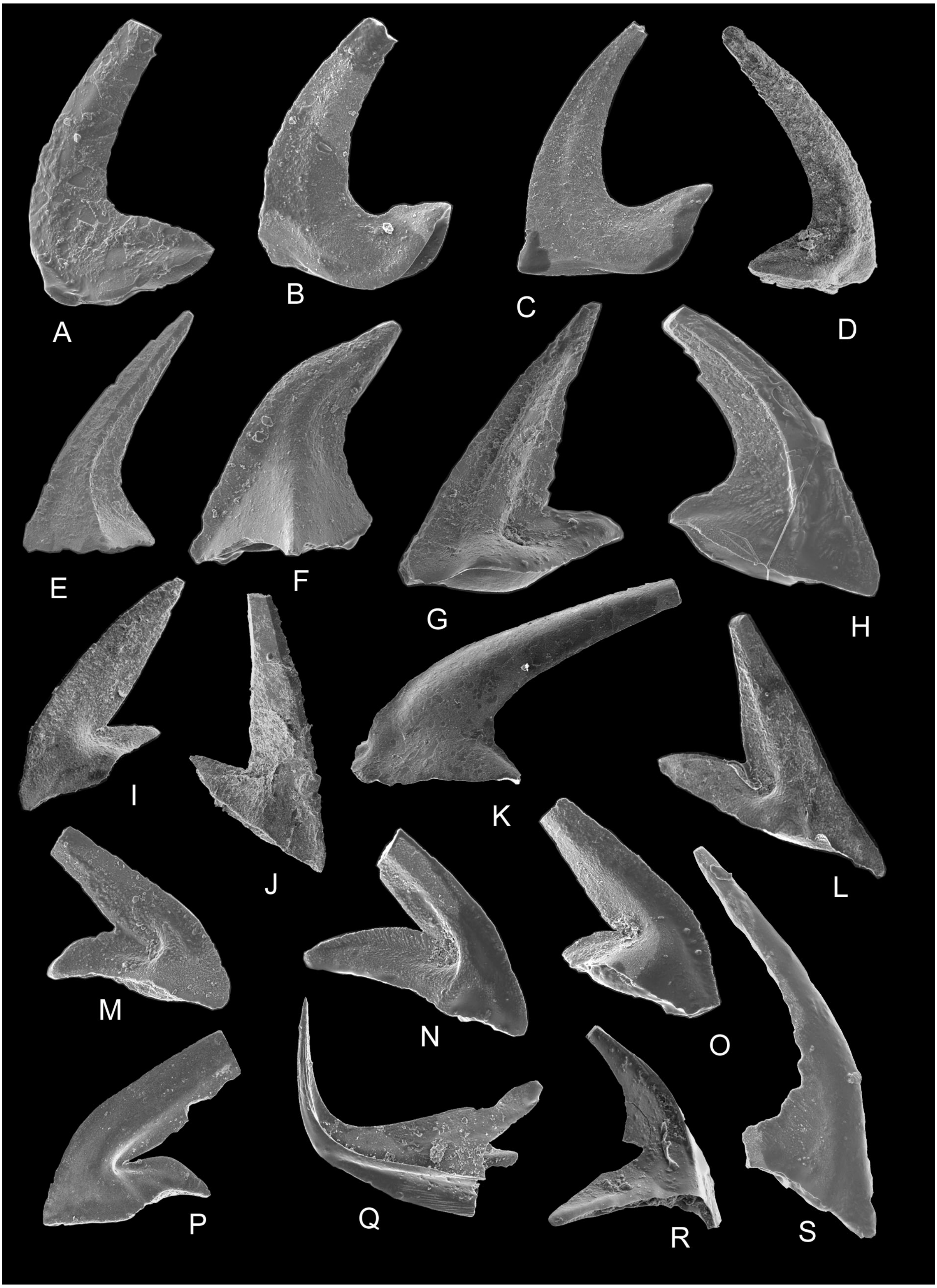
The conodont fauna changes upwards from the level of 420.4 m, in the reddish-brown argillaceous dolomitic limestone of the Baldone Formation. The change is expressed first of all by the appearance of numerous specimens of *Baltoniodus medius* (Fig. 6A, B), *Semiacontiodus cornuformis* and *Scalpellodus gracilis*. The *Eoplacognathus pseudoplanus* Zone is defined by the index species (Fig. 5D, E, G–I) and the upper subzone by *Microzarkodina ozarkodella* (Fig. 7B) in the sample from 416.9 m.

The reddish-brown argillaceous limestone of the Segerstad Formation yielded conodont species of the *Eoplacognathus suecicus* Zone, nominal species (Fig. 5J–M) in the samples from 411.5 m and 408.4 m and *Panderodus sulcatus* from 413.0 m upwards. The sample from 410.2 m is rich in *Baltoniodus* specimens, mostly *B. prevariabilis*, but transitional specimens to *B. medius* are also found. The complete Pa and Pb elements of *Yangtzeplacognathus foliaceus* (Fig. 5N, O) define the *Y. foliaceus* Subzone in the Petseri-330 section.

Dekshino-328 core section

Conodonts of the Zebre Formation were studied in three samples (Fig. 8). The lowermost sample (433.15 m) from yellow-grey glauconitic dolomite contains representatives of the *Paroistodus proteus* Zone, together with conodonts from the underlying *Paltodus deltifer* Zone. The next two higher samples of violet dolomite from 432.6 m and of greenish-grey dolomite from 431.65 m yielded conodonts of the *Oepikodus evae* Zone. The interval 411.7–429.3 m of reddish-brown argillaceous limestone and dolomite of the Kriukai Formation is very poor in conodonts. The specimen of biostratigraphic importance is the single M element identified as *Baltoniodus triangularis* (Fig. 6C) in the sample at 427.15 m in the lowermost part of the Kriukai Formation. This species defines the lower boundary of the Dapingian Stage and the base of the Middle Ordovician. Fragmentary specimens of the genus *Lenodus* appear in the uppermost part of the Kriukai Formation, at 412.5 m, and occur also in the Šakyna Formation (interval ~405.0–411.7 m). Fragmentary specimens of the nominal species of the *Eoplacognathus pseudoplanus* Zone were identified in the upper part of the Baldone Formation. *Eoplacognathus* cf. *suecicus*, *Panderodus sulcatus*, *Costiconus ethingtoni* and *Complexodus* sp. were identified at 394.8 m in the Segerstad Formation. Upwards in the section the subzonal species *Baltoplacognathus robustus* was found in the Stirnas Formation at 387.5 m (Fig. 9F-1, F-2) and *Eoplacognathus lindstroemi*

Fig. 4. Conodonts from the *Paroistodus proteus* and *Oepikodus evae* zones of the studied sections. **A–C**, *Paroistodus proteus* (Lindström). A, GIT 594-1, Pa element, ×95; B, GIT 594-2, Pb element, ×110; C, GIT 594-3, ×95; A–C, Petseri-330 core, depth 444.0 m. **D**, *Paroistodus numarcuatus* (Lindström). GIT 594-4, Sa element, ×70, Tsiistre-327 core, depth 494.65 m. **E**, **G**, *Acodus deltatus* Lindström early form. E, GIT 594-5, P element, ×60, Petseri-330 core, depth 444.25 m; G, GIT 594-6, M element, ×70, Petseri-330 core, depth 444.0 m. **F**, *Acodus deltatus* Lindström, GIT 594-7, ×100, Petseri-330 core, depth 444.0 m. **H**, **L**, *Paltodus subaequalis* Pander. H, GIT 594-8, Sc element, ×95; L, GIT 594-9, M element, ×70; H, L, Petseri-330 core, depth 444.0 m. **I**, *Acodus* cf. *deltatus* Lindström. GIT 594-10, M element, ×85, Tsiistre-327 core, depth 494.65 m. **J**, *Paltodus deltifer* (Lindström). GIT 594-11, M element, ×75, Tsiistre-327 core, depth 494.65 m. **K**, *Scandodus furnishi* Lindström. GIT 594-12, P element, ×55, Petseri-330 core, depth 444.0 m. **M**, **N**, *Periodon* cf. *primus* Stouge & Bagnoli. M, GIT 594-13, M element, ×105; N, GIT 594-14, M element, ×90; M, N, Petseri-330 core, depth 444.0 m. **O**, **S**, *Prioniodus* sp. O, GIT 594-15, M element, ×90; S, GIT 594-16, S element, ×90; O, S, Petseri-330 core, depth 444.0 m. **P**, *Periodon flabellum* (Lindström). GIT 594-17, M element, ×70, Dekshino-328 core, depth 432.6 m. **Q**, **R**, *Stolodus stola* (Lindström). Q, GIT 594-18, S element, ×70; R, GIT 594-19, ×100; Q, R, Petseri-330 core, depth 443.0 m.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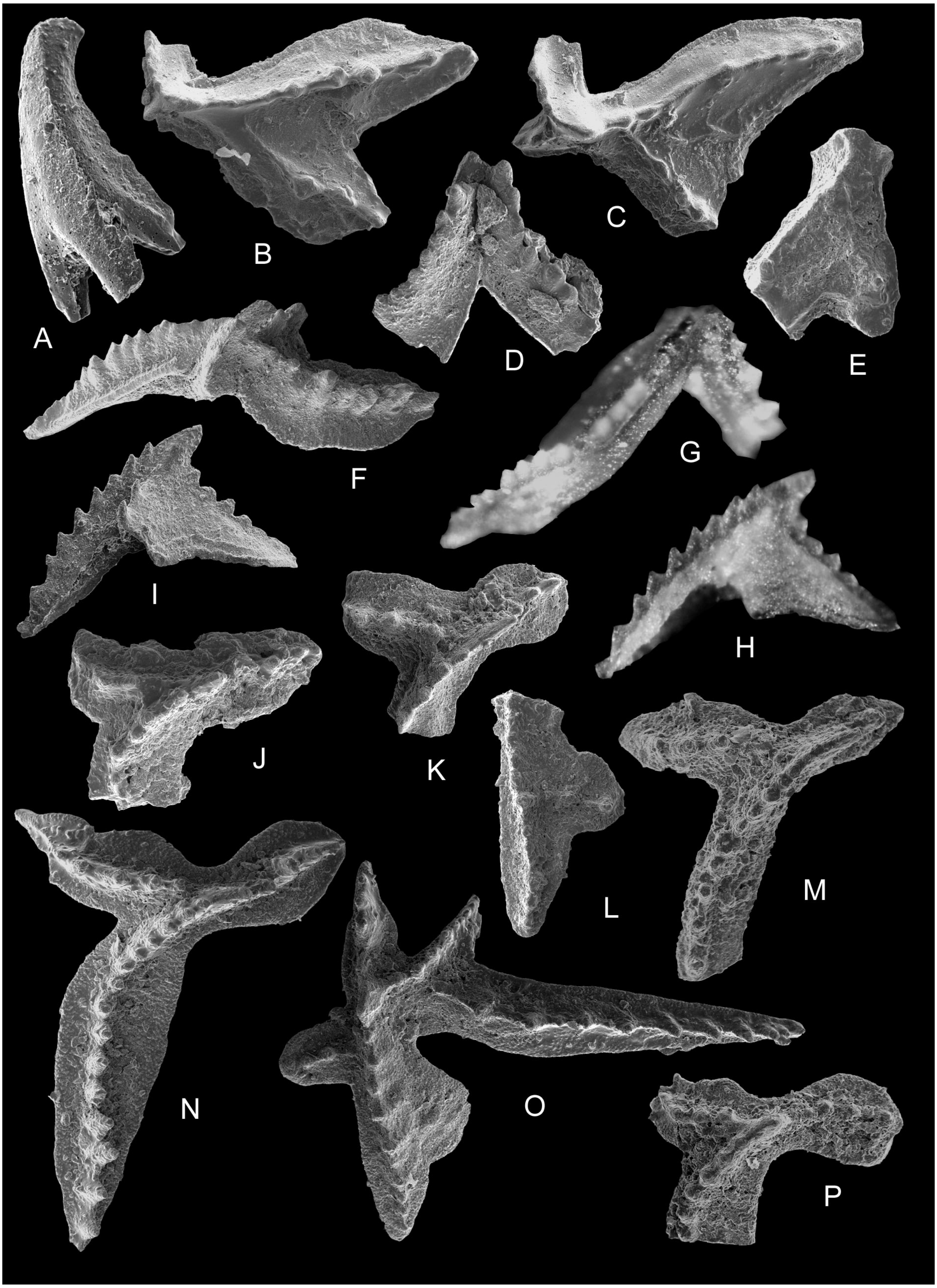
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in the Taurupe Formation at 379.6 m (Fig. 9G). The Ordovician sediments are covered by Devonian siltstones at 377.5 m (Väärsi et al. 1964).

Hino-452 core section

The Lower and Middle Ordovician sequence representing the whole Ordovician in the Hino-452 core is 30.1 m thick and is covered by Devonian sandstone at 489.0 m according to Kajak et al. (1975) (Fig. 10). Seventeen samples were taken, four of which from the interval 514.0–517.7 m were barren of conodonts. The two lowermost samples from the multicoloured (yellow, violet) glauconitic dolomite of the Zebre Formation yielded conodonts of the *Paroistodus proteus* Zone. The next three higher samples, from glauconitic dolomite, belong to the *Oepikodus evae* Zone with the index species illustrated in Fig. 11D. The reddish-brown argillaceous dolomite of the Kriukai Formation contains sparse conodonts. The samples from 503.6 m (Šakyna Formation) and 499.5 m (lower Baldone Formation) mark an interval where fragmentary specimens of the genus *Lenodus* (Fig. 9H, I) are found. A large number of conodonts were obtained from the reddish-brown argillaceous dolomite in the upper part of the Baldone Formation, from 493.7 m. This diverse conodont fauna, including *Eoplacognathus pseudoplanus* (Fig. 9D), *Histiodella kristinae* (Fig. 9N, O) and *Microzarkodina ozarkodella*, indicates the *M. ozarkodella* Subzone of the *E. pseudoplanus* Zone (Löfgren 2004). *Complexodus* sp., identified at 490.1 m, is usually found in northern Estonia in the *Eoplacognathus suecicus* Zone (Viira et al. 2001). The highest sample (488.9 m) from the Devonian dolomitic siltstone contains two redeposited conodont specimens and two thelodont (?) scales.

Tsiistre-327 core section

A detailed study of the Tsiistre-327 core has been published earlier (Põldvere 2007). According to Põldvere (2007), in this core section the Ordovician occupies only 8.7 m from the 494.7 m level upwards, lying below the Devonian sedimentary rocks starting at 486.0 m with weakly cemented sandstone.

Conodonts were studied in four samples, three from the glauconitic dolomite of the Zebre Formation and one from the uppermost brownish-red argillaceous dolomite of the Kriukai Formation (Fig. 12). The lowermost sample, from 494.65 m, represents the *Paroistodus proteus* Zone with *P. proteus*, *Paltodus subaequalis* (Fig. 4H, L) and *Paltodus deltifer* (Fig. 4J). In the next sample (494.45 m) the zonal species *Oepikodus evae* is found. The sample from 494.1 m represents also the *O. evae* Zone with quite numerous specimens of *Stolodus stola*, *Oistodus lanceolatus* and *Drepanoistodus forceps*. The fauna of the uppermost sample, from 493.5 m, with numerous *Oistodus lanceolatus* (Fig. 11H–L, P–R) and *Drepanoistodus forceps* (Fig. 11C) is similar to that in the underlying sample with the exception that it contains *Trapezognathus* cf. *diprion* and *Microzarkodina russica*. The last mentioned taxon is indicative of the uppermost *O. evae* and the *Baltoniodus triangularis* zones (Löfgren & Tolmacheva 2008).

Laanemetsa-70 core section

The conodont elements from the eleven samples of the Laanemetsa-70 core are rather poorly preserved, many specimens are corroded and broken (Fig. 13). Five samples from the reddish-brown and grey argillaceous dolomite of the Kriukai and Šakyna formations (374.7, 372.7, 370.7, 368.9 and 368.4 m) yielded the specimens of *Lenodus* sp. (Fig. 9E). A sample from the lower part of the Baldone Formation (367.0 m) is characterized by the zonal conodont *Yangtzeplacognathus crassus* (Fig. 9B). The zonal species *Eoplacognathus pseudoplanus* is found in the sample from 359.0 m (Fig. 9A). The specimens of *Eoplacognathus* cf. *suecicus*, *Costiconus* and *Periodon* appear in the conodont fauna of the three highest samples of red-coloured dolomite, at 353.6, 351.9 and 350.0 m. This interval may belong to the *E. suecicus* Zone.

Fig. 5. Conodonts from the studied sections. **A**, *Yangtzeplacognathus* cf. *crassus* (Chen & Zhang). GIT 594-57, Sd element, ×100, Petseri-330 core, depth 420.4 m. **B**, **C**, **F**, *Lenodus variabilis* (Sergeeva). B, GIT 594-58, Pa element, ×85, Petseri-330 core, depth 424.0 m; C, GIT 594-59, Pa element, ×105, Petseri-330 core, depth 424.0 m; F, GIT 594.60, Pa element, ×45, Petseri-330 core, depth 425.2 m. **D**, **E**, **G–I**, *Eoplacognathus pseudoplanus* (Viira). D, GIT 594-61, Pb element, ×60; E, GIT 594-62, Pa element, ×85; G, GIT 594-63, Pb element, ×80; H, GIT 594-64, Pb element, ×90; I, GIT 594-65, Pb element, ×100; D, E, G, H, I, Petseri-330 core, depth 416.9 m. **J–M**, *Eoplacognathus suecicus* Bergström. J, GIT 594-66, Pb element, ×75; K, GIT 594-67, Pb element, ×110; L, GIT 594-68, Pa element, ×75; M, GIT 594-69, ×120; J–M, Petseri-330 core, depth 408.4 m. **N**, **O**, *Yangtzeplacognathus foliaceus* (Fåhraeus). N, GIT 594-70, Pb element, ×90; O, GIT 594-71, Pa element, ×90; N, O, Petseri-330 core, depth 407.3 m. **P**, *Yangtzeplacognathus* cf. *foliaceus* (Fåhraeus). GIT 594-72, ×85, Petseri-330 core, depth 407.3 m; G, H, light microscope photos.


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CONODONT ZONATION

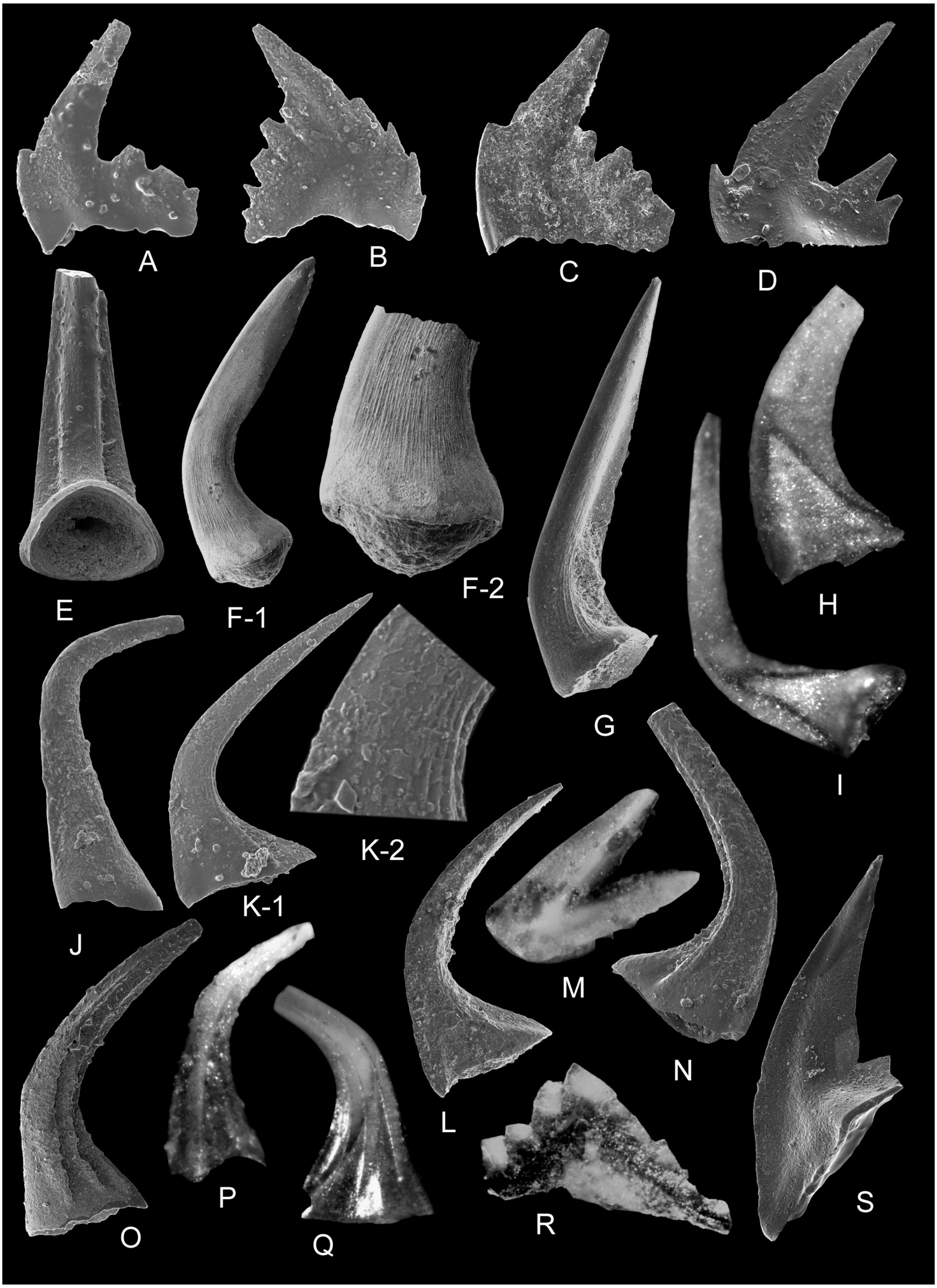
The conodonts found in the five borehole sections of southeastern Estonia represent 10 successive conodont zones and six subzones, from the *Paroistodus proteus* Zone to the *Eoplacognathus lindstroemi* Subzone, occurring in the stratigraphical interval from the Hunneberg to Uhaku stages. Due to small sample sizes and widely spaced samples, the biozone boundaries and full ranges of the zonal species are not always clearly defined here. Two kinds of biostratigraphical zones were distinguished in this study: taxon-range zones in the lower part of the sequence and lineage-zones of the platform conodonts in the remainder part (Murphy & Salvador 1998).

The ***Paroistodus proteus*** **Zone** is found in the Petseri-330, Dekshino-328, Hino-452 and Tsiistre-327 core sections, in the greenish-grey and reddish-brown glauconitic rocks of the Zebre Formation. The studied samples probably represent different parts of the *P. proteus* Zone. The species *Paroistodus proteus*, *Paltodus deltifer*, *Paroistodus numarcuatus*, *Variabiloconus variabilis*, *Westergaardodina* sp. and *Cordylodus* sp. are found in the lowermost part of the zone in the Petseri-330 (at 444.5 m) and Dekshino-328 (at 433.15 m) cores. These are conodonts of the *P. proteus* Zone and conodonts from the underlying *Paltodus deltifer* Zone and even from older biostratigraphic units. Such a mixture of conodonts in the lowermost samples of the Zebre Formation is characteristic of SE Estonia and can be explained by erosion and redeposition of sediments. Redeposited elements are generally discoloured and broken. The edges of the elements are frequently worn away or the elements are recrystallized (Löfgren et al. 2005). The conodonts from the two lowermost samples in the Petseri-330 (at 444.5 m) and Dekshino-328 (at 433.15 m) cores may represent the lower *Drepanoistodus* aff. *D. amoenus* Subzone of the *P. proteus* Zone (Löfgren 1994). The samples of this zone in the Petseri-330 (at 444.0 m), Hino-452 (at 518.9 and 518.73 m) and Tsiistre-327 (at 494.65 m) cores contain, besides the zonal species *P. proteus* (Fig. 4A–C), also *Acodus deltatus*, *Paltodus subaequalis*, *Prioniodus* sp., *Drepanoistodus forceps* and *Drepanodus arcuatus*. These conodont species are characteristic of the second, *Tripodus* Subzone of Löfgren's (1994) subdivision. The upper two subzones of this subdivision are not found in the studied SE Estonia sections. Conodonts of the *P. proteus* Zone are known in the Zirni Member and of the *Paltodus deltifer* Zone in the Lutrini and Kumbri members of the Zebre Formation in western Latvia (Ulst et al. 1982). The *P. proteus* Zone has been established in the lower part of the Leetse Fomation (Hunneberg Stage) in northern Estonia (Viira 1974; Viira et al. 2001, 2006a; Löfgren et al. 2005).

The index species ***Prioniodus elegans*** of the succeeding zone is not found in the studied sections, maybe partly because of the presence of a gap in the sequence, partly because of the big interval between samples. The *Prioniodus elegans* Zone is poorly developed in most of the Swedish sections or occurs as reworked and fragmentary fauna in the base of the *O. evae* Zone (Lindström 1971; Bergström 1988). In northern Estonia the *P. elegans* Zone is known from the Mäekalda and Saka sections (Viira et al. 2001, 2006a).

The ***Oepikodus evae*** **Zone** is defined in four core sections, Petseri-330, Dekshino-328, Hino-452 and Tsiistre-327. The specimens of the nominal species (Fig. 11D) are rare and fragmentary and occur only in samples from the lower part of the zone. The conodont fauna is generally diverse, including *Oistodus lanceolatus*, *Scolopodus striatus*, *Stolodus stola*, *Paroistodus parallelus*, *Drepanoistodus forceps* and *Scandodus furnishi*. The range of *Protopanderodus rectus* (specimens in Figs 14 and 15) begins in this zone. Ulst et al. (1982) have identified an analogous conodont fauna in the Kalvene Member of the Zebre Formation of western Latvia. In Sweden the *O. evae* Zone is represented in many sections, usually with the different conodont fauna in

Fig. 6. Conodonts from the studied sections. **A**, **B**, **G**, **I**, **J**, **O**, **P**, *Baltoniodus medius* (Dzik). A, GIT 594-88, Pa element, ×85, Petseri-330 core, depth 420.4 m; B, GIT 594-89, Pb element, ×75, Petseri-330 core, depth 420.4 m; G, GIT 594-90, Sb element, ×90, Hino-452 core, depth 493.7 m; I, GIT 594-91, Pa element, ×100, Laanemetsa-70 core, depth 350.0 m; J, GIT 594-92, Pb element, ×100, Laanemetsa-70 core, depth 350.0 m; O, GIT 594-93, M element, ×105, Petseri-330 core, depth 418.2 m; P, GIT 594-94, ×110, Hino-452 core, depth 493.7 m. **C**, *Baltoniodus triangularis* (Lindström). GIT 594-95, M element, ×110, Dekshino-328 core, depth 427.15 m. **D–F**, **H**, **K**, **M**, **N**, **Q–S**, *Baltoniodus prevariabilis* (Fåhraeus). D, GIT 594-96, Pb element, ×110; E, GIT 594-97, Sd element, ×65; F, GIT 594-98, Pb element, ×75; H, GIT 594-99, Pa element, ×100; K, GIT 594-100, Sb element, ×60; M, GIT 594-101, Pa element, ×65; N, GIT 594-102, Pa element, ×50; Q, GIT 594-103, M element, ×105; R, GIT 594-104, M element, ×80; S, GIT 594-105, M element, ×95; all Petseri-330 core, depth 407.3 m, except N, Petseri-330 core, depth 410.2 m. **L**, *Baltoniodus navis* (Lindström). GIT 594-106, Sa element, ×65, Petseri-330 core, depth 433.9 m. **T**, *Trapezognathus quadrangulum* Lindström. GIT 594-107, M element, ×115, Petseri-330 core, depth 438.0 m. **U**, *Trapezognathus* cf. *diprion* (Lindström). GIT 594-108, Pb element, ×120, Tsiistre-327 core, depth 493.5 m.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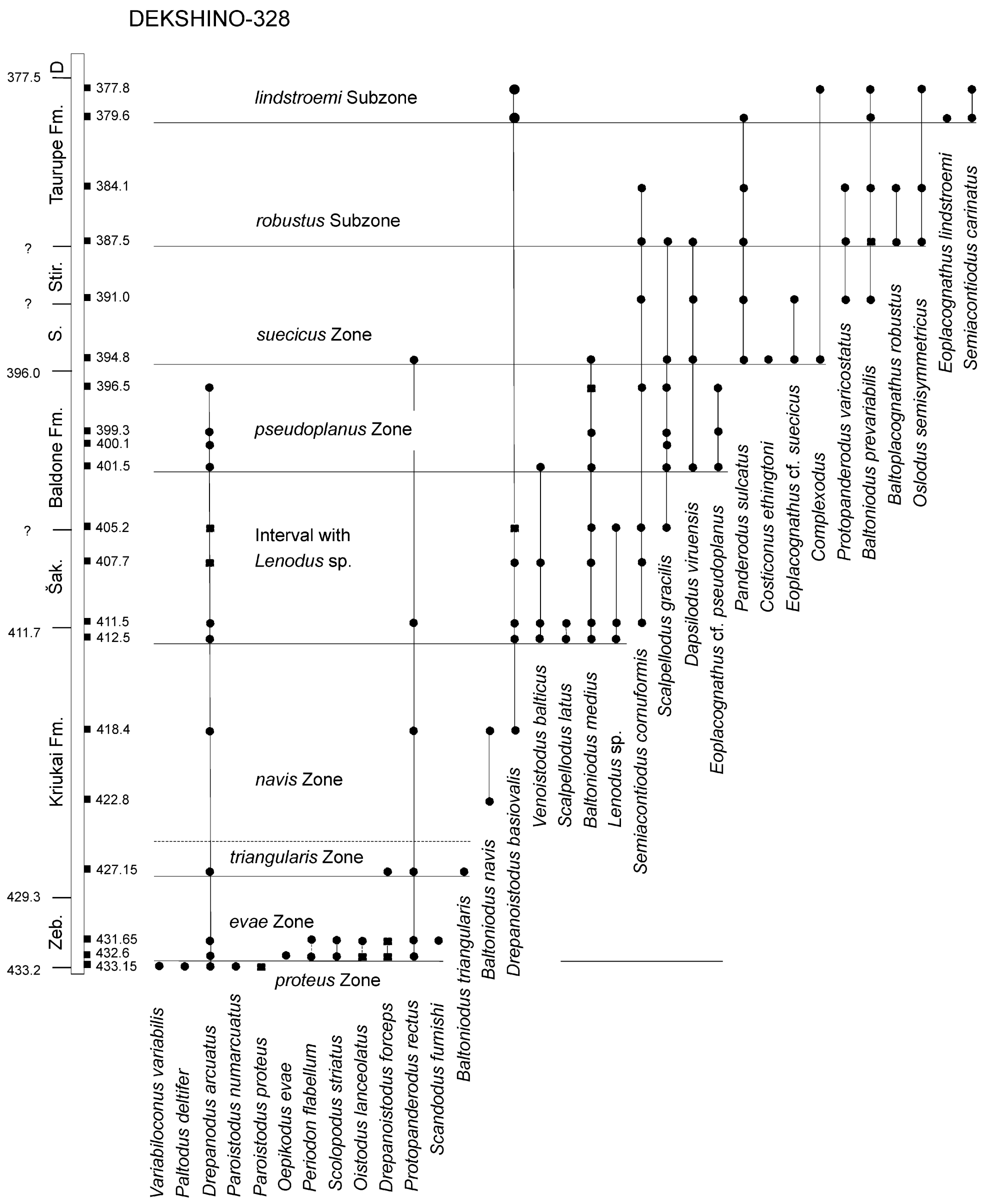
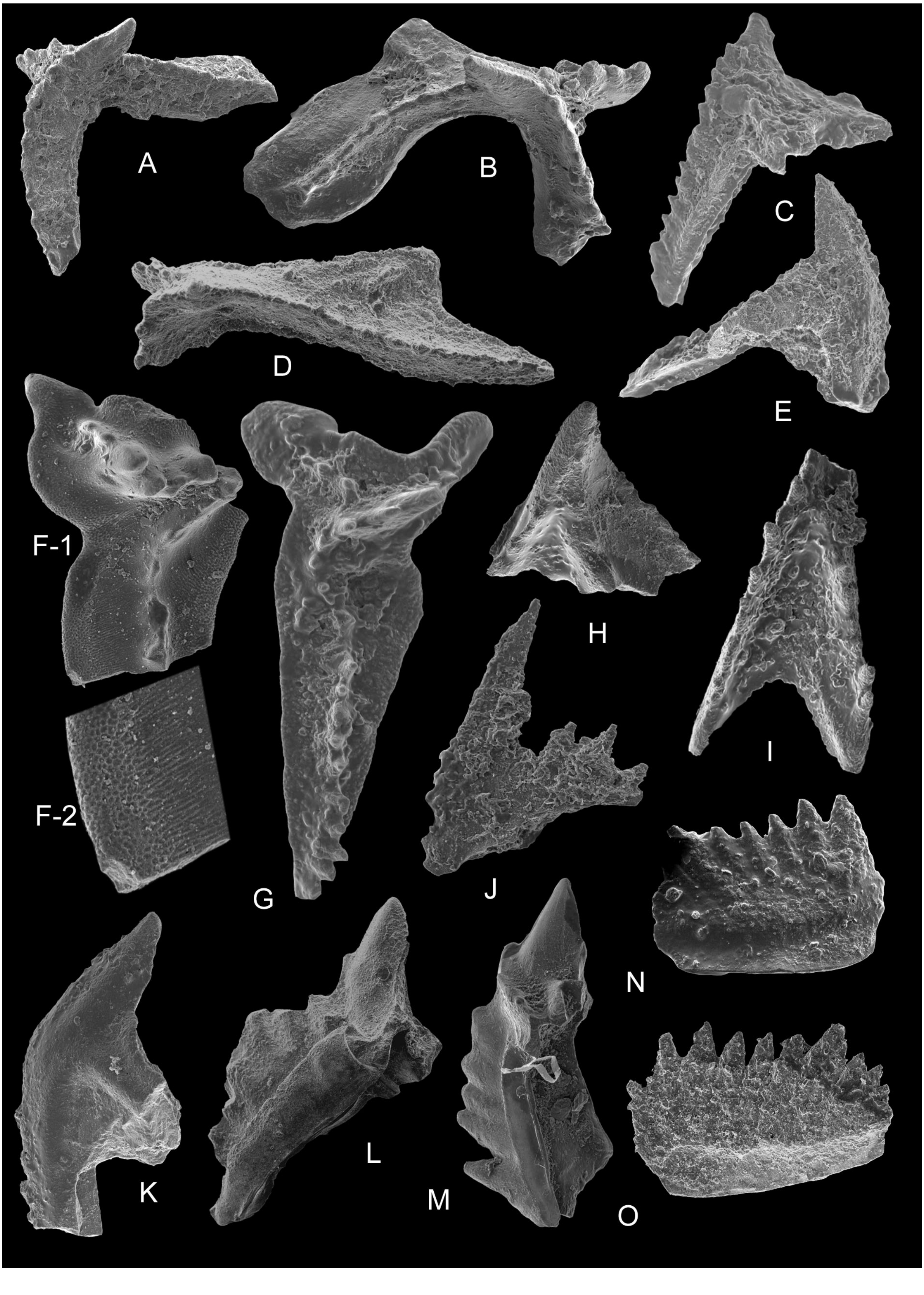


Fig. 8. Distribution of conodonts in the Dekshino-328 core section. For abbreviations see Fig. 3. Depth in metres.

Fig. 7. Conodonts from the studied sections. **A**, *Microzarkodina* cf. *hagetiana* Stouge & Bagnoli. GIT 594-38, P element, ×140, Petseri-330 core, depth 420.4 m. **B**, *Microzarkodina ozarkodella* Lindström. GIT 594-39, P element, ×130, Petseri-330 core, depth 416.9 m. **C**, *Microzarkodina russica* Löfgren & Tolmacheva. GIT 594-40, P element, ×120, Tsiistre-327 core, depth 493.5 m. **D**, *Microzarkodina bella* Löfgren. GIT 594-41, P element, ×170, Laanemetsa-70 core, depth 367.0 m. **E**, **F**, *Semiacontiodus cornuformis* (Sergeeva). E, GIT 594-42, Sa element, ×60, Petseri-330 core, depth 418.2 m; F-1, GIT 594-43, S element, ×60, F-2, basal part with basal filling, ×130, Laanemetsa-70 core, depth 353.6 m. **G**, *Semiacontiodus carinatus* Dzik. GIT 594-44, Pa element, ×70, Dekshino-328 core, depth 377.8 m. **H–J**, *Scalpellodus gracilis* (Sergeeva). H, I, GIT 594-45 and GIT 594-46, P and S elements, ×80, Petseri-330 core, depth 416.9 m; J, GIT 594-47, S element, ×110, Petseri-330 core, depth 418.2 m. **K**, **L**, **N**, *Dapsilodus viruensis* (Fåhraeus). K-1, GIT 594-48, S element, ×100, K-2, part of the cusp with striation; Laanemetsa-70 core, depth 351.9 m; L, GIT 594-49, S element, ×85, Petseri-330 core, depth 416.9 m; N, GIT 594-50, S element, ×85, Petseri-330 core, depth 407.3 m. **M**, *Venoistodus balticus* Löfgren. GIT 594-51, M element, ×70, Petseri-330 core, depth 413.0 m. **O**, **Q**, *Costiconus ethingtoni* (Fåhraeus). O, GIT 594-52, S element, ×55, Petseri-330 core, depth 407.3 m; Q, GIT 594-53, S element, ×70, Petseri-330 core, depth 413.0 m. **P**, *Costiconus iniquus* (Viira). GIT 594-54, S element, ×70, Petseri-330 core, depth 410.2 m; **R**, *Periodon* sp. GIT 594-55, P element, ×100, Petseri core, depth 420.4 m. **S**, *Triangulodus alatus* Dzik. GIT 594-56, M element, ×60, Petseri-330 core, depth 410.2 m; I, H, M, R, P, Q, light microscope photos.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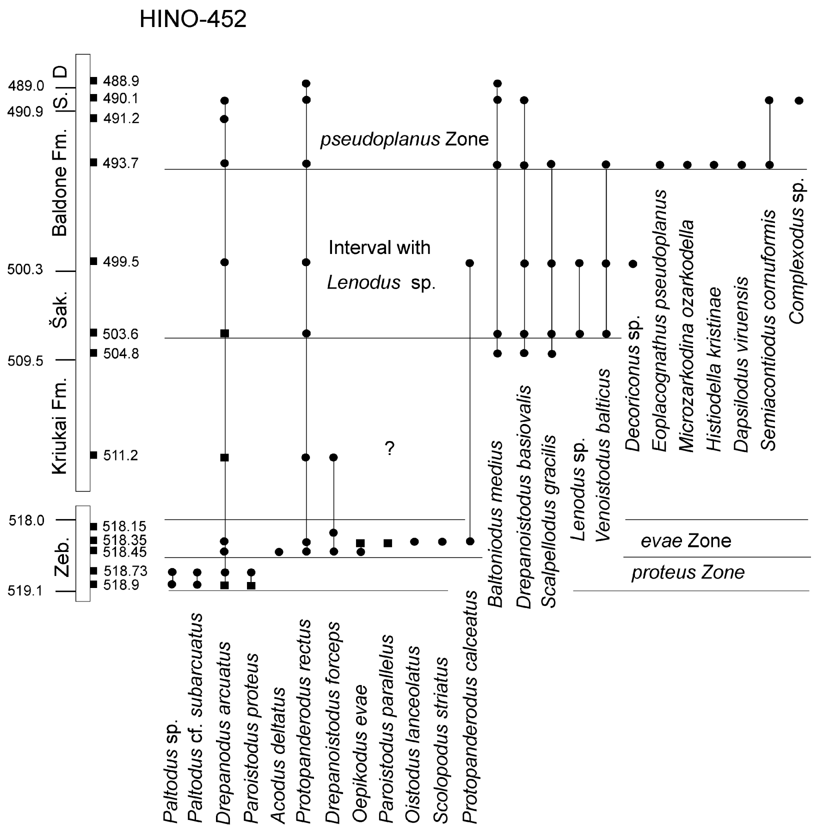

Fig. 10. Distribution of conodonts in the Hino-452 core section. Four barren samples in the interval 514.0–517.7 m are not shown in the figure. For abbreviations see Fig. 3. Depth in metres.

its lower and upper parts (Löfgren 1993). In northern Estonia the lower part with *O. evae* is present in the Mäeküla Member and the upper part without *O. evae* in the Päite Member of the Billingen Stage (Viira et al. 2001).

The interval of reddish-brown argillaceous dolostone in the Kriukai Formation is represented by rare samples and a small number of conodonts. Three zonal species are found in this interval: ***Baltoniodus triangularis*** (Fig. 6C) at 427.15 m in the Dekshino-328 core, ***Baltoniodus navis*** at 422.8 and 418.4 m in the Dekshino-328 core and ***Paroistodus originalis*** at 438.0 and 433.9 m in the Petseri-330 core. This interval is remarkable for occurrences of large, in places numerous, specimens of *Drepanodus* and *Protopanderodus*. A specific feature of the fauna is also the small number of *Baltoniodus* and *Microzarkodina* specimens. According to R. Ulst (Ulst et al. 1982), *B. navis*, *P. originalis* and *Microzarkodina flabellum* are represented in the red marlstones of the Kriukai Formation in western Latvia. The *B. navis* and *P. originalis* zones are known in the Volkhov Stage in many outcrop and borehole sections of Estonia.

Fig. 9. Conodonts from the studied sections. **A**, **D**, *Eoplacognathus pseudoplanus* (Viira). A, GIT 594-73, Pb element, ×90, Laanemetsa-70 core, depth 359.0 m; D, GIT 594-74, Pa element, ×140, Hino-452 core, depth 493.7 m. **B**, *Yangtzeplacognathus crassus* (Chen & Zhang). GIT 594-75, Pa element, ×120, Laanemetsa-70 core, depth 367.0 m. **C**, *Eoplacognathus suecicus* Bergström. GIT 594-76, Pb element, ×110, Laanemetsa-70 core, depth 351.9 m. **E**, **H**, **I**, *Lenodus* sp. E, GIT 594-77, Pa element, ×105, Laanemetsa-70 core, depth 368.4 m; H, GIT 594-78, Pa? element, ×75; I, GIT 594-79, Pa element, ×120; H, I, Hino-452 core depth 499.5 m. **F**, *Baltoplacognathus robustus* (Bergström). F-1, GIT 594-80, Pb element, ×100; F-2, part of the anterior process, Dekshino-328 core, depth 387.5 m. **G**, *Eoplacognathus lindstroemi* (Hamar). GIT 594-81, Pb element, ×120, Dekshino-328 core, depth 379.6 m. **J**, *Periodon* sp. GIT 594-82, P element, ×125, Laanemetsa-70 core, depth 351.9 m. **K–M**, *Complexodus* sp. K, GIT 594-83, P element, ×75, Petseri-330 core, depth 410.2 m; L, GIT 594-84, P element, ×75, Hino-452 core, depth 490.1 m; M, GIT 594-85, P element, ×60, Dekshino-328 core, depth 394.8 m. **N**, **O**, *Histiodella kristinae* Stouge. N, GIT 594-86, P element, ×110; O, GIT 594-87, P element, ×125; N, O, Hino-452 core, depth 393.7 m.


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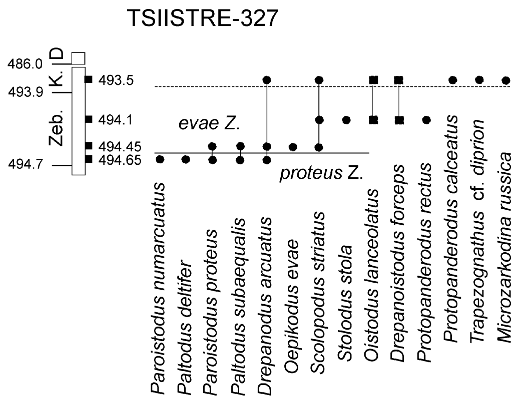


Fig. 12. Distribution of conodonts in the Tsiistre-327 core section. For abbreviations see Fig. 3. Depth in metres.

The appearance of representatives of the genus *Lenodus* in the uppermost Kriukai Formation marks the beginning of the platform conodont lineages whose members become zonal species upwards. *Lenodus* sp. is determined in the Dekshino-328, Hino-452 and Laanemetsa-70 sections in the uppermost Kriukai, Šakyna and lower part of the Baldone formations. These fragmentary specimens may belong either to *Lenodus antivariabilis* from the upper subzone of the *B. norrlandicus* Zone or to the nominal species ***Lenodus variabilis***. Complete specimens of *L. variabilis* are represented in the Petseri-330 core (425.2 and 424.0 m, Fig. 5B, C, F). In northern Estonia the *Lenodus variabilis* Zone has been established in the Kunda Stage, in the Loobu Formation in the Taga-Roostoja (25A) and Kerguta-565 core sections (Viira & Männik 1999; Viira et al. 2006b).

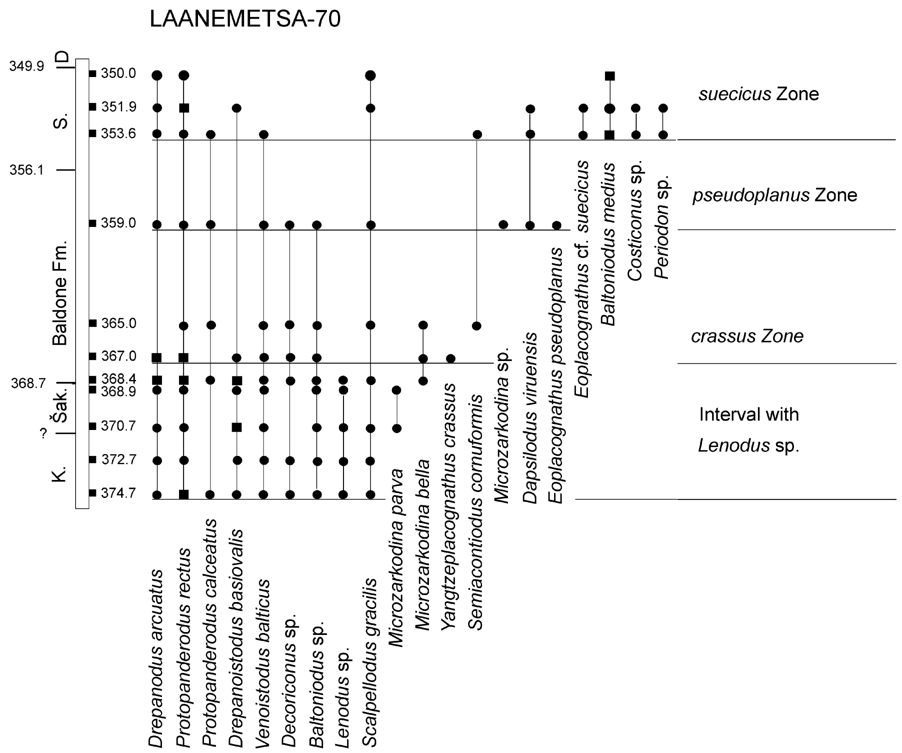
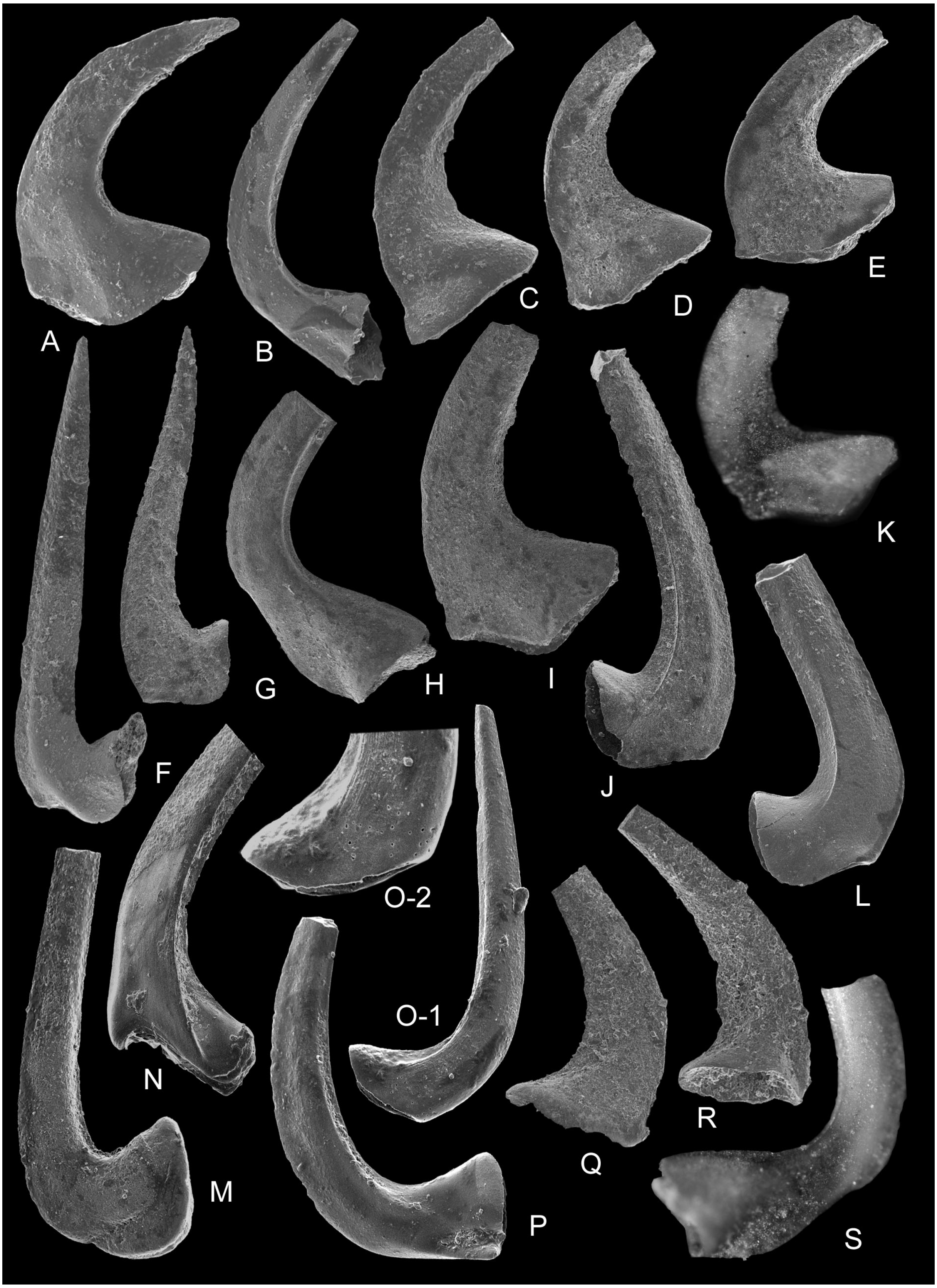


Fig. 13. Distribution of conodonts in the Laanemetsa-70 core section. For abbreviations see Fig. 3. Depth in metres.

Fig. 11. Conodonts from the studied sections. **A**, *Periodon flabellum* (Lindström). GIT 594-20, Sa element, ×90, Petseri-330 core, depth 443.7 m. **B**, **C**, *Drepanoistodus forceps* (Lindström). B, GIT 594-21, M element, ×60, Petseri-330 core, depth 443.0 m; C, GIT 594-22, M element, ×60, Tsiistre-327 core, depth 493.5 m. **D**, *Oepikodus evae* Lindström. GIT 594-23, Pb element, ×85, Hino-452 core, depth 518.35 m. **E**, *Scolopodus striatus* Pander. GIT 594-24, Sa element, regenerated specimen, ×65, Tsiistre-327 core, depth 493.5 m. **F**, ?*Drepanoistodus* sp. GIT 594-25, M element, ×70, Tsiistre-327 core, depth 493.5 m. **G**, *Semiacontiodus cornuformis* (Sergeeva). GIT 594-26, Sa element, ×85, Petseri-330 core, depth 420.4 m. **H–L**, **P–R**, *Oistodus lanceolatus* Pander. H, GIT 594-27, P element, ×105; I, GIT 594-28, S element, ×70; J, GIT 594-29, P element, ×95; K, GIT 594-30, Sa element, ×125; L, GIT 594-31, P element, ×100; P, GIT 594-32, S element, ×100; Q, GIT 594-33, S element, ×80; R, GIT 594-34, S element, ×70; H–L, P, R, Petseri-330 core, depth 443.7 m; Q, Tsiistre-327 core, depth 493.5 m. **M**, *Drepanoistodus* cf. *basiovalis* (Sergeeva). GIT 594-35, M element, ×65, Tsiistre-327 core, depth 493.5 m. **N**, *Drepanoistodus* cf. *stougei* Rasmussen. GIT 594-36, M element, ×60, Laanemetsa-70 core, depth 368.4 m. **O**, *Paroistodus parallelus* (Pander). GIT 594-37, P element, ×65, Hino-452 core, depth 518.35 m.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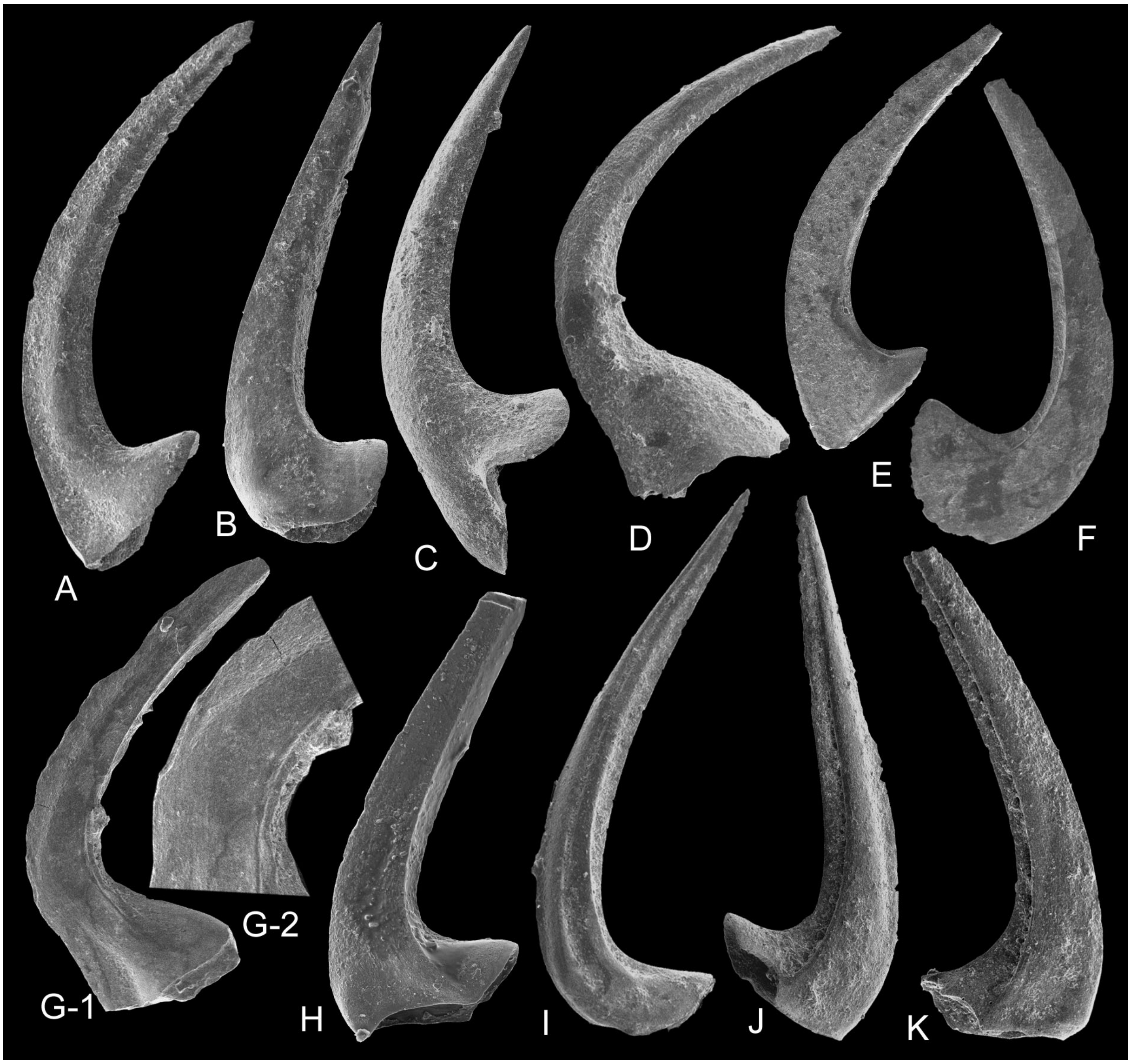

Fig. 15. Conodonts from the studied sections. **A–G**, *Drepanodus arcuatus* Pander. A, GIT 594-128, M element, ×65; B, GIT 594-129, Pb element, ×90; C, GIT 594-130, Pa element, ×90; D, GIT 594-131, Sa element, ×95; E, GIT 594-132, M element, ×35; F, GIT 594-133, Sc element, ×40; G-1, GIT 594-134, Sa element, ×40; G-2, part of the cusp; A–D, Tsiistre-327 core, depth 493.5 m; E, Laanemetsa-70 core, depth 368.4 m; F, Hino-452 core, depth 493.7 m; G, Dekshino-328 core, depth 401.5 m. **H**, **K**, *Protopanderodus rectus* (Lindström). H, GIT 594-135, Sc element, ×80, Laanemetsa-70 core, depth 365.0 m; K, GIT 594-136, Sc element, ×85, Tsiistre-327 core, depth 493.5 m. **I**, **J**, *Protopanderodus calceatus* Bagnoli & Stouge. I, GIT 594-137, Sb? element, ×50; J, GIT 594-138, Pa element, ×65; Tsiistre-327 core, depth 493.5 m.

Fig. 14. Conodonts from the studied sections. **A–I**, **K**, **S**, *Drepanodus arcuatus* Pander. A, GIT 594-109, Sc element, ×45; B, GIT 594-110, Sb element, ×45; C, GIT 594-111, Sd element, ×60; D, GIT 594-112, Sd element, ×60; E, GIT 594-113, Sc element, ×50; F, GIT 594-114, Pb element, ×35; G, GIT 594-115, Pb element, ×40; H, GIT 594-116, Sa element, ×40; I, GIT 594-117, Sc element, ×40; K, GIT 594-118, Sc element, ×60; S, GIT 594-119, Sa element, ×40; A, B, F, H, I, S, Petseri-330 core, depth 427.8 m; C–E, G, Petseri-330 core, depth 425.2 m. **J**, **L**, **M**, **P**, *Drepanodus* cf. *arcuatus* Pander. J, GIT 594-120, Pb element, ×75; L, GIT 594-121, Pb element, ×55; M, GIT 594-122, Sc element, ×65; P, GIT 594-123, ×50; J, L, P, Petseri-330 core, depth 416.9 m; M, Petseri-330 core, depth 408.7 m. **N**, **O**, *Protopanderodus rectus* (Lindström). N, GIT 594-124, Sb element, ×80, Petseri-330 core, depth 420.2 m; O-1, GIT 594-125, Sa? element, ×80, O-2, lower part of the cusp, Petseri-330 core, depth 443.0 m. **Q**, **R**, *Scalpellodus latus* (van Wamel). Q, GIT 594-126, P element, ×90; R, GIT 594-127, P element, ×110; Q, R, Petseri-330 core, depth 430.9 m; K, S, light microscope photos.

The ***Yangtzeplacognathus crassus*** Zone is proved by a find of a complete specimen of the index species (Fig. 9B) at 367.0 m in the Laanemetsa-70 core and of the Sa element at 420.4 m in the Petseri-330 core. From the *Y. crassus* Zone level upwards, the conodont taxa are represented by more numerous specimens, including species of the genus *Baltoniodus*, which may indicate the shallowing of the basin (Löfgren 2003). In North Estonia *Y. crassus* has been identified in the Kerguta-565 core (at 187.7 and 187.2 m), in the lower part of the Loobu Formation of the Kunda Stage (Viira et al. 2006b).

The ***Eoplacognathus pseudoplanus* Zone** is represented by the nominal species in four core sections: Petseri-330 (depth 416.9 m), Dekshino-328 (401.5, 399.3 and 396.5 m), Hino-452 (493.7 m) and Laanemetsa-70 (359.0 m). The occurrences of *Microzarkodina ozarkodella* in the same samples in the Petseri-330 and Hino-452 cores determine the upper subzone of the *E. pseudoplanus* Zone (Löfgren 2004). The occurrence of *M.* cf. *hagetiana*, the index species of the lower subzone in the *Y. crassus* Zone (Petseri-330), is in accordance with the range of this species from the *L. variabilis* Zone up to the *E. pseudoplanus* Zone (Löfgren & Tolmacheva 2008). In southeastern Estonia the *E. pseudoplanus* Zone is found in the upper part of the Baldone Formation. In the Mehikoorma-421 core section *E. pseudoplanus* is also found in the upper part of the Baldone Formation (Männik & Viira 2005). In North Estonia this zone is known from the Pakri, Loobu and Napa formations of the Kunda Stage (Viira et al. 2001, 2006b).

The nominal species of the ***Eoplacognathus suecicus* Zone** is found in the Petseri-330 core at 411.5 and 408.4 m and in the Dekshino-328 core at 394.8 and 391.0 m, on the level corresponding to the Segerstad Formation. The illustrated specimens of *E. suecicus* from the Petseri-330 core (sample from 408.4 m; Fig. 5J–M) are morphologically similar to the specimens from the *E. suecicus* Zone, illustrated by Zhang (1999, fig. 2). Usually *Panderodus sulcatus* appears in this zone. In North Estonia *E. suecicus* is found in the Aseri and uppermost Kunda stages in the Mäekalda section and in the Aseri Stage in the Taga-Roostoja-25A section (Viira & Männik 1999; Viira et al. 2001).

The next two zonal species ***Pygodus serra*** and ***Pygodus anserinus*** were not found but the nominal taxa of the three following subzones are present in the Petseri-330 and Dekshino-328 sections. The ***Yangtzeplacognathus foliaceus*** Subzone was identified by the presence of two complete specimens of the nominal species in the Stirnas Formation of the Petseri-330 core at a depth of 407.3 m (Fig. 5N, O). *Yangtzeplacognathus foliaceus* has been recognized in Estonia in the lower part of the Väo Formation of the Lasnamägi Stage (Viira 1967, 1974; Viira & Männik 1999; Männik & Viira 2005). The broken specimen of ***Baltoplacognathus robustus*** (Fig. 9F), identified in the sample from 387.5 m in the Dekshino-328 core, defines the subzone of the same name. The *Baltoplacognathus robustus* is found in the Taurupe Formation of the Ruhnu-500 core, and in the Väo Formation (Lasnamägi Stage) in many core sections of Estonia, such as Ohesaare, Kerguta-565, Äiamaa, Taga-Roostoja-25A and Kaagvere (Viira 1967; Viira & Männik 1999; Männik 2003; Viira et al. 2006b; unpublished material by the author). A complete Pa element of the subzonal species ***Eoplacognathus lindstroemi*** (Fig. 9G) was found at 379.6 m in the Dekshino-328 core, in a sample of grey argillaceous dolostone of the Taurupe Formation. This species is also known from the middle part of the Taurupe Formation in the Ruhnu-500 core (Männik 2003). In northern Estonia *E. lindstroemi* has been identified from the upper Väo and Kõrgekallas formations of the Ohesaare, Äiamaa, Kerguta-565, Taga-Roostoja-25A, Mehikoorma-421 and Kaagvere core sections (Viira 1967; Viira & Männik 1999; Männik & Viira 2005; Viira et al. 2006b; unpublished material by the author).

REMARKS ON CONODONT FAUNA

The Lower–Middle Ordovician conodont fauna of southeastern Estonia is comparable to the diverse and abundant shallow shelf fauna of northern Estonia and deeper shelf fauna of Sweden. In southern Estonia the red-coloured sediments of the Volkhov Stage were deposited in the deep shelf of the Central Baltoscandian facies belt (Männil 1966; Ulst et al. 1982). The southeastern Estonian conodonts should be observed in three successive faunas. The conodont assemblage of the first **Hunneberg–Billingen fauna** is generally similar to those in northern Estonia (Viira et al. 2001, 2006a; Löfgren et al. 2005). The study of conodonts in the SE Estonian sections starts with the *Paroistodus proteus* Zone. The lowermost samples have mixed fauna with redeposited conodonts from the underlying *Paltodus deltifer* Zone. The same situation is recognized in the Uuga section, NW Estonia, where conodont elements of these two zones are mixed in the whole range of the *P. proteus* Zone (Löfgren et al. 2005). The *Prioniodus elegans* Zone is absent in the studied sections, possibly because the interval with *Prioniodus elegans* is often very thin. Another possibility is that this zone together with the upper part of the *Paroistodus proteus* Zone is absent because of a gap. The *Prioniodus elegans* Zone is poorly developed in most of the Swedish sections, or occurs as reworked and fragmentary fauna at the base of the

O. evae Zone (Lindström 1971; Bergström 1988). In NW Estonia (Uuga, Keila-Joa) the conodonts of the *Prioniodus elegans* Zone are redeposited, while elsewhere in northern Estonia (Mäekalda, Jägala, Varangu, Narva) the thickness of the zone is about 0.3–0.5 m, reaching 1 m only in the Saka section (Viira et al. 2001, 2006a; Löfgren et al. 2005). The *Oepikodus evae* Zone is commonly present in all previously investigated sections of Billingen age, both in North Estonian outcrop sections, and South and Central Estonian borehole sections, including unpublished core sections (Uuga, Mäekalda, Jägala, Saka, Taga-Roostoja-25A, Kerguta-565, Ohesaare, Kaagvere, Karula, Abja). In Sweden this zone is well represented, and usually the upper part of the zone is without the zonal indicator (Lindström 1971; Löfgren 1993). The situation is similar in Estonian sections, where the zonal species occurs in the lower and *Periodon flabellum* in the upper part of the zone (Viira 1974; Viira et al. 2001).

The SE Estonian conodonts of the **Volkhov fauna** differ largely from the shallow shelf faunas of northern Estonia. The difference in the studied conodont fauna first of all lies in the small number of *Baltoniodus* specimens, particularly in the Kriukai Formation. Only single specimens determine the *B. triangularis* and *B. navis* zones in the Petseri-330 and Dekshino-328 cores. Usually *Baltoniodus* species are the most abundant in the shallow shelf settings of northern Estonia and also in deeper-water environments of Scandinavia. According to Löfgren (2003), *Baltoniodus* has comparable abundance maxima in shallow parts of the basin as well as in deeper parts. Löfgren (2003) also noted that some environmental factor other than water depth may influence its distribution. Rasmussen & Stouge (1995) considered the *Baltoniodus* biofacies to be typical of the shallow and deeper shelf environment. Secondly, *Drepanodus* and *Protopanderodus* found in great numbers and specimens in the upper Kriukai, Šagina and lower Baldone formations are frequently very large (Figs 14, 15). *Drepanodus arcuatus* and *Protopanderodus rectus* occur in almost all northern Estonian sections but never in such abundance and large sizes. According to Löfgren (2003, 2004), species of *Drepanodus* and *Protopanderodus* of the Swedish conodont faunas preferred the areas representing deeper parts of the epicontinental sea. As stated by Rasmussen & Stouge (1995), the *Protopanderodus–Periodon* biofacies characterizes the slope environment. It should also be noted that the studied sections contain only few specimens of *Microzarkodina* species, whereas the representatives of this genus are typical of fairly shallow-water settings (Löfgren & Tolmacheva 2008).

Consequently, the conodont associations in the deep shelf settings of SE Estonia have some peculiarities probably caused by multiple factors. The impoverishment of the conodont fauna in the Volkhov Stage may be closely connected with maximal submersion of the Jelgava depression and currents in the deep shelf (Kiipli et al. 2009). The Jelgava depression in Latvia came into being in Hunneberg–Billingen time and deepening proceeded up to the end of Kunda time (Männil 1966; Ulst et al. 1982). The occurrences of large specimens of some species (*Drepanodus* and *Protopanderodus*) in the lower Darriwilian could be explained by upwelling activity (Kiipli et al. 2010).

Conodonts of the subsequent **Darriwilian fauna** of SE Estonia became more variable and abundant, and more similar to the usual deep shelf assemblages, for instance in the Mehikoorma-421 and Tartu-453 sections (Põldvere 1998; Männik & Viira 2005).

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Alam- ja Kesk-Ordoviitsiumi konodondid Kagu-Eesti puuraukudes

Viive Viira

On uuritud konodontide levikut Alam- ja Kesk-Ordoviitsiumi kihtides viies Kagu-Eesti puuraugu läbilõikes. On kindlaks tehtud kümme konodondi tsooni ja kuus alamtsooni, alates *Paroistodus proteus*'e tsoonist kuni *Eoplacognathus lindstroemi* alamtsoonini. Üldiselt on kindlakstehtud konodondi fauna sarnane Põhja-Eesti samaealisele faunale. Erinevus on Volhovi lademes, mis sisaldab märkimisväärselt vähe konodonte, eriti *Baltoniodus*'e liike. Kuid *Drepanodus arcuatus*'e ja *Protopanderodus rectus*'e suuri eksemplare on arvukalt leitud Ülem-Volhovi ning Alam-Kunda lademe setetes. Üldiselt on Kagu-Eesti sügava šelfi konodondi kooslused võrreldud Põhja-Eesti madala šelfi kooslustega.