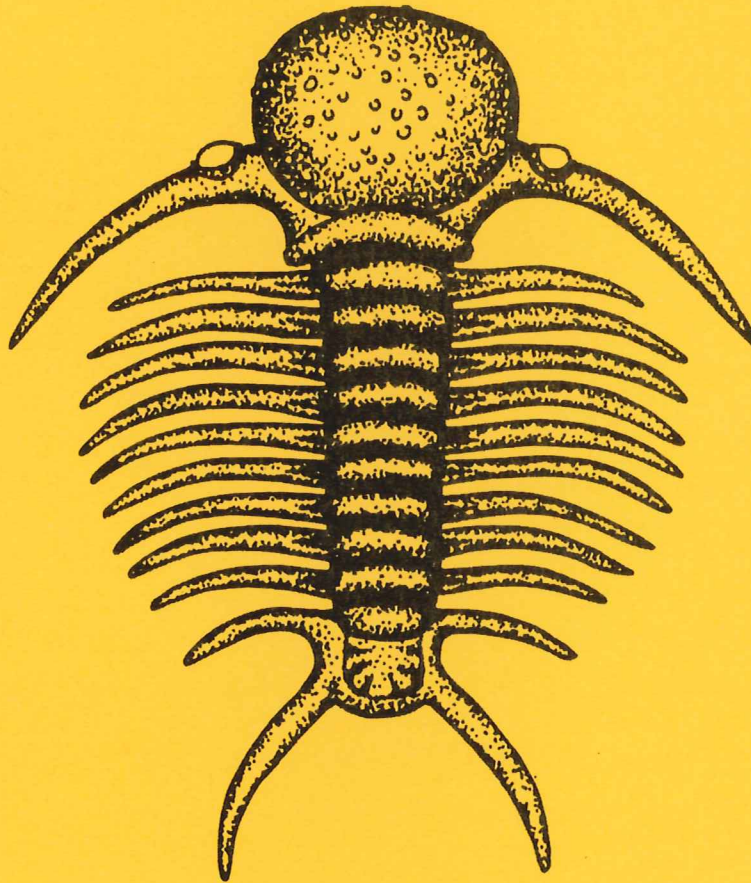


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EXAMENSARBETE I GEOLOGI VID LUNDS UNIVERSITET

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of the Tamsalu drill core, central Estonia**

Lisa Sjöstrand

Lund 2003

Examensarbete, 20 p

Nr 156

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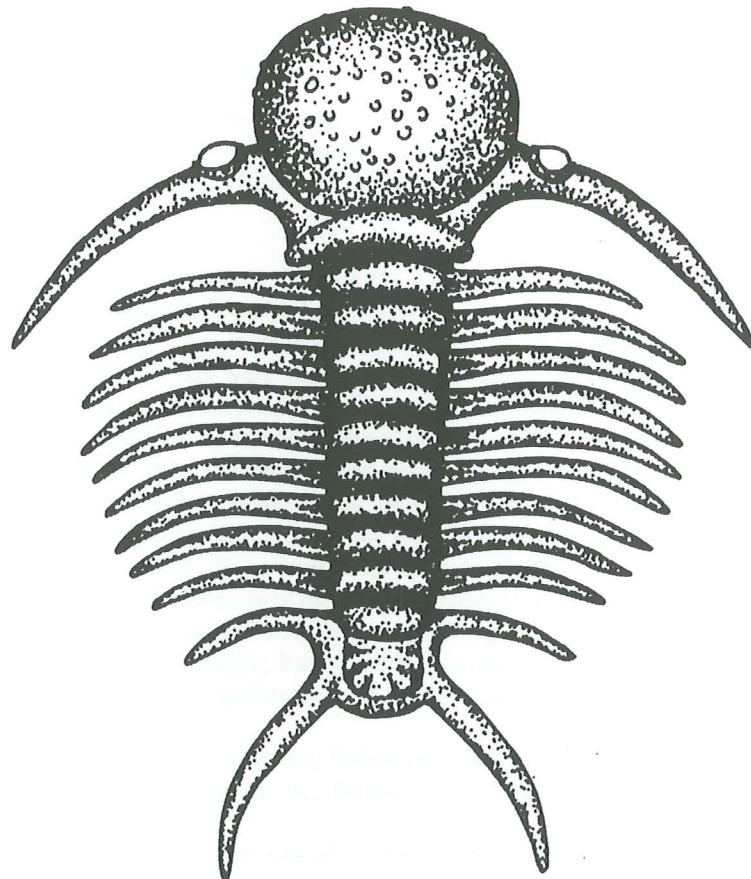
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LISA L. M. SJÖSTRAND

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Abstract: This investigation examines the distribution of conodont elements in the Early to early Middle Ordovician Latorpian, Volkhovian, Kundan and Aserian stages of the Tamsalu drill core in central Estonia. Slightly more than 24, 600 conodont elements from 17 samples were examined, and the biostratigraphic results were compared to previous works on conodont biostratigraphy from localities in Estonia, Russia and Öland, Sweden. The samples are indicative of the *Oepikodus evae* Zone, the *Baltoniodus navis* Zone, the *Paroistodus originalis* Zone, the *Baltoniodus norrlandicus* Zone, the *Lenodus variabilis* Zone, the *Yangtzeplacognathus crassus* Zone, the *Eoplacognathus pseudoplanus* Zone, (the latter including the *Microzarkodina hage-tiana* and the *Microzarkodina ozarkodella* subzones) and finally the *Eoplacognathus suecicus* Zone. The thicknesses of the different stages (Latorpian, Volkhovian, Kundan and Aserian) are compared between the following localities in Estonia: Tamsalu, Kaugatuma, Ohesaare, Rumba, Kullamaa, Mäekalda, Tartu, Taga-Roostoja and Ontika. Two new species, *Parapaltodus* n. sp. A and *Texania* n. sp. A, are described.

Keywords: Ordovician, Latorpian, Volkhovian, Kundan, Aserian, conodonts, biostratigraphy, *Parapaltodus* n. sp. A., *Texania* sp. A, Tamsalu, Estonia.

Lisa L. M. Sjöstrand, Department of Geology, Lund University, Sölvegatan 13, SE-223 62 Lund, Sweden. E-mail: lisa.sjostrand@hassleholm.mail.telia.com

Conodonts belong to the Conodontophorida (or Conodonta), a group of early chordates, and are provided with small, phosphatic, tooth-like structures that are preserved in some abundance (Sweet 1988). They are found in marine rocks of late Cambrian to late Triassic age. The conodonts have been the object for study for over 100 years and were first discovered by Pander (1856). Their value for biostratigraphy continues to grow, because of their rapid morphological evolution, small size, relative abundance and wide distribution. They are also fairly resistant to the rigours of diagenesis and tectonism, and amenable to extraction from carbonaterocks by using weak organic acid or by physical methods (Brasier 1980).

The main aim of this study is to investigate the conodont fauna from the Tamsalu drill core, in central Estonia

(Fig. 1) biostratigraphically, and compare it to conodont faunas of similar age from localities in Estonia: Mäekalda (Viira et al. 2001), Tartu (Männik 1998), Taga-Roostoja (Poldvere 1999), Ontika (Mägi 1990) and Kaugatuma and in Öland, Sweden: Gillberga (Löfgren 2000b) and Horns Udde (Bagnoli & Stouge 1997). A general comparison of thicknesses of Latorpian, Volkhovian, Kundan and Aserian beds in different parts of Estonia: Kaugatuma, Ohesaare (Viira 1967), Rumba (Kaljo & Nestor 1990), Kullamaa (Kaljo & Nestor 1990), Mäekalda (Viira et al. 2001), Tartu (Männik 1998), Taga-Roostoja (Poldvere 1999), and Ontika (Mägi 1990) has also been made (Figs. 2 and 3). Two new species, *Parapaltodus* n. sp. A and *Texania* n. sp. A were discovered during the investigation and are described here.

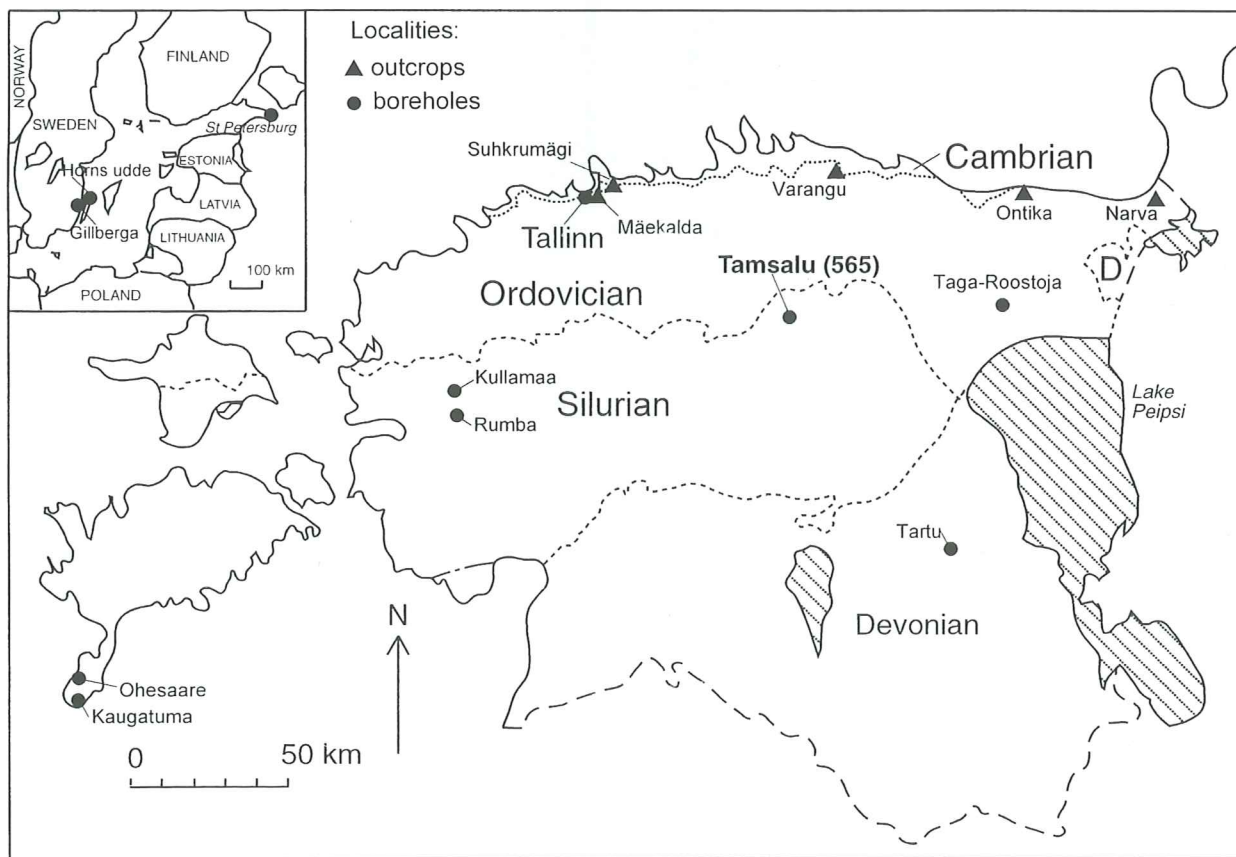


Fig. 1. Map of Estonia, showing the location of the Tamsalu drill core and the localities discussed in the text: Kaugatuma, Ohesaare, Kullamaa, Rumba, Mäekalda, Tartu, Taga-Roostja and Ontika. The inset map shows the localities on Öland, Sweden: Gillberga and Horns Udde and St Petersburg.

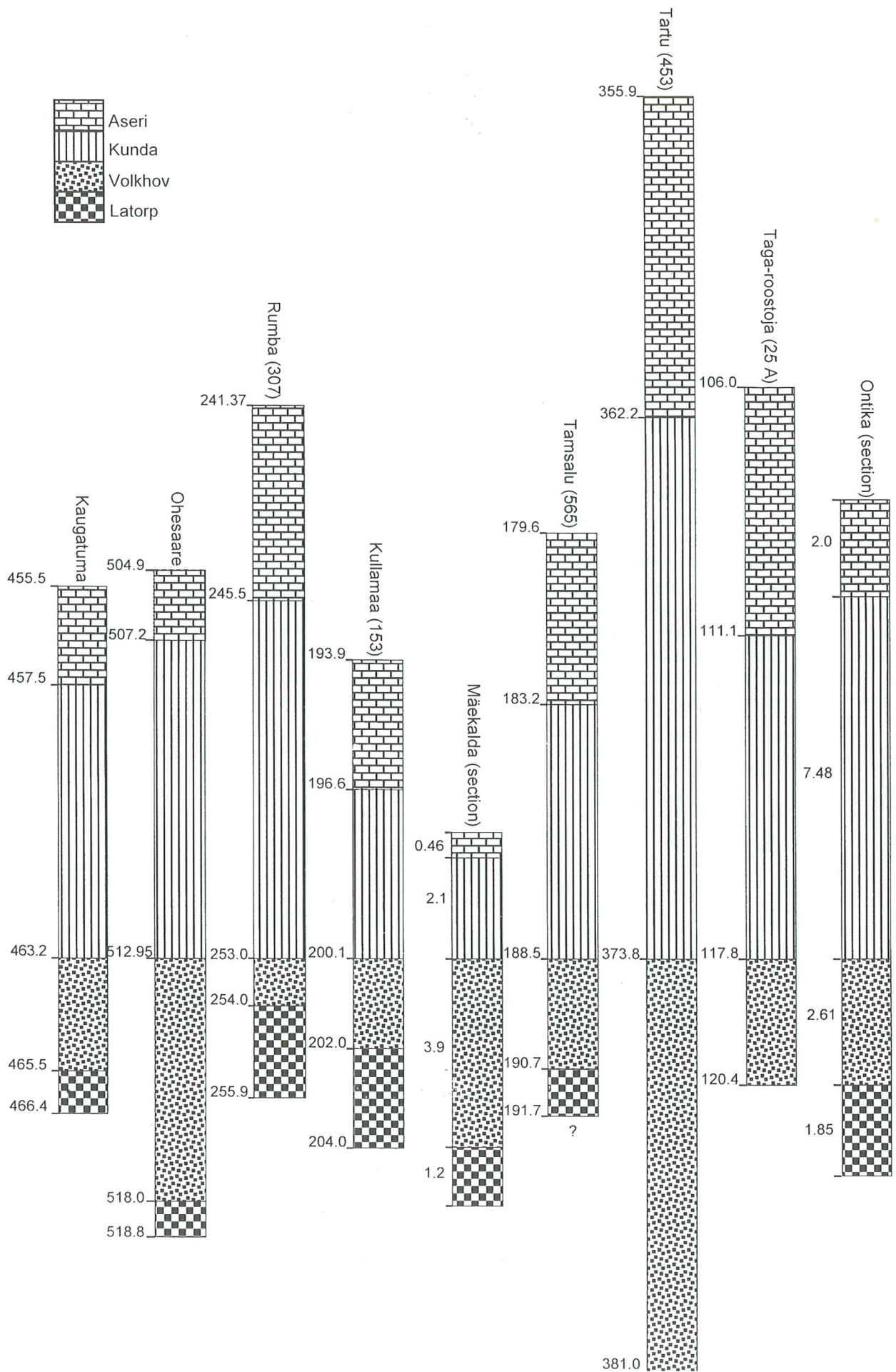


Fig. 2. Varying thicknesses of Latorpian, Volkhovian, Kundan and Aserian beds in Estonia. Sections are generally arranged from W to E. For location, see Fig. 1.

Geological setting

In the early Ordovician, Baltoscandia was situated at 25–35°S and epicontinental seas with extensive distribution of carbonate sediments had a greater extent than during any other period. The marine flora and fauna changed markedly in this period and a number of major taxonomic groups appeared or became common: bryozoans, brachiopods, echinoderms, planktic graptolites, conodonts, ostracods, chitinozoans and others (Stanley 1993). Estonia, on the Baltic plate, is among the areas in the world where this fauna is particularly well preserved and easily available for study (see Raukas & Teedumäe 1997). The large-scale biogeographical and facies differentiation within the Ordovician Palaeobasin of Baltoscandia is expressed in the concept of confacies belts (Jaanusson 1976; see also Raukas & Teedumäe 1997). The territory of Estonia is divided between the North Estonian and the Central Baltoscandian confacies belts (see Raukas & Teedumäe 1997). Tamsalu is within the North Estonian belt.

The Tamsalu borehole was drilled through strata in central Estonia and includes beds from the Latorpian, Volkhovian, Kundan and Aserian stages. The Billingen Substage in Estonia comprises the upper part of the Latorpian Stage and is characterised by the two zonal indicators *Prioniodus elegans* and *Oepikodus evae*, respectively. This substage is mostly represented by glauconitic limestones in the North and by the reddish-brown, occasionally glauconitic dolomites in central Estonia (see Raukas & Teedumäe 1997).

The Volkhovian Stage is represented by the first appearance of *Baltoniodus triangularis*, followed by the successive zones of *Baltoniodus navis*, *Paroistodus originalis*, *Baltoniodus norrlandicus* (Raukas & Teedumäe

1997) and in the upper part *Lenodus antivariabilis* (see Zhang 1998). The term "Volkov Stage" was introduced by Röömusoks (1956) and this interval was thoroughly described by Orviku (1960), who also introduced a three-fold subdivision of the Volkov Stage, which was thought to be consistent with the established eastern Baltic subtidal units, from the base: Saka, Vääna, and Langevoja substages (Dronov et al. 2000). The Volkov Stage is lithologically complex, as most of the beds consist of partly dolomitized glauconitic limestone or greenish-grey limestones and marls or grey argillaceous glauconitic limestones (see Raukas & Teedumäe 1997).

The Kundan Stage is divided into the *Lenodus variabilis*, *Yangtzeplacognathus crassus* and *Eoplacognathus pseudoplanus* zones. The last mentioned zone is subdivided into the *Microzarkodina hagetiana* and *Microzarkodina ozarkodella* subzones (Zhang 1998). The Kundan Stage is represented by oolitic, glauconitic and sandy limestone in northern Estonia, by yellowish-grey sandy limestones and calcareous sandstones in the W, and by up to 15 m red mottled oolitic limestone in central Estonia (see Raukas & Teedumäe 1997). The thickness of the Kundan Stage shows an obvious decrease from the central part towards northwestern Estonia. In northern and central Estonia it does not exceed 10 m, but may locally reach 20 m in southeastern Estonia (see Raukas & Teedumäe 1997).

In northern and central Estonia the Aseri Stage is 0.1–5 m thick and consists of bioclastic limestones with unevenly distributed ooids, predominantly brown iron (goethitic) ooids (see Raukas & Teedumäe 1997). The zonal indicator for the lower part of this stage is *Eoplacognathus suecicus* (Zhang 1998).

Material and methods

The 17 conodont samples in this study were collected from the Tamsalu drill core, central Estonia (Fig. 1), and the extraction of the conodonts was performed in Uppsala, Sweden, by using a buffered acetic acid method similar to the one described by Jeppsson et al. (1985). A little more than 24,600 conodont elements were sorted and glued in microfossil slides, and species determined by Anita M. Löfgren. The preservation of the conodonts is generally good, with some minor variations between the samples and all conodont elements have a CAI value of less than 1.5 (for explanation of index; see Epstein et al. 1977). Each sample contains between 383 and 6052 elements. The samples have been referred to stages, zones and subzones, according to the conodont distribution with the help of literature and previously established biostratigraphy.

The Aserian Stage is 3.6 m thick and the samples EST 86-18 B and EST 86-19 belong to this, while samples EST 86-1 to EST 86-18A belong to the top of the Kundan Stage (183.2 m) and downwards (Lars Holmer, Uppsala, personal communication to Anita M. Löfgren, 1992). Samples EST-12 and EST 86-13 are missing and EST 86-5 did not contain enough elements to investigate further.

Regional stage Locality	Aserian (m)	Kundan (m)	Volkhovian (m)	Latorpian (m)	Thickness (m)
Kaugatuma	2.0	5.7	2.3	0.9	10.9
Ohesaare	2.3	5.8	5.0	0.8	13.9
Rumba (307)	4.1	7.5	1.0	1.9	14.5
Kullamaa (153)	2.7	3.5	1.9	2.0	10.1
Mäekalda (section)	0.5	2.1	3.9	1.2	7.7
Tamsalu (565)	3.6	5.3	2.2	>1.0?	
Tartu (453)	6.3	11.6	7.2		25.1
Taga-Roostoja (25A)	5.1	6.7	2.6		14.4
Ontika (section)	2.0	7.5	2.6	1.9	14.0

Fig. 3. Thickness of Regional stages at Tamsalu and other selected localities in Estonia. Numbers in parentheses after names denote the core's specific directory number of the Estonian Geological Survey.

I have also correlated Tamsalu is with other localities in Estonia and Sweden and similarities as well as differences of the species composition and the thicknesses of the different stages are noted. Some specimens of biostratigraphically important species have been chosen for SEM photographing. These elements have been coated with gold and photographed, and the separate pictures then scanned from the negatives and digitally collected to "plates". The elements of the two new species have been drawn with help of Camera Lucida equipment.

Repository of material. -*The material is housed in the type collection of the Geological Institute, Technical University of Tallinn, Estonia.*

Thickness

A comparison is made between Tamsalu and other localities in Estonia (Fig. 1) with respect to thickness of the Latorpian, Volkhovian, Kundan and Aserian stages (Fig. 2). Possibly, the Latorpian and Aserian stages are thicker than described in the comparison between the various localities, because their tops and/or bases have not been encountered. In western Estonia, on the island of Saaremaa, there are two drillings, that include the four stages above, Ohesaare with about 13.9 m and Kaugatuma with about 10.9 m in thickness (Fig. 3). The successions of the localities Rumba and Kullamaa are about 14.5 m and 10.1 m thick, respectively (Fig. 3). Mäekalda is situated on the N coast of Estonia near Tallinn, and a little farther E is Ontika, with thicknesses of about 7.7 m and 13.9 m respectively (Fig. 3). The succession of Taga-Roostoja in northeastern Estonia, which did not include the Latorpian Stage, is 14.4 m and that of Tartu in the southeastern part is 25.1 m (Fig. 3). Finally, the Tamsalu drill core central Estonia is 12.1 m.

The Latorpian Stage is 0.8 – 2.0 m in Estonia (Fig. 3). Kullamaa in western Estonia has the highest value (2.0 m), and the lowest value (0.8 m) is from the island of Saaremaa on the west coast of Estonia. In Mäekalda and Ontika the Latorpian Stage varies between 1.2 and 1.9 m. The samples from the Tamsalu drill core do not include the lower boundary of the Latorpian Stage. Only 0.10 m of this stage is represented.

The Volkhovian Stage varies between 1.0 m and 7.2 m (Fig. 3). On the island of Saaremaa, there is a difference between the Ohesaare and Kaugatuma borings of 2.8 m although there is only c.10 km between these sites. The highest value of the Volkhovian Stage is from Tartu (7.2 m).

The Kundan Stage also has its greatest thickness in the Tartu drill core with 11.6 m and the lowest at Mäekalda with 2.1 m (Fig. 3). It looks as if the Kundan Stage decreases in thickness towards the NW and then increases to the SW, S and SE Estonia. If we compare Mäekalda and Ontika in the N there is a difference of 5.4 m.

The Aserian Stage also shows a marked difference between the localities. The Tartu drill core has the highest value (6.3 m) and Mäekalda the lowest one (0.5 m) (Fig. 3).

Description of the samples

The conodont element distribution for each of the 17 samples from the Tamsalu drill core is shown in Fig. 4, together with the relative frequencies and their abundance in Fig. 5. Three samples, EST 86-5, EST 86-12 and EST 86-13, have not been included, because the residues were not available for EST 86-12 and -13 and in EST 86-5 there were too few conodont elements. The characteristics of the samples and descriptions of the different conodont zones to which they have been assigned, are described below.

Latorpian Stage

The *Oepikodus evae* Zone (191.7-190.7m)

The *Oepikodus evae* Zone was first described by Lindström (1971), and *O. evae* (Lindström, 1955) was proposed as a zonal indicator. This zone is also characterized by the first appearance of *Oistodus lanceolatus* Pander, 1856, *Periodon flabellum* (Lindström, 1955) and *Stolodus stola* (Lindström, 1955) according to Stouge (1989). Several taxa have their last occurrences at Tamsalu in this zone: *Oepikodus evae*, *Stolodus stola*, *Parapaltodus* n. sp. A, *Tripodus* cf. *T. laevis*, *Decoriconus peselephantis* and *Texania* n. sp. A.

EST 86-18 A (191.7 m)

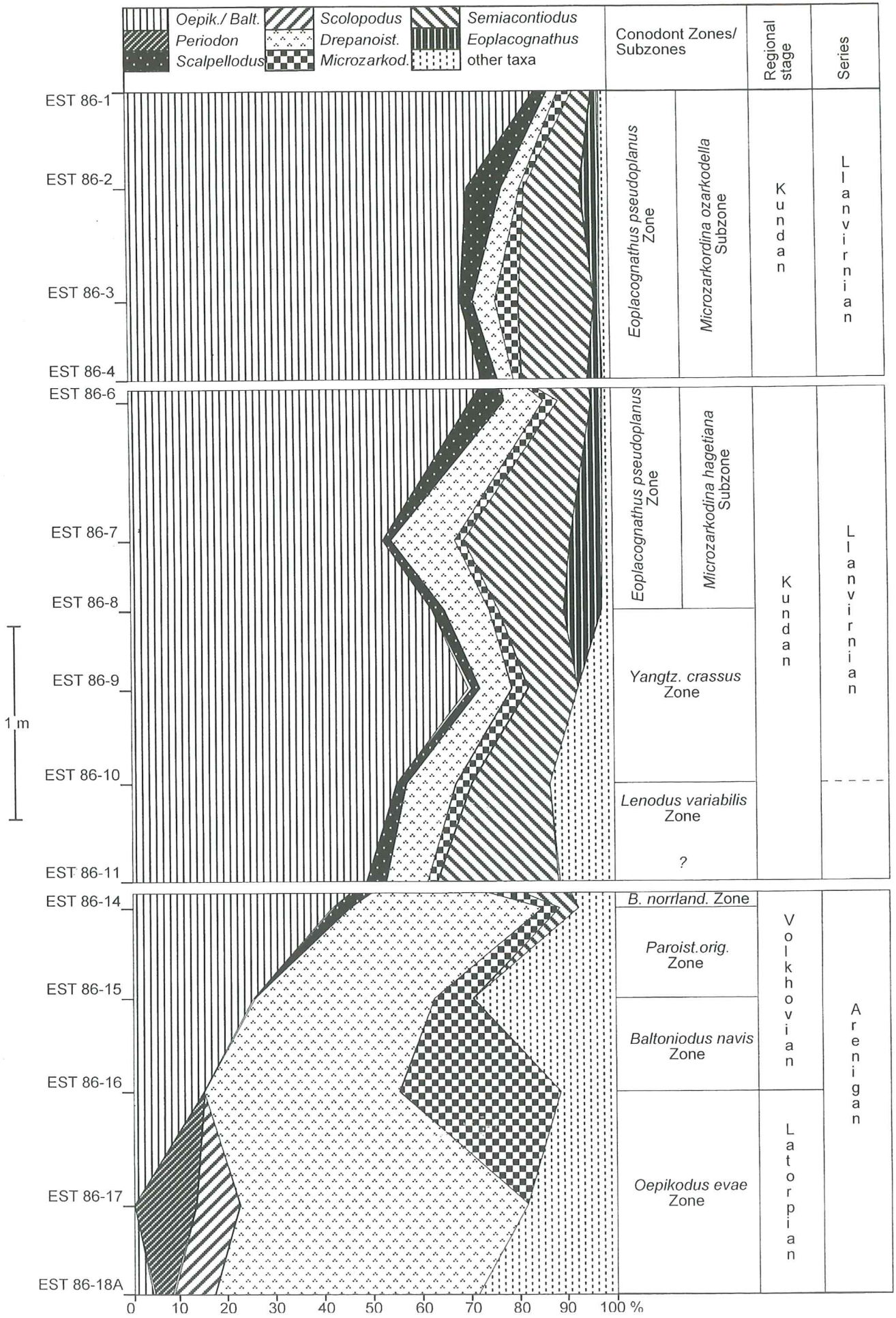
The 1210 elements in this sample represent 20 different species, but two of these, *Prioniodus elegans* and *Tripodus* sp., are probably redeposited since their edges are worn. The most abundant species is *Drepanoistodus forceps*, which is by far the most numerous, and then *Scolopodus striatus* Pander, 1856, *Oistodus lanceolatus*, *Drepanodus arcuatus* Pander, 1856, *Protopanderodus rectus* (Lindström, 1955) *Periodon flabellum* and *Oepikodus evae*. In the sample there is a new species, *Parapaltodus* n. sp. A., which will be described below (see appendix).

EST 86-17 (191.3 m)

This sample is represented by 1950 conodont elements of 15 different species. No elements of *Oepikodus evae* were found, but instead some new species have been added, such as *Texania* n. sp. A and *Drepanoistodus* cf. *basiovalis* (Sergeeva, 1963). *Drepanoistodus forceps* is still dominant in numbers. Only three elements of *Paroistodus originalis* (Sergeeva, 1963) were found in this sample, but a lot of *Periodon flabellum*. This is typical of the

Fig. 4. Conodont element distribution, absolute numbers and relative abundance percentage in the samples from the Tamsalu drill core and occurrence of the same species in Mäekalda, Tartu, Ontika, Kaugatuma, Gillberga and Horns Udde. Samples EST 86-18A and EST 86-17 belong to the upper *Oepikodus evae* Zone, EST 86-16 to the *Baltoniodus navis* Zone, EST 86-15 to the *Paroistodus originalis* Zone, EST 86-14 to the lower *Baltoniodus norrländicus* Zone, EST 86-11 to the *Lenodus variabilis* Zone, EST 86-10 and EST 86-9 to the *Yangtzeplacognathus crassus* Zone, EST 86-8 to EST 86-6 to the *Eoplacognathus pseudoplanus* Zone, *Microzarkodina hagetiana* Subzone, EST 86-4 to EST 86-1 to the *E. pseudoplanus* Zone, *Microzarkodina ozarkodella* Subzone, EST 86-18B to EST 86-19 to the lower part of the *Eoplacognathus suecicus* Zone.

Species	Tamsalu samples and other localities																	Total	Mäekalda	Tartu	Taga-Roostoja	Ontika	Kaugatama	Gillberga	Horns udde	
	EST 86-18A	EST 86-17	EST 86-16	EST 86-15	EST 86-14	EST 86-11	EST 86-10	EST 86-9	EST 86-8	EST 86-7	EST 86-6	EST 86-4	EST 86-3	EST 86-2	EST 86-1	EST 86-18B	EST 86-19									
<i>Oepikodus evae</i>	4.1 50																	50	x		x	x	x		x	
<i>Stolodus stola</i>	2.4 29																	29	x			x	x		x	
<i>Parapaltodus n. sp. A</i>	0.1 1	0.2 3																4							x?	
<i>Semiacontiodus sp.</i>	0.2 2		0.02 1															3	x	x						
<i>Periodon flabellum</i>	4.1 50	12.8 250			0.07 2													302	x		x	x	x		x	
<i>Tripodus cf. T. laevis</i>	2.2 26	0.8 15																41	x							
<i>Drepanoistodus forceps</i>	55.1 667	59.6 1163	31.9 1932															3762	x	x	x	x	x	x	x	
<i>Oistodus lanceolatus</i>	7.4 90	5.2 102			0.04 1													193	x	x	x	x	x		x	
<i>Protopanderodus rectus</i>	4.6 56	2.2 42	4.5 275	1.6 17	1.7 46	0.3 1						0.2 2	0.2 1				440	x	x	x	x	x			x	
<i>Decoriconus peselephantis</i>	0.3 4	3.9 76															80	x		x					x	
<i>Scolopodus striatus</i>	8.1 98	8.5 166	0.8 47		0.1 3												314	x	x	x	x	x			x	
<i>Drepanodus arcuatus</i>	5.6 68	1.8 35	0.1 6	1.7 19	3.8 104	0.3 1			0.1 1	0.1 1	0.2 1				0.3 3	0.1 1	1.1 13	253	x	x	x	x	x		x	
<i>Cornuodus longibasis</i>	1.3 16	2.8 54	0.2 13	1.8 2	0.4 11	0.8 3	0.3 2	0.2 1	0.1 1		0.2 3							106	x			x	x		x	
<i>Texania n. sp. A</i>		0.4 8																8								
<i>Drepanoist. cf. basiovalis</i>		1.1 22	8.4 508															530	x			x			x	
<i>Paroistodus originalis</i>		0.2 3		12.9 141	0.7 18													162	x	x	x	x	x		x	
<i>Baltoniodus navis</i>			14.2 859	22.1 235	1.5													1094	x	x		x	x	x	x	
<i>Trapetz. quadrang.</i>			4.5 272	0.2 2	0.1 3													277	x	x				x	x	
<i>Microzark. flabellum</i>			34.5 2086															2086	x		x	x	x	x	x	
<i>Scalpellodus latus</i>		0.1 9	0.1 1	2.8 63														73	x	x	x?	x	x	x	x	
<i>Triangul. brevibasis</i>		0.1 7	12.8 140	0.04 1														148	x	x		x		x	x	
<i>Microzarkodina parva</i>			7.4 81	5.0 139	0.8 3	2.1 15	3.2 20											258	x	x		x	x	x	x	
<i>Drepanoist. basiovalis</i>			41.6 455	39.9 1104	6.8 26	9.6 68	6.5 40	8.6 82	13.1 240	8.7 128	3.5 20	5.2 52	3.4 22	2.0 22	7.2 82	11.8 142		2483	x				x	x	x	
<i>Baltoniodus norrland.</i>				43.2 1195														1195	x	x	x	x	x	x	x	
<i>Semiacon. comufomis</i>				2.6 72	25.8 116	16.3 67	10.8 142	14.9 228	7.7 113	10.3 59	12.1 121	12.4 79	4.1 45	5.5 62	12.8 154			1357	x	x	x	x	x	x	x	
<i>Baltoniodus medius</i>				49.9 191	55.4 393	70.2 435	63.7 606	52.8 966	71.7 1055	73.8 423	69.4 693	70.8 452	84.5 924	68.3 775	53.2 641			7555	x	x	x	x		x		
<i>Lenodus variabilis</i>				9.7 37	9.2 65													102		x	x	x	x	x		
<i>Drepanoist. venustus</i>				2.6 10	1.3 9	0.8 5	0.9 9	0.6 11	0.3 4			0.3 2		3.5 40	1.6 19			109	x		x			x	x	
<i>Scalpellodus gracilis</i>				2.9 11	2.0 14	1.8 11	1.5 14	1.7 31	6.8 100	2.8 16	2.8 28	7.7 79	3.2 35	4.4 50	7.8 94			453	x	x	x		x	x	x	
<i>Yangtzepl. crassus</i>					3.1 21	6.3 39												60							x	
<i>Dapsilodus viruensis</i>						0.3 2	1.3 12	0.4 7			0.2 2			2.0 23	0.4 5			51	x						x	
<i>Microzark. hagetiana</i>								1.1 10	0.8 15	1.6 22								48		x					x	
<i>Eoplac. pseudoplanus</i>								7.5 71	8.1 148	0.8 12	3.7 21	0.8 8	3.6 23	1.6 18	1.3 15			316	x		x				x	
<i>Semiacontiodus davidi</i>								10.1 183	2.1 29	4.7 44	4.4 44	0.2 1						284							x	
<i>Microzark. ozarkodella</i>										0.9 5	4.5 45	0.5 3	3.2 35	5.6 64	1.8 22			174	x		x	x	x	x		
<i>Eoplac. suecicus</i>														1.1 12	3.2 38			50	x		x	x	x			
<i>Protopand. cf. graeai</i>														0.3 3	6.5 78			81			x					
"Others"	4.4 53	0.6 11	0.6 37	0	0.3 7	0.3 1	1.0 7	0	0.3 3	0.05 1	0.1 2	0.2 1	0.4 4	1.0 6	1.0 12	0.6 7	0	152								
Total number of elements	1210	1950	6052	1093	2769	383	710	620	950	1831	1471	573	999	638	1094	1134	1206	24683								



upper *O. evae* Zone in Estonia (cf. Viira et al. 2001) and also of a few levels in the same interval in the St. Petersburg region (Tolmacheva 2001). In this sample the last elements of *Parapaltodus* n. sp. A and *Texania* n. sp. A occur.

Volkhovian Stage

The *Baltoniodus navis* Zone (190.7-190.3 m)

The *Baltoniodus navis* Zone was first defined by Lindström (1971), and *B. navis* (Lindström, 1955) was proposed as a zonal indicator. The zonal definition was later revised by Löfgren (1993) and Bagnoli & Stouge (1997). The base of the zone is currently defined by the first appearance of *B. navis* and its top by the abundant occurrence (> 0.3 %) of *Triangulodus brevibasis* (see Löfgren 1995).

EST-86-16 (190.7 m)

This sample contains 6052 elements of 13 different species. The most common species is *Microzarkodina flabellum* (Lindström, 1955) and thereafter *Drepanoistodus forceps*, *Baltoniodus navis*, *Drepanoistodus* cf. *basiovalis* and *Trapezognathus quadrangulum*. (Lindström, 1955). No *Paroistodus originalis* elements were found in this sample.

The *Paroistodus originalis* Zone (190.3-189.7 m)

The *Paroistodus originalis* Zone was first defined by Lindström (1971), and it is characterized by the abundant occurrence of *Paroistodus originalis*. Its boundaries were discussed in detail by Löfgren (1995). Here the base is drawn at the level where *T. brevibasis* exceeds 0.3% in abundance. The upper boundary is drawn just below the first appearance of *B. norrlandicus* (see Löfgren 2000a)

EST 86-15 (190.2 m)

The 1093 elements in this sample represent 10 different species. *Paroistodus originalis*, which was found in an earlier sample (EST 86-17), reappears here in fair abundance (13%). The species *Drepanoistodus forceps*, *Drepanoistodus* cf. *basiovalis* and *Microzarkodina flabellum* have disappeared and have been replaced by *Drepanoistodus basiovalis* (Sergeeva, 1963) and *Microzarkodina parva*. *Baltoniodus navis* is still abundant but *Trapezognathus quadrangulum* is rare.

The *Baltoniodus norrlandicus* Zone (189.7-? m), *Trapezognathus quadrangulum* Subzone

The *Baltoniodus norrlandicus* Zone was introduced by Bagnoli & Stouge (1997) and they defined the Zone as the interval between the first appearance of *Baltoniodus norrlandicus* (Löfgren, 1978) to the first appearance of *Lenodus antivariabilis* (An, 1981). Löfgren (2000a) ex-

tended the zone to also include beds up to the first appearance of *Lenodus variabilis* (Sergeeva, 1963), and distinguished a lower subzone (with *T. quadrangulum*) and an upper subzone (with *L. antivariabilis*). The lower boundary is easy to recognize in the East Baltic, across the different biofacies belts in Sweden and in Norway (see Löfgren 2000a). Only the lower subzone has been identified in the Tamsalu drill core.

EST 86-14 (189.7 m)

The total number of elements in this sample is 2769, representing 17 different species. The most abundant taxa are *Baltoniodus norrlandicus* and *Drepanoistodus basiovalis* with nearly equal numbers (~ 40%). The species indicating the *Trapezognathus quadrangulum* Subzone disappears with this sample with only few elements. *Trapezognathus quadrangulum* had its highest abundance in the *P. originalis* Zone. Since there were no *Lenodus antivariabilis* found in the sample, it could be assigned to the lower part of the zone. Other species in this sample are *Paroistodus originalis*, *Scolopodus striatus*, *Periodon flabellum*, *Scalpellodus latus*, *Triangulodus brevibasis* and *Oistodus lanceolatus*, all of which also disappear with this sample. One other species, *Semiacontiodus cornuformis* (Sergeeva, 1963) (cf. Löfgren 1999) appears for the first time.

Kundan Stage

The *Lenodus variabilis* Zone [188.2 (188.5)-187.7 m]

The *Lenodus variabilis* Zone is equivalent to the early *Amorphognathus variabilis* Zone (*sensu* Lindström 1971). *Lenodus variabilis* first appears slightly above the lower boundary of the Kundan Stage (Löfgren 2000a). The top of the zone is defined as the level of first appearance of *Y. crassus* (see Zhang 1998). *Baltoniodus medius* (Dzik, 1976) and *Scalpellodus gracilis* (Sergeeva, 1974) first appear in the lower part of this zone.

EST 86-11 (188.2 or 188.5 m)

The 383 elements in this sample represent 11 species. The most abundant species is *Baltoniodus medius* (Dzik, 1976). Some other new species also appear, such as *Lenodus variabilis*, *Scalpellodus gracilis* and *Drepanoistodus venustus* (Stauffer, 1935). Species with continued range are, e.g., *Protopanderodus rectus* and *Drepanodus arcuatus*. They are lacking entirely from beds immediately above this, only to reappear again higher up in the sequence. There is still a lot of *Semiacontiodus cornuformis*.

The *Yangtzeplacognathus crassus* Zone (187.7-186.8 m)

The base of the *Yangtzeplacognathus crassus* Zone is indicated by the first appearance of the species *Y. crassus* (Chen & Zhang, 1992) and its top by the last appearance of this species (Zhang 1998).

EST 86-10 (187.7 m)

The total number of elements in this sample is 710, representing 12 species. *Baltoniodus medius* is still dominating and the less common species are the same as in

Fig. 5. Relative abundance of selected genera in samples from the Tamsalu drill core. Note the extremely rich abundance of *Baltoniodus* in the upper two thirds of the sequence represented here. The breaks between EST 86-14 and EST 86-11 and between EST 86-6 and EST 86-5 are due to missing samples.

the preceding sample. One new species appears, *Yangtzeplacognathus crassus*, which also has given the zone its name.

EST 86-9 (187.2 m)

The 620 elements in this sample represent 9 species. The sample is dominated by *Baltoniodus medius*. *Lenodus variabilis* is lacking, but a new species has appeared: *Dapsilodus viruensis* (Fåhræus, 1966). Both *Yangtzeplacognathus crassus* and *Microzarkodina parva* disappear at the top of this zone.

The *Eoplacognathus pseudoplanus* Zone, *Microzarkodina hagetiana* Subzone (186.8-184.7? m) and *Microzarkodina ozarkodella* Subzone (184.7?-183.2 m)

The *Eoplacognathus pseudoplanus* Zone is subdivided into two subzones, the lower one characterized by *Microzarkodina hagetiana* Stouge & Bagnoli, 1990, and the upper one by *M. ozarkodella* (Lindström, 1971) (see Löfgren 2000b). That *E. pseudoplanus* (Viira, 1974) could be used as a zonal index of the upper part of the Kundan Stage was first proposed by Viira (1974) (Zhang 1998).

EST 86-8 (186.8 m), *M. hagetiana* Subzone

The total number of elements in this sample is 950, representing 11 species. *E. pseudoplanus* indicates the zone and few elements of *M. hagetiana* the subzone. The dominating species are *B. medius* followed by *S. cornuformis* and *D. basiovalis*. Only a few elements of *C. longibasis* (Lindström, 1955), *D. venustus*, *S. gracilis* and *Dapsilodus viruensis* are represented in the sample.

EST 86-7 (186.4 m), *M. hagetiana* Subzone

The 1831 elements in this sample represent 11 species. The dominating species is *B. medius*. There are a lot of elements of *D. basiovalis*, *S. cornuformis*, and *E. pseudoplanus*, but few of *D. venustus*, *S. gracilis*, *Dapsilodus viruensis* and *M. hagetiana*. *Drepanodus arcuatus* reappears, but only with one element. *Semiacontiodus davidi* Löfgren, 1999 first appears in the middle of the zone. There are no elements of *Cornuodus longibasis*.

EST 86-6 (185.7 m), *M. hagetiana* Subzone

The total number of elements in this sample is 1471, representing 11 species. *B. medius* is still dominating in the sample, followed by *D. basiovalis*, *S. cornuformis* and *S. gracilis*. *Cornuodus longibasis* appears for the last time in the sample.

EST 86-4 (184.7 m), *M. ozarkodella* Subzone

The 573 elements in this sample represent 9 species. A new species, *Microzarkodina ozarkodella* appears. This could have happened already in sample number 5, which was not available to me. The extent of the subzone is thus unclear. *B. medius* is dominating in the sample. The same species are represented as in sample number 6 and *D. arcuatus* disappears again.

EST 86-3 (184.3 m), *M. ozarkodella* Subzone

The total number of elements in this sample is 999, representing 12 species. *Dapsilodus viruensis* and *Proto-*

panderodus rectus appear again. The remainder of the species are the same as in sample number 4. *B. medius* is the dominating species.

EST 86-2 (183.7 m) *M. ozarkodella* Subzone

The 638 elements in this sample represent 11 species. *D. venustus* reappears and disappears in the sample. Both *P. rectus* and *S. davidi* disappear. The same species are represented as in the preceding sample and *B. medius* is still dominating.

EST 86-1 (183.2 m), *M. ozarkodella* Subzone

The total number of elements in this sample is 1094, representing 11 species. The dominating species is *Baltoniodus medius*, and *Drepanodus arcuatus* appears again. For the rest, the same species are represented as in sample number 2.

Aserian Stage

The *Eoplacognathus suecicus* Zone (183.2 m -)

The *Eoplacognathus suecicus* Zone is characterized by the nominal species, by a lot of *B. medius*, and in Estonia even by *S. cornuformis* (Viira et al. 2001)

EST 86-18 B

The 1134 elements in this sample represent 12 species. Two species *Eoplacognathus suecicus* Bergström, 1971, and *Protopanderodus cf. graeai* (Fåhræus, 1966), first appear. The most abundant species is still *B. medius*. *D. basiovalis*, *S. gracilis* and *M. ozarkodella* occur more frequently (are more common).

EST 86-19

The total number of elements is 1206, representing 10 species. The species are the same as in the preceding sample, number 18 B, with increased numbers of elements for most of them.

B. medius still dominates.

Comparisons with other sections

Similarity and dissimilarity between Tamsalu and other previously studied localities in Estonia and in northern Öland, Sweden, will be discussed below. The localities I have compared to Tamsalu are Mäekalda (Viira et al. 2001), Tartu (Männik 1998), Taga-Roostoja (Poldvere 1999), Ontika (Mägi 1990) and Kaugatuma in Estonia, and Gillberga (Löfgren 2000b) and Horns Udde (Bagnoli & Stouge 1997) in Sweden (Fig. 1). The species, which are found in every locality (Fig. 4), are *Drepanoistodus forceps*, *Baltoniodus navis* (except possibly in Taga-Roostoja?), *Baltoniodus norrlandicus* and *Semiacontiodus cornuformis*. *Texania* n. sp. A occurs only in Tamsalu. *Parapaltodus* n. sp. A occurs only in Tamsalu and possibly at Horns Udde. *Yangtzeplacognathus crassus* has only been reported from Tamsalu and Gillberga.

Mäekalda.— The Mäekalda section in North Estonia is about 12 m thick with well-preserved conodont elements. The section includes the Baltoscandian zones from the Tremadocian Varanguan *Paltodus deltifera* Zone up

British Series	Regional Stages	Conodont Zones and Subzones (Bergström 1971; Lindström 1971; Bagnoli & Stouge 1997; Zhang 1998; Löfgren 2000a)		
Llanvirnian	Aserian	<i>Y. foliaceus</i>		
		<i>E. suecicus</i>		
	Kundan	<i>E. pseudoplanus</i>	<i>M. ozarkodella</i>	
			<i>M. hagetiana</i>	
		<i>Yangzepl. crassus</i>		
		<i>Lenodus variabilis</i>		
	Arenigan	Volkhovian	<i>B. norlandicus</i>	<i>L. antivariabilis</i>
				<i>T. quadrangulum</i>
			<i>Paroistodus originalis</i>	
			<i>Baltoniodus navis</i>	
		<i>B. triangularis</i>		
Billingen		<i>Oepikodus evae</i>		
		<i>Prioniodus elegans</i>		
Hunneberg		<i>Paroistodus proteus</i>		
Tremadocian	Varangu	<i>Paltodus deltifer</i>		
	Pakerort	<i>Cordylodus</i> spp. Zones		

Fig. 6. Chronostratigraphic and conodont biostratigraphic units of the upper Tremadocian to the Llanvirnian in Baltoscandia.

to the Aserian *Yangtzeplacognathus foliaceus* Zone (Viira et al. 2001) (Fig. 6). The *Yangtzeplacognathus crassus* Zone has not been identified here. Tamsalu and Mäekalda yielded largely the same list of conodont species, except a few, such as *Parapaltodus* n. sp. A, *Texania* n. sp. A, *Lenodus variabilis*, *Yangtzeplacognathus crassus*, *Microzarkodina hagetiana*, *Semiacontiodus davidi* and *Protopanderodus* cf. *graeai*, which occur at Tamsalu, but not at Mäekalda (Fig. 4).

In Mäekalda some species occur that are not found in Tamsalu. These species are: *Protopanderodus* cf. *gradatus* in the *P. elegans* and *O. evae* zones, *Polonodus tablepointensis* in the *E. pseudoplanus* Zone, *Parapaltodus simplicissimus* and *Semiacontiodus bulbosus* in the upper *E. pseudoplanus* Zone.

Tartu. – The investigated drill core from Tartu is about 72 m. It contains conodont elements from the Lower Ordovician to the upper Middle Ordovician, with the

Latorpian, Volkhovian, Kundan, Aserian, Lasnamägi, Uhaku, Kukruse, Idavere, Jõhvi and Keila stages (see Männik 1998). The Tartu drill core, has mostly the same species as found at Tamsalu (Fig. 4). There are more differences, however, between Tartu and Tamsalu than between Tamsalu and Mäekalda. In the interval assigned to the *Oepikodus evae* Zone there are no elements found of the zonal indicator. *Stolodus stola* and *Periodon flabellum* are also missing, and only *Oistodus lanceolatus* represents the *O. evae* Zone. The *Baltoniodus navis* Zone, the *Paroistodus originalis* Zone and the *Baltoniodus norlandicus* Zone are all represented at Tartu. A zone that seems to be lacking at Tartu is the *Yangtzeplacognathus crassus* Zone. Only the subzonal species *Microzarkodina hagetiana* and *Microzarkodina ozarkodella* represent the *E. pseudoplanus* Zone.

Species that are found in Tartu but not in Tamsalu are *Trapezognathus diprion* in the *O. evae* Zone, *Balto-*

niodus triangularis in the *B. triangularis* Zone, *Drepanoistodus stougei* in the *L. variabilis* Zone and *Protopanderodus robustus* in the *B. norrlandicus* Zone and the *M. hagetiana* Subzone.

Taga-Roostoja. – This is a drill core (14.4 m), from c. 70 km E of Tamsalu and is comparable to Tamsalu and Mäekalda in the distribution of conodont species and zones (Fig. 4). The two zones that are not represented here are the *Baltoniodus navis* and the *Yangtzeplacognathus crassus* zones. Probably, the *Baltoniodus navis* Zone may occur within an unsampled interval (1.2 m) of the drill core (Poldvere 1999). The *Lenodus antivariabilis* Subzone of the *B. norrlandicus* Zone was identified at Taga-Roostoja in contrast to Tamsalu where there is no record of this zone, although the uninvestigated samples, EST 86-12 and 13 may represent it. Consequently, one species that was found in Taga-Roostoja but not in Tamsalu is *Lenodus* cf. *antivariabilis*. Species that are not found in Taga-Roostoja are *Stolodus stola*, *Tripodus* cf. *T. laevis*, *Cornuodus longibasis*, *Drepanoistodus* cf. *basiovalis*, *Trapezognathus quadrangulum*, *Scalpellodus latus* (included in *Scalpellodus gracilis*, see Poldvere 1999), *Triangulodus brevibasis*, *Microzarkodina parva*, *Drepanoistodus basiovalis*, *Yangtzeplacognathus crassus*, *Dapsilodus viruensis*, *Microzarkodina hagetiana* and *Semiacontiodus davidi* (Fig. 4).

Ontika. – This is a section in northern Estonia. The section contains stages from the Latorpian to the base of the Aserian. The species are nearly all the same as in Tamsalu, Taga-Roostoja and Mäekalda (Fig. 4). One can identify the *Oepikodus evae* Zone with *O. evae*, *S. stola* and *P. flabellum*, the *Baltoniodus navis* Zone with *B. navis* and *T. brevibasis*, the *Paroistodus originalis* Zone with *P. originalis* and appearance of *B. norrlandicus* in the upper part of this zone (and thus including part of the *B. norrlandicus* Zone as well). The *Lenodus variabilis* Zone contains *L. variabilis*. The *Y. crassus* Zone has not been identified. The *Eoplacognathus pseudoplanus* Zone is only represented by the subzonal species *M. ozarkodella* in the upper part of this zone. The *E. suecicus* Zone is characterized by the nominal species and by *B. medius* and *S. cornuformis*. Other species that were found at Tamsalu, but have not been reported from Ontika are *Parapaltodus* n. sp. A, *Tripodus* cf. *T. laevis*, *Decoriconus peselephantis*, *Texania* n. sp. A, *Drepanoistodus basiovalis*, *D. venustus*, *Scalpellodus gracilis*, *Dapsilodus viruensis*, *M. hagetiana*, *Semiacontiodus davidi* and *Protopanderodus* cf. *graeai*. In Ontika there are also species that are not found in Tamsalu. The species are: *Baltoniodus triangularis* in the *B. triangularis* Zone, *Scolopodus* cf. *bulbosus*, *Ansella* cf. *jemtlandica* and *Polonodus* (*Dzikodus*) *clivus*.

Kaugatuma. – This is a drill core from the island Saaremaa in western Estonia, about 10.90 m long. In the Kaugatuma drill core all stages from the Latorpian Stage are represented with the *O. evae* Zone to the Aserian Stage with the *E. suecicus* Zone. The species composition and the zonation is mostly the same as in Tamsalu. The zonal indicator of the *E. pseudoplanus* Zone is lacking and the zone only characterised by *M. ozarkodella*,

the subzonal species indicator for the upper subzone. Species that were found in Tamsalu but not here are *Parapaltodus* n. sp. A., *Tripodus* cf. *T. laevis*, *Decoriconus peselephantis*, *Texania* n. sp. A, *Drepanoistodus* cf. *basiovalis*, *Trapezognathus quadrangulum*, *Triangulodus brevibasis*, *Baltoniodus medius*, *D. venustus*, *Y. crassus*, *Dapsilodus viruensis*, *M. hagetiana*, *E. pseudoplanus*, *Semiacontiodus davidi* and *Protopanderodus* cf. *graeai*. Species that are not found in Tamsalu but in Kaugatuma are *Polonodus* (*Dzikodus*) *clivus* and *Drepanoistodus conulatus*.

Gillberga. – The Gillberga quarry in northern Öland provides a c. 16 m thick sequence through middle Völkho-vian to upper Kundan (mid-Arenig to early Llanvirn) beds (Löfgren 2000b). The sequence ranges from the middle part of the *Baltoniodus navis* Zone to the middle or upper part of the *Microzarkodina ozarkodella* Subzone of the *Eoplacognathus pseudoplanus* Zone (Löfgren 2000b). Because zones below the *Baltoniodus navis* Zone have not been investigated and beds above the *Eoplacognathus pseudoplanus* Zone are unavailable in the area, the species from these intervals were not recorded. The *Yangtzeplacognathus crassus* Zone and the *Trapezognathus quadrangulum* Subzone are both represented here as they are in Tamsalu. Species that are found in Gillberga but not in Tamsalu are *Lenodus antivariabilis*, *Parapaltodus simplicissimus*, *Ansella* cf. *jemtlandica*, *Parapanderodus quietus* and *Microzarkodina bella*.

Horns Udde. – The faunal succession is from two representative sections: North of Horns Udde and Horns Udde quarry, Öland (Bagnoli & Stouge 1997). The sections contain beds from the *Oepikodus evae* Zone in the Latorpian Stage to the *Lenodus* sp. A Zone (approx. equal to the *L. variabilis* Zone and the *Y. crassus* Zone) in the Kundan Stage. Here is the only additional place where the species *Parapaltodus* n. sp. A that was also found in Tamsalu may be present (Fig. 4). The species composition is similar to that of Tamsalu. Only a few species are lacking here: *Tripodus* cf. *T. laevis*, *Texania* n. sp. A, *Drepanoistodus* cf. *basiovalis* and *Baltoniodus medius*. At Horns Udde there are some typical species from Öland that are not found at Tamsalu, nor at other localities in Estonia. These species are: *Protopanderodus floridus*, *Protopanderodus sulcatus*, *Protoprioniodus aranda*, *Protoprioniodus costatus* and *Protoprioniodus papiliosus*. Other species that are present at Horns Udde but not found in Tamsalu are *Trapezognathus diprion* and *Drepanoistodus contractus*.

Discussion

The conodont fauna at Tamsalu (Figs. 7 and 8) is in many respects similar to those from other investigated drill cores and sections in Estonia and Öland, Sweden. Comparisons were made between the faunas from the Tamsalu drill core and from the following Estonian and Swedish localities: Mäekalda (Viira et al. 2001) in northern Estonia, Tartu (Männik 1998) in southeastern Estonia, Taga-Roostoja (Poldvere 1999) in northeastern Estonia, Ontika (Mägi 1990) in northeastern Estonia, Kaugatuma (D.



Fig. 7. Conodont elements from the Tamsalu drill core. (A) *Oepikodus evae* (Lindström, 1955) from sample EST 86-18A, x80, (B-D) *Texania* n. sp. A from sample EST 86-17, B:x80, C:x50, D:x60, (E) *Oistodus lanceolatus* Pander, 1856, from sample EST 86-17, x30, (F) *Periodon flabellum* (Lindström, 1955) from sample EST 86-17, x90, (G-H) *Microzarkodina flabellum* (Lindström, 1955) from sample EST 86-16, x100, (I) *Microzarkodina hagetiana* Stouge & Bagnoli, 1990, from sample EST 86-6, I:x70, (J-K) *Microzarkodina ozarkodella* (Lindström, 1971) from sample EST 86-18B, x70, (L) *Triangulodus brevibasis* (Sergeeva, 1963) from sample EST 86-15, x50, (M) *Microzarkodina parva* (Lindström, 1971) from sample EST 86-14, x70, (N) *Baltoniodus norrlandicus* (Löfgren, 1978) from sample EST 86-14, x70, (O-Q) *Baltoniodus navis* (Lindström, 1955) from sample EST 86-16, O:x80, P:x50, Q:x70, (R) *Scolopodus striatus* Pander, 1856, from sample EST 86-17, x60, (S-U) *Tripodus* cf. *laevis* from sample EST 86-18A, x60.

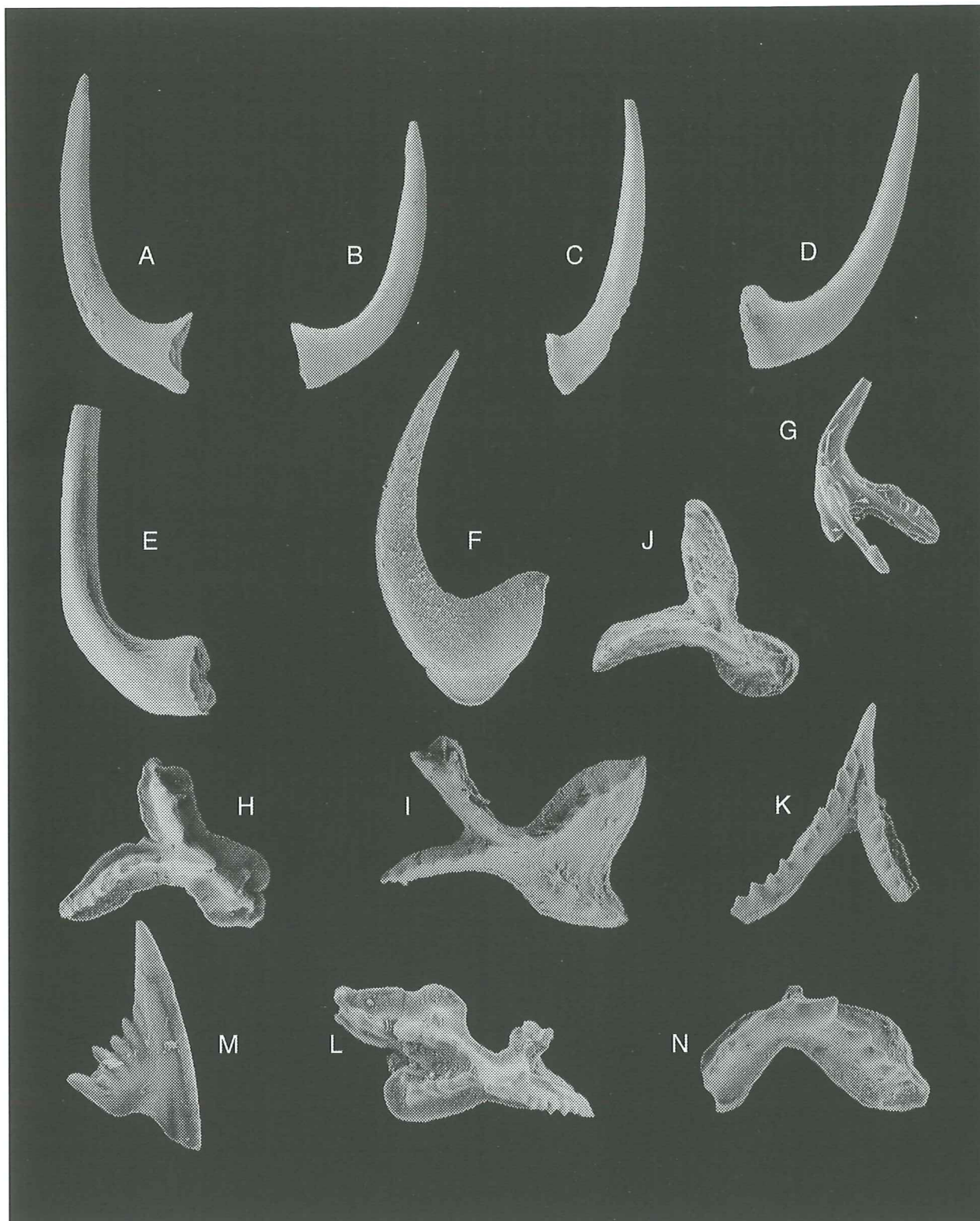


Fig. 8. Conodont elements from Tamsalu drill core. (A-B) *Parapaltodus* n. sp. A from sample EST 86-17, A:x70, B:x50. (C) *Parapaltodus* n. sp. A from samples EST 86-18A x60. (D) *Scolopodus striatus* Pander, 1856, from sample EST 86-17, x60, (E) *Semiacontiodus cornuformis* (Sergeeva, 1963) from sample EST 86-11, x100, (F) *Paroistodus originalis* (Sergeeva, 1963) from sample EST 86-15, x110, (G) *Baltoniodus medius* (Dzik, 1976) Sb element from sample EST 86-7, x70, (H-I) *Lenodus variabilis* (Sergeeva, 1963) from sample EST 86-11, H:x120, I:x50, (J) *Yangtzeplacognathus crassus* (Chen & Zhang, 1992) from sample EST 86-9, x70, (K-L) *Eoplacognathus suecicus* (Bergström, 1971) from sample EST 86-19, K:x90, L:x70, (M-N) *Eoplacognathus pseudoplanus* (Viira, 1974) from sample EST 86-8, M:x80, N:x90.

Kaljo, pers. comm. 1984) on the island of Saaremaa on the west coast of Estonia, Gillberga (Löfgren 2000b) and Horns Udde (Bagnoli & Stouge 1997) sections on northern Öland, Sweden.

The two lowermost Tamsalu samples, EST 86-18A and EST 86-17, are referred to the upper part of the *O. evae* Zone (Fig. 4). The most abundant species is *D. forceps* (55.1% and 59.6%) which together with *P. flabellum* (4.1% and 12.8%) is typical of the upper part of *O. evae* Zone in Estonia (cf. Viira et al. 2001) and also of a few levels in the same interval in the St. Petersburg region (Tolmacheva 2001). The *O. evae* Zone was identified also in the other, earlier investigated localities in my investigation except Tartu (missing the zonal indicator) and Gillberga (level not investigated). In samples EST 86-18A and EST 86-17 two new species were found: *Parapaltodus* n. sp. A in samples EST 86-18A and EST 86-17, and *Texania* n. sp. A in sample EST 86-17. These species have not been found in any earlier investigated localities in Estonia or Sweden (a possibly conspecific element of *Parapaltodus* was found at Horns Udde, Sweden). Since the zonal indicator *B. triangularis* is missing in the sample immediately above the *O. evae* Zone from the Tamsalu drill core I have placed this sample, EST 86-16, in the *B. navis* Zone instead. In EST 86-16, the *B. navis* Zone is represented by the most abundant species *M. flabellum* (34.5%) together with *D. forceps* (31.9%). This zone has been encountered in all localities except Taga-Roostoja (the zone could possibly have been found in an uninvestigated interval of the drill core here).

The next sample, EST 86-15 is indicative the *Paroistodus originalis* Zone, because of the high abundance of the zonal indicator, *P. originalis* (12.9%) and because *T. brevisbasis* exceeds 0.3% in abundance (in this case 12.8%). The upper boundary is delimited by the first appearance of *B. norrlandicus* (see Löfgren 2000a). The *P. originalis* Zone is represented in many localities, both in Estonia and Sweden (Löfgren 1995). The *B. norrlandicus* Zone is represented by the zonal indicator *B. norrlandicus* (43.2%), and other species typical for the zone (see Tolmacheva 2001): *D. basiovalis* (39.9%) and *M. parva* (5.0%) in the sample EST 86-14. The presence of *Trapezognathus quadrangulum* in this sample denotes the lower subzone of the *B. norrlandicus* Zone. This zone could also be identified in the other localities in Estonia and Sweden. The upper subzone of the *B. norrlandicus* Zone, the *Lenodus antivariabilis* Subzone, has not been found in the Tamsalu drill core, but may be represented by one or both of the missing samples EST 86-13 and EST 86-12.

The sample EST 86-11 indicates the *Lenodus variabilis* Zone with the most abundant species *B. medius* (49.9%) together with the zonal indicator *Lenodus variabilis* (9.7%) and some other species, which first appear here. This zone has been identified in all the localities investigated in Estonia and Sweden. The *Yangtzeplacognathus crassus* Zone has only been identified in Tamsalu, Estonia, and in Gillberga, Sweden. In Tamsalu the zone is represented by the samples EST 86-10 and EST 86-9. The base of the *Yangtzeplacognathus crassus* Zone

is indicated by the first appearance of the zonal species *Y. crassus* (Chen & Zhang, 1992) and its top by the last appearance of this species (Zhang 1998) which is also the case here. The species *Y. crassus* has a relative abundance of 3.1% in EST 86-10 and 6.3% in EST 86-9.

The next zone in the Tamsalu drill core is the *Eoplacognathus pseudoplanus* Zone with the two subzones with *Microzarkodina hagetiana* and *Microzarkodina ozarkodella*, respectively. The samples EST 86-8, EST 86-7 and EST 86-6 represent the *Microzarkodina hagetiana* Subzone with the typical subzonal indicator, *M. hagetiana*, reaching a relative abundance of 1.1%, 0.8% and 1.6%, respectively in the three samples. The *Microzarkodina ozarkodella* Subzone is represented by EST 86-4, EST 86-3, EST 86-2 and EST 86-1. The relative abundance of the subzonal indicator, *M. ozarkodella*, is 0.9%, 4.5%, 0.5% and 3.2%. Sample EST 86-5, that did not contain enough elements, has been excluded. The fact that *E. pseudoplanus* (Viira, 1974) could be used as a zonal index of the upper part of the Kundan Stage was first proposed by Viira (1974) (Zhang 1998). This zone, the *E. pseudoplanus* Zone, has been identified in all investigated localities in Estonia (except Taga-Roostoja) and at Gillberga, Sweden. In some cases only the subzonal indicators are represented. In the Tartu drillcore, the zone is only identified by the subzonal species *M. hagetiana* and *M. ozarkodella* and in Ontika and Kaugatuma the zone is only represented by *M. ozarkodella*.

The last two samples from the Tamsalu core, EST 86-18B and EST 86-19 contain the zonal indicator *Eoplacognathus suecicus* (1.1% and 3.2%, respect.). The *E. suecicus* Zone has also been recognized in Mäekalda.

The most abundant species in the Tamsalu drill core (Fig. 5) from the basal sample, EST 86-18A to the top one, EST 86-19, are *B. medius*, *B. norrlandicus*, *B. navis*, *D. forceps*, *D. basiovalis* and *M. flabellum*.

The comparison between Tamsalu and the localities (Fig. 2): Kaugatuma, Ohesaare (Viira 1967), Rumba (Kaljo & Nestor 1990), Kullamaa (Kaljo & Nestor 1990), Mäekalda (Viira et al. 2001), Tartu (Männik 1998), Taga-Roostoja (Poldvere 1999) and Ontika (Mägi 1990) in Estonia shows a small difference in thickness, except for the Tartu area (see Raukas and Teedumäe 1997). Generally, the Volkhovian, Kundan and Aserian Stages are thickest in the Tartu drill core in southeastern Estonia. The Latorpian Stage did not exhibit such a big difference regarding the thickness between the localities. The maximum thickness of the Latorpian Stage appears to be in western Estonia (Rumba and Kullamaa) and in north-eastern Estonia (Ontika). The Latorpian is only measured down to 466.4 m in Kaugatuma and to 191.7 m in Tamsalu, since the base was not encountered.

The Volkhovian Stage exhibits more pronounced differences between the localities. The highest value of thickness is in southeastern Estonia (Tartu) and it thins out on the W mainland (Rumba and Kullamaa), increases in the central and northern Estonia and to the W on the island of Saaremaa. The Volkhovian Stage is measured down to 120.4 m in Taga-Roostoja, without the base being reached.

The Kundan Stage increases thickness in northeastern and southeastern Estonia, decreases in northern and central Estonia, and increases again in the W. The highest value of thickness is in Tartu and the lowest one in Mäekalda. The base and the top of the Kundan Stage in the Tamsalu drill core were difficult to decide, because the lacking samples EST 86-13 and EST 86-12.

The Aserian Stage also varies between the localities in Estonia. The lowest value is in Mäekalda in the north and the highest value in Tartu in southeastern Estonia. In northeastern Estonia (Ontika) the Aserian Stage is thinner than in the southeast and central Estonia. Its thickness increases on the W mainland but decreases on the island of Saremaa.

Conclusions

The comparison of the Tamsalu drill core and the other previously investigated drill cores and sections in Estonia and Sweden points to similarities between them all, except for a few species and zones/subzones that occur in some localities but not in others. In some cases this could be explained by that level not having been investigated or by lack of the zonal indices. The investigated Tamsalu drill core represents a sequence deposited in a shallower part of the palaeobasin than represented by most of the other drill cores, but probably deeper than represented by the sections in the N. (e.g., Mäekalda). The species *P. flabellum*, in the *O. evae* Zone, that is represented in all localities except Tartu, indicates deep water and an open ocean. This taxon would increase only at the peak of transgression in the lower parts of the ramp zone. The species *P. originalis* is known to increase in intervals considered to represent transgressive events (Löfgren 1995). The regressive events are instead represented by shallow water species such as *S. cornuformis* and possibly species of *Microzarkodina* which also occur in the Tamsalu drill core.

The thicknesses of the different stages (Latorpian, Volkhovian, Kundan and Aserian) and the localities (Tamsalu, Kaugatuma, Ohesaare, Rumba, Kullamaa, Mäekalda, Tartu, Taga-Roostoja and Ontika) show an increase in the western, middle and eastern parts of Estonia and a decrease in the North (see Raukas & Teedumäe 1997).

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Appendix

Description of two new taxa: *Parapaltodus* n. sp. A and *Texania* n. sp. A.

Genus *Parapaltodus* Stouge, 1984

Type species. – *Parapaltodus simplicissimus* Stouge, 1984, pl. 1, figs. 20, 21, 26-28A.

Remarks. – Stouge (1984) diagnosed *Parapaltodus* as having erect to proclined drepanodontiforms and twisted oistodontiforms (scandodontiforms). The elements have a large laterally compressed cusp with sharp anterior and posterior keels and a triangular base. The basal cavity is also triangular.

Parapaltodus n. sp. A

Fig. 8: A-C, Fig. 9: A-D.

Occurrence. – From the *Oepikodus evae* Zone, samples EST 86-18A and EST 86-17, in the Tamsalu drill core. The *Parapaltodus* elements reported from the *O. evae* Zone at Horns Udde by Bagnoli & Stouge (1997) may possibly belong to the same species.

Material. – 4 drepanodontiform elements.

Diagnosis. – A species with drepanodontiform elements having a proclined to suberect, stout cusp with lenticular cross section and a small base with laterally compressed basal cavity with an extended tip (peak).

Description. – The drepanodontiforms have a proclined to suberect cusp with a broad, lenticular cross section. The lateral carinae are rounded, and become narrower at the anterior and posterior edges which gives the lenticular form of the cusp cross section. The basal cavity is

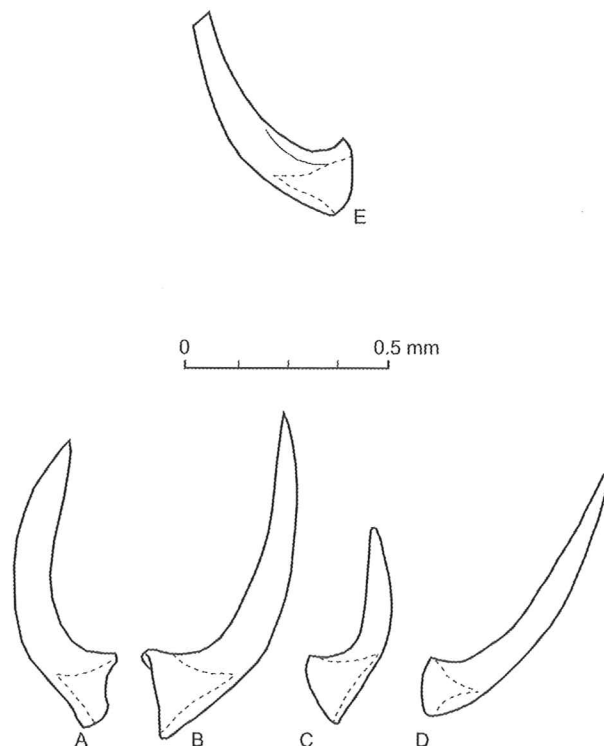


Fig. 9. Camera lucida drawings of four different elements of *Parapaltodus* n. sp. A (A-D), from the Tamsalu drill core, Estonia and one of *Parapaltodus simplicissimus* (E), from the Gillberga quarry, Öland, Sweden. A. *Parapaltodus* n. sp. A from sample EST 86-18A, *O. evae* Zone. B-D. *Parapaltodus* n. sp. A from sample EST 86-17, *O. evae* Zone. E. *Parapaltodus simplicissimus* from sample ÖL 83-106, *Yangtzeplacognathus crassus* Zone. The *Parapaltodus* n. sp. A elements are also shown as photos in Fig. 8, A-C.

moderately deep and triangular with concave sides in lateral view. The basal cavity apex is extended and close to the anterior edge. The aboral margin is convex, with rounded posterobasal and anterobasal corners. The cusp lacks the anterior lateral furrow running along the length of the cusp, which is present in *Parapaltodus simplicissimus*.

Remarks. – *Parapaltodus* n. sp. A differs from *Parapaltodus simplicissimus* Stouge, 1984 by its rounded carinae and its lenticular cross-section of the cusp and has no lateral furrow running along the length of the cusp. The basal cavity is less deep than in *P. simplicissimus* (Fig. 9 E) and with an extended apex close to the anterior edge (Fig. 9 A-D).

Genus *Texania* Pohler, 1994

Type species. – *Texania heligma* Pohler, 1994, pl. 8, figs. 11-15; Text-figure 16.

Description. – “Genus includes albid seximembrate condont apparatuses with ozarkodiniform (Pa, Pb), oistodontiform (M) and ramiform (Sa, Sb, Sc) elements in the apparatus. Ozarkodiniform and ramiform elements possess a single denticulated (posterior) process. Cusp is reclined and may be costate. Oistodontiform elements display a reclined cusp that is longer than the posterior process, and sharp edged. Base of most elements is dark brown; basal cavity is shallow “ (Pohler 1994).

Texania n. sp. A

Fig. 7:B-D, Fig. 10:A-F.

Occurrence. – Oepikodus evae Zone, sample EST 86-17 in the Tamsalu drill core.

Material. – 8 elements; 6 ramiform (Sa, Sb, Sc), 1 ozarkodiniform (P) and 1 oistodontiform element (M).

Diagnosis. – A species of *Texania* with P, M, Sa, Sb and Sc elements, all of which are white with a dark basal cavity surrounded by a hyaline area. Ramiform and M elements typically show strong lateral flexion.

Description. – The oistodontiform and ramiform elements in this species of *Texania* are characterised by strong flexure of the posterior process. In accordance with the genus characterisation all elements are white in the upper part and the basal cavity is dark surrounded by a hyaline area. The cusp of the oistodontiform element is recurved and the curved posterior process is flexed towards the aboral margin. The margin is convex and the oral aboral margin is concave. The basal cavity is moderately deep and has faintly concave triangular sides.

The P element has a straight aboral margin that makes an almost right angle with the anterior margin of the cusp. There are five laterally compressed and confluent denticles on the posterior process. The denticles are suberect to erect, while the anterior process is rudimentary and adentate.

The ramiform elements have a fairly long, reclined to recurved cusp, which is laterally compressed. There may be up to two denticles on the anterior edge. Costate ramiform element has two edges of the cusp developed as keels. The posterior process possesses five to seven denticles and which are confluent and laterally compressed. The Sb element shows slightly curved denticles. The anterobasal corner is rounded. The ramiform elements are deflected in three different directions.

Remarks. – The ramiform elements in *Texania* n. sp. A differ from those of *T. heligma* because of the two denticles on the anterior edge of Sc elements and that the denticles on the posterior process are confluent. The anterior denticles are typical for elements of *Microzarkodina* and *Periodon*, but as a rule not *Texania*. In this case the denticles are very small and only two in number and *Microzarkodina* often seems to have more than one and often bigger anterior denticles than those found on elements of *Texania*. *Periodon* usually has more denticles on its elements. Consequently, *Texania* seems to be the best place for this new species, at least until more elements have been retrieved.

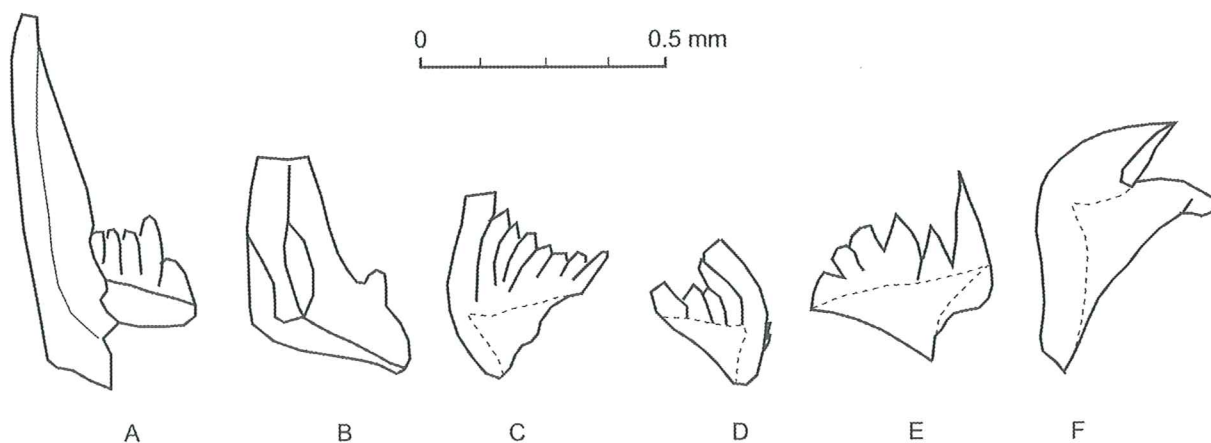


Fig. 10. Camera lucida drawings of *Texania* n. sp. A from the Tamsalu drill core, Estonia. An elements are from sample EST 86-17, *O. evae* Zone. A. Ozarkodiniform element (Pa) of *Texania* n. sp. A. B. Ramiform element (Sa) of *Texania* sp. A. C. Ramiform element (Sc) of *Texania* sp. A. D-E. Ramiform element (Sb) of *Texania* sp. A. F. Oistodontiform element (M) of *Texania* sp. A. The *Texania* sp. A specimens are shown as photos in Fig. 7 B-D; there A corresponds with D, D corresponds with C and E corresponds with B on the photos.

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