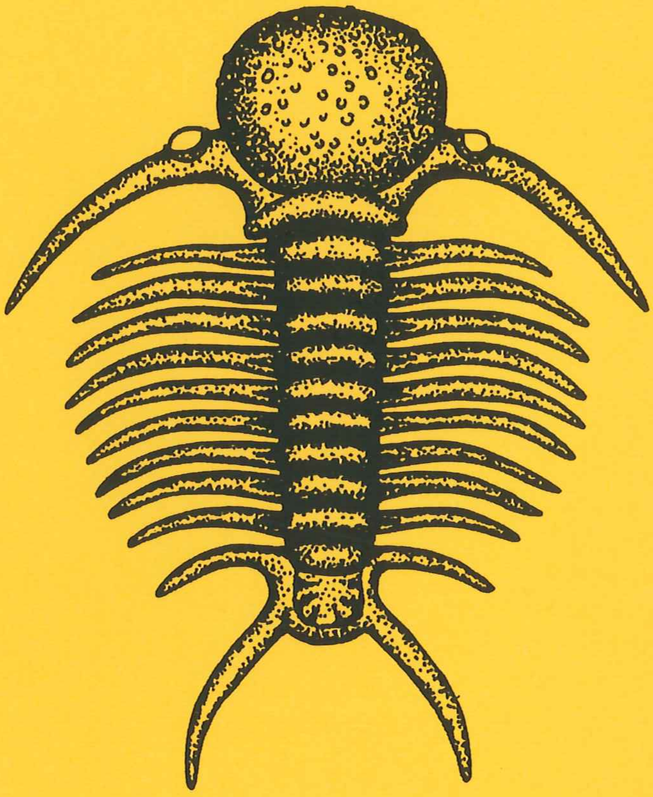
EXAMENSARBETE I GEOLOGI VID LUNDS UNIVERSITET

Historisk geologi och Paleontologi



Conodont biostratigraphy in Volkhovian sediments from the Mäekalda section, north-central Estonia

Jenny Wickström

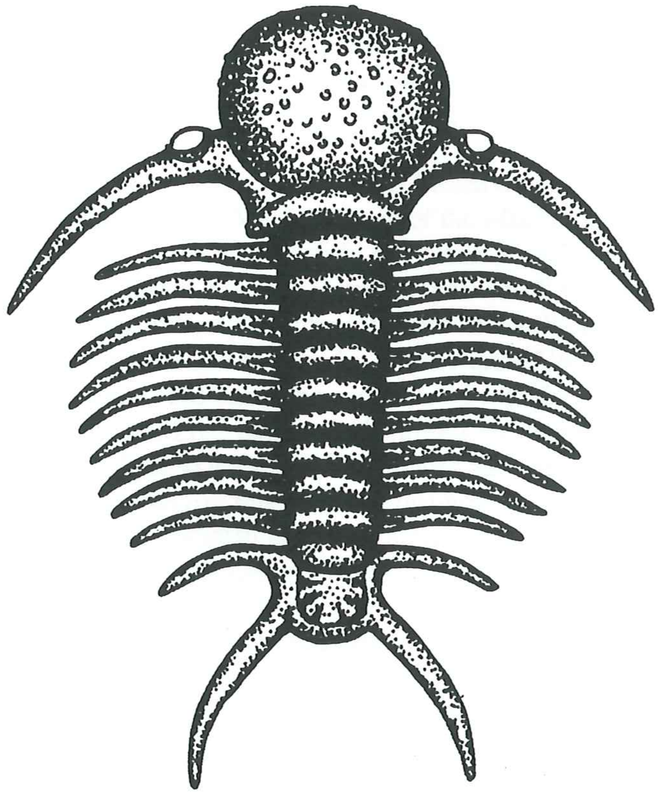
Examensarbete, 20 p
…nstitutionen, Lunds Universitet

Nr 113

Coden:SE-LUNBDS/NBGO-99/501113+16s

EXAMENSARBETE I GEOLOGI VID LUNDS UNIVERSITET

Historisk geologi och Paleontologi



Conodont biostratigraphy in Volkhovian sediments from the Mäekalda section, north-central Estonia

Jenny Wickström

Lund 1999 Examensarbete, 20 p Nr 113
Geologiska Institutionen, Lunds Universitet

Conodont biostratigraphy in Volkhovian sediments from the Mäekalda section, north-central Estonia

JENNY C. WICKSTRÖM

Wickström, J.C., 1999: Conodont biostratigraphy in Volkhovian sediments from the Mäekalda section, north-central Estonia. *Examensarbete i geologi vid Lunds Universitet, Historisk geologi och paleontologi, 20 poäng*, Nr 113, pp. 1-16.

Abstract: This investigation examines the distribution of conodont elements in the upper Lower Ordovician (Arenig) Volkhov Stage of the Mäekalda section situated in the Tallinn area, north-central Estonia. Slightly more than 36,000 conodont elements from 18 samples were investigated, and the biostratigraphic result was compared to previous works on conodont biostratigraphy from localities in south-central Sweden. Relative frequencies of taxa were compared with data from Närke, Västergötland, the Bothnian Bay, Öland and Jämtland. The samples are correlated with the *Baltoniodus navis* Zone, the *Paroistodus originalis* Zone and the *Baltoniodus norrlandicus* Zone. Previously, a subdivision based on physical events (transgressions and regressions) of the *P. originalis* Zone has been made, and five phases can be distinguished. The fauna from Mäekalda is correlated with coeval Swedish conodont assemblages, even though differences in depositional environment, principally owing to variation in water depth in the Baltoscandian palaeobasin led to some variation in fauna and sediment thickness. The conodont fauna from Mäekalda reflects a sedimentary sequence deposited in a shallow part of the Baltoscandian palaeobasin which was sensitive to transgressions and regressions. Other sections in western Baltoscandia reflect the same physical events, but in a deeper water setting.

Keywords: Conodonts, biostratigraphy, *Baltoniodus navis* Zone, *Paroistodus originalis* Zone, *Baltoniodus norrlandicus* Zone, Toila Formation, Volkhov, Arenig, Ordovician, Mäekalda, Estonia.

Jenny C. Wickström, Department of Geology, Division of Historical geology and palaeontology, University of Lund, Sölvegatan 13, SE-223 62 Lund, Sweden. E-mail: JYW@novell.geol.lu.se

Conodonts are phosphatic microfossils belonging to an extinct group of animals. They have a world-wide distribution in most marine rocks of Cambrian to Triassic age. They were first discovered by Pander (1856), and their disclosure led to a wealth of research concerning their origin. In 1982 an almost complete conodont animal, a so called natural assemblage, was found in the Carboniferous "shrimp-bed" in Scotland. Based on this, and some subsequent finds from the same locality, Briggs et al. (1983) suggested that conodont elements are relics from jaw apparatuses belonging to a vertebrate, or at least a chordate. This theory is today the most popular one, but the affinity and function of conodonts is still uncertain. The fossil group is one of the most important in Palaeozoic biostratigraphy, due to their rapid evolution, widespread distribution and relative abundance in most Palaeozoic marine rocks.

The aim of this study is to investigate the conodont fauna from the middle-upper part of the Mäekalda section in north-central Estonia (Fig. 1) biostratigraphically, and to compare it to conodont faunas of similar age from localities in south-central Sweden (Orreholmen, Lanna, Gillberga and Finngrundet), described by Löfgren (e.g. 1978; 1985; 1995; 1996), as Sweden and Estonia were both situated within the North Atlantic faunal region or province; cold-water realm, during the Ordovician (Dzik 1983).

Geological setting

During the Arenig, Baltoscandia was situated 45-50° south of the palaeoequator (Torsvik et al. 1996), and the climate was probably relatively cool, with fluctuating temperatures (Lindström 1984). The Iapetus Ocean was located west of Baltica, and Laurentia was situated further westwards, on the other side of the Iapetus Ocean (Fig. 2). The width of the Iapetus Ocean (Baltica-Laurentia) at this time has been estimated by Torsvik et al. (1996) to be about 3000 km. Siberia was located north-west of Baltica, and Gondwana to the south (Fig. 2). In the Baltoscandian palaeobasin, marine carbonate sediments were deposited, possibly representing a subantarctic shallow water carbonate platform (Lindström 1984). The succession in north Estonia was probably deposited in the shallowest part of the basin, and may have been the most sensitive part to sea level fluctuations (Meidla et al. 1998).

The confacies belts, introduced by Jaanusson (1976), divide the Ordovician palaeobasin of Baltica into different parts, each part with similarities in biofacies and lithofacies (Fig. 3). Estonia is divided into two parts by the Central Baltoscandian Confacies Belt and the North Estonian Confacies Belt (Lindström 1984; Meidla et al. 1998). The southern parts of Estonia belong to a part of the Central Baltoscandian Confacies Belt called the Livonian Tongue (Lindström

Fig. 1. (A) Sketch map of Estonia showing the locality Mäekalda (marked by a filled square). (B) Simplified map of the Baltic area.

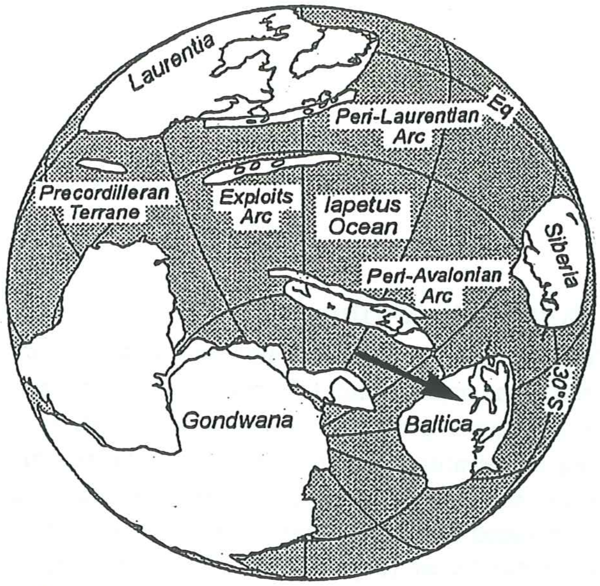


Fig. 2. Palaeogeographic map showing the location of Baltica during Early-Middle Ordovician. (From Mac Niocaill et al. 1997; Fig. 2).

1984; Meidla et al. 1998). The sedimentation in this area is believed to have taken place in the lower ramp zone (Meidla et al. 1998). South-central and central Sweden also belong to the Central Baltoscandian Confacies Belt (Lindström 1984). The northern part of Estonia and Gotland belong to the North Estonian Confacies Belt (Lindström 1984; Meidla et al. 1998). Here discontinuous sedimentation is characteristic; presumably indicating deposition near fair-weather base in a middle-upper ramp zone (Meidla et al. 1998).

The section at Mäekalda is situated in the Tallinn area, close to the Bay of Tallinn, in north-central Estonia (Fig. 1). The sequence is exposed in a roadcut, and comprises sediments from the Lower Cambrian to the Middle Ordovician (Llanvirn), and it has for a long time been used as a type section for northern Estonia. The Cambrian-Ordovician boundary has proved impossible to define in the section as the boundary beds contain disconformities (Mens et al. 1989). Today, the lowermost part of the sequence is no longer available for studies as it has been covered during road construction.

Material and methods

The 18 conodont samples in this study were collected at the Mäekalda section, and the extraction of the conodonts was performed in Estonia. The extraction of the conodonts was made by using standard techniques, according to Jeppsson et al. (1985), with the exception that non-buffered acetic acid was used for the dissolution of the limestone. The samples were then decanted to clean them from the clay fraction, and the conodonts were separated from the other residues. The slightly more than 36, 000 conodont elements were sorted and glued in microfossil slides by the present author and Dr. Anita M. Löfgren. The preservation of the conodonts is generally very good, with some minor variations between the samples. In several of the samples small phosphatic brachiopods and *Milaculum* were discovered, but these have not been investigated further in this study.

Representative conodont elements were selected and fixed with double adhesive tape on a SEM knob for electron scanning and photographing, and these are illustrated in Fig. 8.

Colour Alteration Index (CAI)

When conodonts are exposed to heat, their colour change, and this process is progressive, cumulative and irreversible (Epstein et al. 1977). Epstein et al. (1977) exposed unaffected conodonts to different temperatures, and from their results an eight degree col-

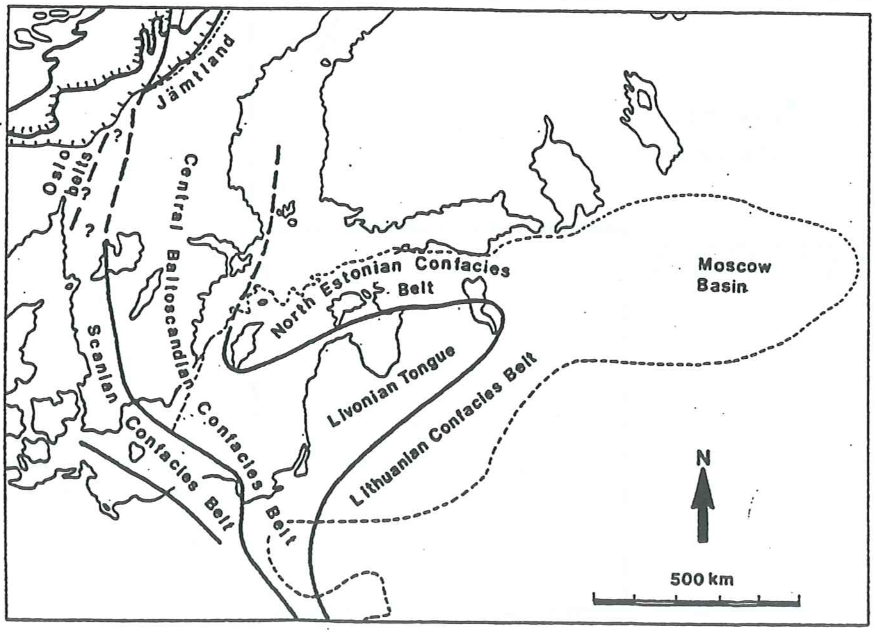


Fig. 3. Confacies belts of the Baltoscandian palaeobasin in the late Early-Middle Ordovician. (From Lindström 1984; Fig. 1).

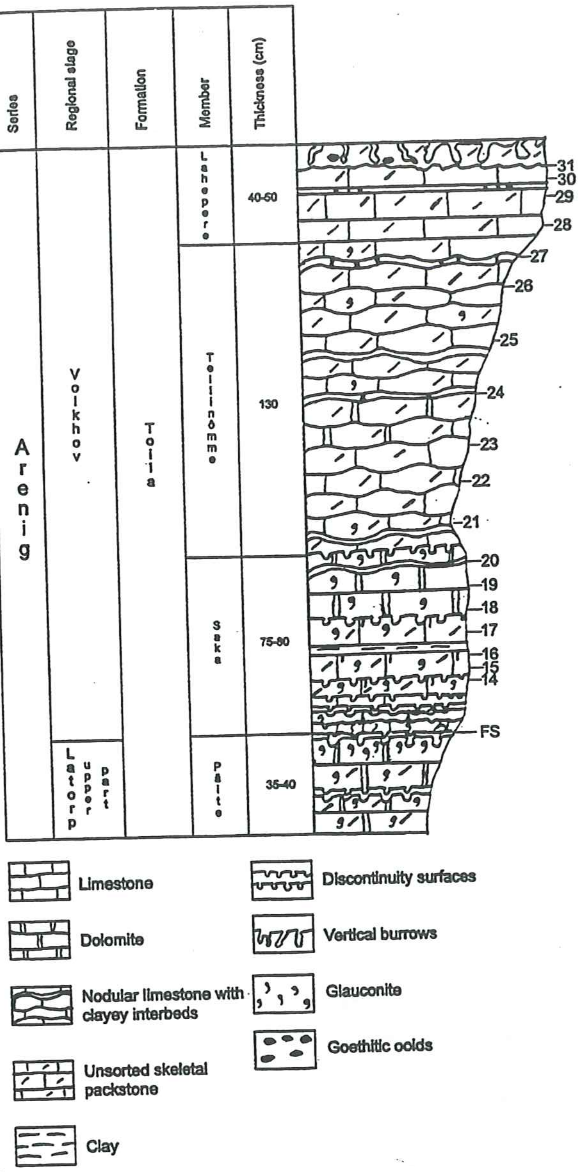


Fig. 4. Lithology of the Toila Formation in the Mäekalda section with the sample levels shown on the right, modified after Viira in Einasto et al. (1996). (FS = the Flowery Sheet).

our chart scale was made, where each number on the scale represents a temperature interval which the rock has been subjected to. This makes conodonts important in the oil and gas industry since the organic maturation in the rock can be estimated by comparing the colour of the conodonts with the colour chart scale (Epstein et al. 1977).

The colours of the elements in this study were compared with the colour chart in Epstein et al. (1977) and the Colour Alteration Index, CAI, could subsequently be assessed. The conodont elements in this investigation are pale yellow to very pale brown, (CAI varying between 1-1.5), which means that they are basically unaltered and have only been exposed to temperatures below 90° C (Epstein et al. 1977).

Some elements in the samples, e.g. *Drepanodus arcuatus*, are slightly reddish, probably due to a discolouring by iron in the sediment.

Biostratigraphy and lithology of the Volkhov Stage

The microflora and fauna of the Mäekalda section are very rich, and several publications on acritarchs, ostracodes, trilobites, brachiopods, chitinozoans and conodonts from the section have been published (e.g. Einasto et al. 1996; Heinsalu & Viira 1997a; Heinsalu & Viira 1997b; Meidla 1997a; Meidla 1997b; Meidla 1997c; Meidla 1997d). Mens et al. (1989) examined acritarchs, conodonts and inarticulate brachiopods from the lowermost (Cambrian) part of the section, which today is not available for further investigations. The lowermost visible part of the section belongs to the Tremadocian Pakerort Stage and Varangu Stage.

The part of the section at Mäekalda where the samples in this study were collected from is of Volkhovian age and belongs to the Toila Formation (Fig. 4). At Mäekalda the Toila Formation is divided into four members; the Päite Member, which belongs to the Latorp Stage, and the Saka, Telinõmme and Lahepere Members, belonging to the Volkhov Stage. The Toila Formation is well developed in the northern parts of Estonia, and within this area the formation has been strongly dolomitized (Meidla 1997c). Brachiopods and ostracodes are abundant, and gastropods, cystoids and cephalopods occur within the formation (Meidla 1997c). The Saka Member constitutes the base of the Volkhov Stage in northern Estonia, and it is overlain by the Künnapõhja Member in the eastern part, and by the Telinõmme Member in the west (Meidla 1997c). The upper part of the formation consists of the Lahepere Member west of Tallinn and the Kalvi Member east of Tallinn (Meidla 1997c). The Lahepere Member is assumed to be the younger unit, since it locally overlies the other member (Meidla 1997c). The Volkhov Stage has previously been divided into four conodont zones: the *Baltoniodus triangularis* Zone, the *Baltoniodus navis* Zone, the *Paroistodus originalis* Zone and the *Baltoniodus norrlandicus* Zone or the *Microzarkodina parva* Zone (Fig. 5). The 18 samples in this study were derived from the latter three zones spanning the Saka, Telinõmme and Lahepere Members (Fig. 4).

The lowermost samples studied in this investigation, Mä-14 - 20, belong to the Saka Member, samples Mä-21 - 27 to the Telinõmme Member and the upper samples, Mä-28 - 31, to the Lahepere Member (Fig. 4). Einasto et al. (1996) described the lithology and the fauna of the Mäekalda section, and here a short review of that description is made from the base of the Saka to the top of the Lahepere Member.

The Saka Member is about 75-80 cm thick at the Mäekalda section. The base (the uppermost bed of

Series	Baltic Stages W	Baltic Stages E	Trilobite Zones Sweden	Trilobite Zones Estonia	Conodont Zones
Llanvirn	Kunda (lower part)		*Asaphus expansus* Zone		*E.? variabilis - M. parva* Subzone
Arenig	Lanna	Volkhov	*Megistaspis (M.) limbata* Zone	*Asaphus lepidurus* Zone	*Baltoniodus norrlandicus* Zone
			Megistaspis (M.) simon Zone		*Paroistodus originalis* Zone: Phase 5, Phase 4, Phase 3, Phase 2, Phase 1
			Megistaspis (M.) lata Zone	*Megistaspis (M.) lata* Zone	*Baltoniodus navis* Zone
					Baltoniodus triangularis Zone
	Latorp (upper part)		*Megistaspis (V.) estonica* Zone		*Oepikodus evae* Zone (upper part)

Fig. 5. Biostratigraphic and chronostratigraphic subdivision of the middle-upper Arenig to lower Llanvirn in Baltoscandia, modified from Löfgren (1995).

the Päite Member) is a discontinuity surface with numerous vertical burrows, known in Sweden as "Blommiga Bladet" and in Estonia as "Püstakkiht" (in English the Flowery Sheet). The Saka Member consists of a dark grey, hard dolomite containing glauconite grains (Einasto et al. 1996). Phosphatized and partially limonitized discontinuity surfaces occur 4-6 cm above the base and below the top of the member (Einasto et al. 1996). Conodonts characteristic of the *P. navis* Zone; *Microzarkodina flabellum* (Lindström) and *Prionodus navis* Lindström, occur in the lower part of the member at the Mäekalda section (Einasto et al. 1996). This conodont zone has been revised (Lindström 1971), and it is equivalent to the *Baltoniodus navis* Zone used in this study. In the middle and upper parts of the Saka Member *Paroistodus originalis* (Sergeeva), the index fossil for the *P. originalis* Zone, occurs (Einasto et al. 1996). The lingulate brachiopod *Acrotreta tallinnensis* Holmer and Popov is also present within this interval (Einasto et al. 1996).

The overlying member, the Telinõmme Member, is about 130 cm thick at Mäekalda; a light grey, fine-grained, semi-nodular limestone with clayey intercalations of grey green argillite, containing some glauconite grains (Einasto et al. 1996). The lower part of the member is dolomitized with beige or green burrows and abundant coarse-grained glauconite in the basal 20 cm (Einasto et al. 1996). Conodonts indicative of the *P. originalis* Zone, and lingulate brachiopods, e.g. *Eosiphonotreta verrucosa* Eichwald, occur within this interval (Einasto et al. 1996).

The thickness of the upper member of the Toila Formation, the Lahepere Member, is about 40-50 cm at the Mäekalda section. It consists of a light grey, dolomitized, thick bedded limestone with several glauconitic, pyritized and phosphatized discontinuity surfaces (Einasto et al. 1996). In the middle-upper part of the member, *Microzarkodina flabellum parva* Lindström appears (Einasto et al. 1996). It has been suggested that this is indicative of the *Microzarkodina parva* Zone or the *Baltoniodus norrlandicus* Zone.

Species / Sample	Mä-14	Mä-15	Mä-16	Mä-17	Mä-18	Mä-19	Mä-20	Mä-21	Mä-22	Mä-23	Mä-24	Mä-25	Mä-26	Mä-27	Mä-28	Mä-29	Mä-30	Mä-31	Total
Drepanoistodus forceps	1086	920	223	107	1109	4													3449
Microzarkodina flabellum	689	543	101	54	336	43	334	68											2168
Baltoniodus navis	663	315	87	30	288	212	537	218	333	2127	1842	820	234	456	1228	301	478	181	10350
Protopanderodus rectus	182	102	38	53	247	40	215	19	21	54	47	32	5	2	20	53	75	9	1214
Scolopodus rex	113	65	16	5	18	68	37	4							24	28			378
Drepanoistodus cf. *basiovalis*	66	78	28	15	69									------*Ph. 4*------					256
Decoriconus cf. *mercurius*	38	44	5	9	86	7	38	7	6	33	16	9			3	16	6	3	326
Cornuodus longibasis	35	3	2		5	2	12		3	10	52	19	1		4		10		158
Trapezognathus sp.	32	90	36	5	59	12	37	29	4	34	58	29		2	26	15	1	2	471
Scalpellodus latus	5	4	3	2	34	6	47	30	32	88	27	22	16	5	68	115	124	12	640
Drepanodus arcuatus	5				3	8	28	16	13	43	68	45	3	2	16	16	19	11	296
Triangulodus brevibasis	3	2	3	6	54	125	249	100	132	496	394	207	35	67	100	74	80	74	2201
'Semiacontiodus' aff. cornuformis		4	2	1	44	3	2	16	6	29	7	4	6		60	98	119	21	422
Periodon flabellum					3	1											*-B. no. Z-.*		4
Paroistodus originalis	*--B. na. Z.--*				106	126	461	58	186	614	1646	675	162	51	67	1	28		4181
Drepanoistodus basiovalis			*--Ph. 1--*			411	863	426	330	1487	1641	787	110	90	473	370	304	155	7447
Microzarkodina parva					---------*Ph. 2*---------				144	540	592	218	98	149	381	357	169	60	2708
'Others'				2	1				--------------*Ph. 3*--------------							2	8	4	17
Total number of elements	2917	2170	544	289	2462	1068	2860	991	1210	5555	6390	2867	670	824	2470	1446	1421	532	36686

Fig. 6. Conodont element distribution in the Mäekalda samples. Zones as well as phases of the *P. originalis* Zone are shown in the table. Taxa with less than 1% in abundance are included in *'Others'*, except for some taxa that are considered very important (*'Semiacontiodus'* aff. *cornuformis* and *Periodon flabellum*). Abbreviations: *B. na. Z. - Baltoniodus navis* Zone; *Ph 1-4* - Phases 1-4 of the *Paroistodus originalis* Zone; *B. no. Z. - Baltoniodus norrlandicus* Zone.

Sample number	*Drepanoistodus forceps*	*Microzarkodina flabellum*	*Baltoniodus navis*	*Protopanderodus rectus*	*Scolopodus rex*	*Drepanoistodus* cf. *basiovalis*	*Decoriconus* cf. *mercurius*	*Cornuodus longibasis*	*Trapezognathus* sp.	*Scalpellodus latus*	*Drepanodus arcuatus*	*Triangulodus brevibasis*	*'Semiacontiodus'* aff. *cornuformis*	*Periodon flabellum*	*Paroistodus originalis*	*Drepanoistodus basiovalis*	*Microzarkodina parva*	'Others'	Zones/phases of *P. originalis* Zone
Mä-31			34%	1.7%			0.60%		0.40%	2.3%	2.1%	14%	3.9%			29%	11%	0.80%	*B. norrlandicus* Zone
Mä-30			34%	5.3%			0.40%	0.70%	0.10%	8.7%	1.3%	5.6%	8.4%		2.0%	21%	12%	0.60%	(lower part)
Mä-29			21%	3.7%	1.9%		1.1%		1.0%	8.0%	1.1%	5.1%	6.8%		0.10%	26%	25%	0.14%	
Mä-28			50%	0.80%	1.0%		0.10%	0.20%	1.1%	2.8%	0.60%	4.0%	2.4%		2.7%	19%	15%		Phase 4
Mä-27			55%	0.20%					0.20%	0.60%	0.20%	8.1%			6.2%	11%	18%		-----
Mä-26			35%	0.70%				0.10%		2.4%	0.40%	5.2%	0.90%		24%	16%	15%		
Mä-25			29%	1.1%			0.30%	0.70%	1.0%	0.80%	1.6%	7.2%	0.10%		24%	28%	7.6%		
Mä-24			29%	0.70%			0.30%	0.80%	0.90%	0.40%	1.1%	6.2%	0.10%		26%	26%	9.3%		Phase 3 *P. originalis*
Mä-23			38%	1.0%			0.60%	0.20%	0.60%	1.6%	0.80%	8.9%	0.50%		11%	27%	9.7%		Zone
Mä-22			28%	1.7%			0.50%	0.20%	0.30%	2.6%	1.1%	11%	0.50%		15%	27%	12%		
Mä-21		6.9%	22%	1.9%	0.40%		0.70%		2.9%	3.0%	1.6%	10%	1.6%		5.9%	43%			-----
Mä-20		12%	19%	7.5%	1.3%		1.3%	0.40%	1.3%	1.6%	1.0%	8.7%	0.10%		16%	30%			Phase 2
Mä-19	0.40%	4.0%	20%	3.7%	6.4%		0.70%	0.20%	1.1%	0.60%	0.70%	12%	0.30%	0.10%	12%	39%			
Mä-18	45%	14%	12%	10%	0.70%	2.8%	3.5%	0.20%	2.4%	1.4%	0.10%	2.2%	1.8%	0.10%	4.3%			0.04%	-----
Mä-17	37%	19%	10%	18%	1.7%	5.2%	3.1%		1.7%	0.70%		2.1%	0.30%					0.70%	
Mä-16	41%	19%	16%	7.0%	2.9%	5.1%	0.90%	0.40%	6.6%	0.60%		0.60%	0.40%						Phase 1
Mä-15	42%	25%	15%	4.7%	3.0%	3.6%	2.0%	0.10%	4.1%	0.20%		0.10%	0.20%						*B. navis* Zone
Mä-14	37%	24%	23%	6.2%	3.9%	2.3%	1.3%	1.2%	1.1%	0.20%	0.20%	0.10%							(upper part)

Fig. 7. Conodont element distribution (relative frequencies) in the Mäekalda samples. Zones as well as phases of the *P. originalis* Zone are shown on the right. Taxa with less than 1% in abundance are included in *'Others'*, except for some taxa that are considered very important (*'Semiacontiodus'* aff. *cornuformis* and *Periodon flabellum*).

Description of the samples

The conodont element distribution for each of the 18 samples from the Mäekalda section is shown in Fig. 6. The relative frequencies, together with the biostratigraphic subdivision made herein, are presented in Fig. 7. The characteristics of the samples are described below, along with brief descriptions of the conodont zones to which they have been assigned.

Baltoniodus navis Zone

The *Baltoniodus navis* Zone was first described by Lindström (1971), and *B. navis* was proposed as a zonal indicator. The definition of the zone was later revised by, e.g., Löfgren (1993) and Bagnoli & Stouge (1997). Typical for the upper part of the zone is the co-occurrence of *B. navis* (Fig. 8A) and *Triangulodus brevibasis* (< 0.3%), (Fig. 8K), before the level where *D. basiovalis* (Fig. 8D) outnumbers *D. forceps* (Fig. 8G), which indicates the lower boundary of the *Paroistodus originalis* Zone (Löfgren 1993). *Paroistodus originalis* has not yet appeared in great numbers within this interval (Löfgren 1995).

Mä-14 (24 cm above the Flowery Sheet)

The 2917 elements in this sample represent 12 different species. The most abundant of them are *Drepanoistodus forceps* (37.2%), *Microzarkodina flabellum* (23.6%), (Fig. 8F), and *Baltoniodus navis* (22.7%). In accordance with Löfgren (1995), this indicates that the sample is from the upper *Baltoniodus navis* Zone, since the relative frequency of *Drepanoistodus forceps* outnumbers *Drepanoistodus* cf. *basiovalis* (2.3%), and the relative frequency of *Triangulodus brevibasis* is less than 0.3% (0.1%). No elements of *Paroistodus originalis* have been found in this sample.

Mä-15 (32 cm above the Flowery Sheet)

Among the 2170 elements in this sample 12 different species were identified, and the most frequent taxa are, as in Mä-14, *Drepanoistodus forceps* (42.4%), *Microzarkodina flabellum* (25.0%) and *Baltoniodus navis* (14.5%). The relative frequency of *Triangulodus brevibasis* is 0.1%, and no elements of *Paroistodus originalis* were found. The conodont assemblage indicates that the sample belongs to the top of the *Baltoniodus navis* Zone.

Paroistodus originalis Zone

The *Paroistodus originalis* Zone was first defined by Lindström (1971), but the definitions of its boundaries has later been altered. The lower boundary of the *P. originalis* Zone is defined as the level where *Triangulodus brevibasis* increases to more than 0.3% of the fauna (Löfgren 1995). Löfgren (1995) discussed three events that could be used to mark the upper boundary of the zone: (1) the first appearance of *'Semiacontiodus' cornuformis*; (2) the first appearance of *Baltoniodus norrlandicus*; and (3) the last occurrence of *T. brevibasis*. Event (2) was suggested to be the most suitable marker for the upper boundary of the zone (Löfgren 1995), and it is the one also used in this study. Löfgren (1995) distinguished five successive phases within the *P. origina-*

lis Zone, and suggested that these faunal changes represent physical events, most probably caused by sea level fluctuations. Regional differences in relative frequencies within these phases are natural, since depositional conditions must have varied in different parts of the basin. The criteria for the five successive phases are summarized below.

Phase 1 is the lowest interval in the *P. originalis* Zone, and it is distinguished by an increase of the zonal fossil (Fig. 8L-M), and the co-occurrence of *Triangulodus brevibasis*, *Microzarkodina flabellum* and *Drepanoistodus forceps*. Within this interval the two species *Microzarkodina flabellum* and *Drepanoistodus forceps* show a decrease, and in the late part of the phase *Drepanoistodus basiovalis* replaces *Drepanoistodus forceps*.

The second interval, Phase 2, is characterized by the co-occurrence of *Microzarkodina flabellum* and *Drepanoistodus basiovalis* with *Periodon flabellum* (Figs. 8B, 8E).

The third interval within the *P. originalis* Zone, Phase 3, is presumably the longest of the five phases, and it is characterized by the replacement of *Microzarkodina flabellum* by *Microzarkodina parva* (Fig. 8C), and the co-occurrence of the latter taxon and *Triangulodus brevibasis*. The relative frequency of the zonal fossil, *P. originalis*, is in this interval often more than 30%.

Phase 4 is proposed to be a regressive event, characterized by a sharp decrease or total absence of *P. originalis*. Within this interval *Drepanoistodus basiovalis* is still rather common, and *Microzarkodina parva* is generally more common than in the previous phase.

The uppermost interval within the *P. originalis* Zone, Phase 5, is distinguished by the reappearance of the zonal fossil prior to the first appearance of *Baltoniodus norrlandicus*, and before or at the beginning of the continuous range of '*Semiacontiodus*' *cornuformis*. *Drepanoistodus basiovalis* is less abundant than in Phase 4, and the number of *Microzarkodina parva* elements decreases.

The samples from Mäekalda belonging to the *P. originalis* Zone have, as far as possible, been arranged within these "phases".

Mä-16 (35 cm above the Flowery Sheet)
This sample, containing 544 elements from 12 different species, is suggested to belong to the *Paroistodus originalis* Zone, even though the zonal fossil has not yet appeared. The reason for this conclusion is that the number of *Triangulodus brevibasis* has reached 0.6% (>0.3%). The lack of the zonal fossil could indicate that the sample is probably taken near or at the lower boundary of the zone. The most abundant taxa are *Drepanoistodus forceps* (41.0%), *Microzarkodina flabellum* (18.6) and *Baltoniodus navis* (16.0%). According to the subdivision made by Löfgren (1995) the sample should belong to Phase 1, as these three species occur together.

Mä-17 (40 cm above the Flowery Sheet)
The 289 elements in this sample represent 12 different species. *Drepanoistodus forceps* is the most abundant taxon (37.0%). By looking at the M-elements, it was possible to discern the number of *Drepanoistodus* cf. *basiovalis* and *Drepanoistodus forceps*. This gave a fair picture of their individual relative frequencies (*D.* cf. *basiovalis* 12.5% and *D. forceps* 87.5%). Other abundant taxa are *Microzarkodina flabellum* (18.7%), *Protopanderodus rectus* (18.3%) and *Baltoniodus navis* (10.4%). *Triangulodus brevibasis* has increased to 2.1%. This sample is also assigned to Phase 1 of the *Paroistodus originalis* Zone. Included in *'Others'* is *Acodus* sp. (0.70%).

Mä-18 (47 cm above the Flowery Sheet)
The number of elements in this sample is 2462, and they represent 16 different species. The most abundant taxa are *Drepanoistodus forceps* (45.0%), *Microzarkodina flabellum* (13.6%) and *Baltoniodus navis* (11.7%). Within this sample the zonal fossil *Paroistodus originalis* (4.3%) and *Periodon flabellum* (0.1%) first appear. *Triangulodus brevibasis* has a relative frequency of 2.2%. The co-occurrence of *Drepanoistodus forceps*, *Microzarkodina flabellum* and *Triangulodus brevibasis* is typical for Phase 1, but the co-occurrence of *Periodon flabellum*, *Microzarkodina flabellum* and *Drepanoistodus* cf. *basiovalis* is indicative for Phase 2. The sample is tentatively referred to Phase 2, and is believed to be close to the boundary between Phase 1 and Phase 2, due to the presence of *Periodon flabellum*. *Protopanderodus calceatus* (0.04%) is included in *'Others'*.

Mä-19 (63 cm above the Flowery Sheet)
The 1068 elements represent 17 different species. *Drepanoistodus basiovalis* (38.5%) is the most common taxon, and it has almost totally replaced *Drepanoistodus forceps* (0.4%). This fact, along with the co-occurrence of *Drepanoistodus basiovalis*, *Microzarkodina flabellum* and *Periodon flabellum*, suggests that this sample may belong to Phase 2. The relative frequencies of *Paroistodus originalis* (11.8%) and *Triangulodus brevibasis* (11.7%) have increased compared to the previous sample, and the number of *Scolopodus rex* elements (Fig. 8N) is higher than in any other sample from Mäekalda (6.4%).

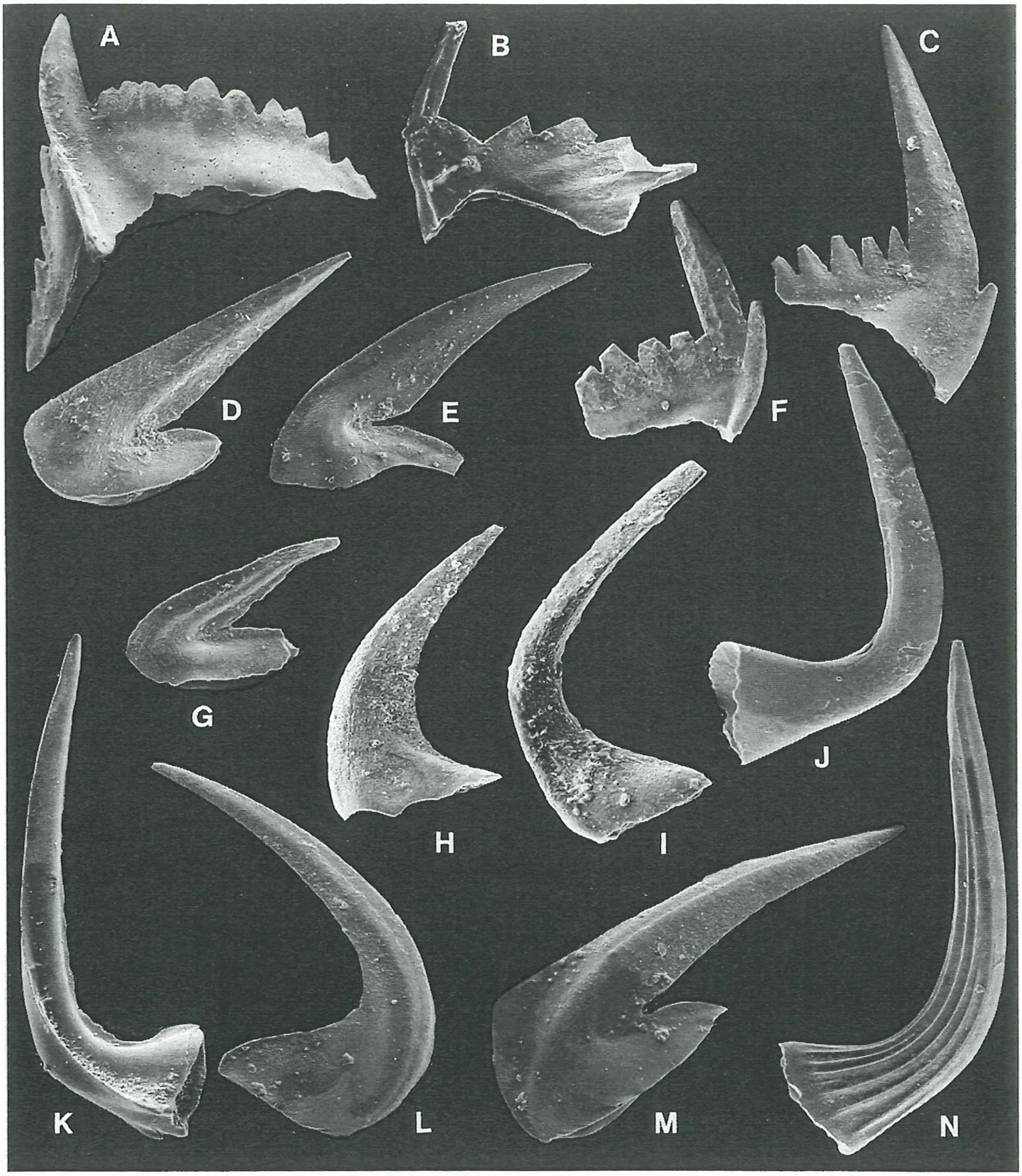


Fig. 8. Conodont elements from the *Baltoniodus navis* Zone (Mä-14 - 15), the *Paroistodus originalis* Zone (Mä-16 - 29) and the *Baltoniodus norrlandicus* Zone (Mä-30 - 31). **A.** *Baltoniodus navis* (Lindström), Pa-element, x 95, from Mä-14 (*Baltoniodus navis* Zone). Note the round holes through the basal cavity wall on the right (posterior) process, probably caused by epibionts. **B.** *Periodon flabellum* (Lindström), S-element (multiramiform element), x 100, from Mä-18 (*Paroistodus originalis* Zone, phase 2). **C.** *Microzarkodina parva* Lindström, P-element, x 120, from Mä-15 (*Baltoniodus navis* Zone). **D.** *Drepanoistodus basiovalis* (Sergeeva), oistodontiform element, x 90, from Mä-23 (*Paroistodus originalis* Zone, phase 3). **E.** *Periodon flabellum* (Lindström), M-element (oistodontiform element, inner side), x 60, from Mä-18 (*Paroistodus originalis* Zone, phase 2). **F.** *Microzarkodina flabellum* (Lindström), P-element, x 120, from Mä-15 (*Baltoniodus navis* Zone). **G.** *Drepanoistodus forceps* (Lindström), oistodontiform element, x 100, from Mä-16 (*Paroistodus originalis* Zone, phase 1). **H - I.** *Scalpellodus latus* (van Wamel). H. P-element, x 120, from Mä-30 (*Baltoniodus norrlandicus* Zone). I. Long-based S-element, x 140, from Mä-28 (*Paroistodus originalis* Zone, phase 4). **J.** *Cornuodus longibasis* (Lindström), asymmetrical element, type A, x 110, from Mä-20 (*Paroistodus originalis* Zone, phase 2). **K.** *Triangulodus brevibasis* (Sergeeva), three-edged scandodontiform element, x 90, from Mä-21 (*Paroistodus originalis* Zone, phase 2). **L - M.** *Paroistodus originalis* (Sergeeva). L. Drepanodontiform element, x 110, from Mä-24 (*Paroistodus originalis* Zone, phase 3). M. M-element (oistodontiform element, outer side), x 110, from Mä-24 (*Paroistodus originalis* Zone, phase 3). **N.** *Scolopodus rex* Lindström, 'normal', symmetrical element type, x 75, from Mä-15 (*Baltoniodus navis* Zone).

Mä-20 (72 cm above the Flowery Sheet)
The sample contains 2858 elements representing 17 different species, and it is assigned to Phase 2, although *Periodon flabellum* is absent. The reason for this assumption is that *Microzarkodina parva* has not appeared and replaced *Microzarkodina flabellum*, and that *Drepanoistodus forceps* is lacking and has been replaced by *D. basiovalis*, which is indicative for this phase. The most common taxa are *Drepanoistodus basiovalis* (30.2%), *Baltoniodus navis* (18.8%), *Paroistodus originalis* (16.1%) and *Microzarkodina flabellum* (11.7%).

Mä-21 (82 cm above the Flowery Sheet)
The sample contains 991 elements representing 12 different species. It much resembles the previous sample, and is therefore also assumed to belong to Phase 2. Maybe this sample is representing the upper part of Phase 2, since *Microzarkodina flabellum* has its last occurrence herein (6.9%).

Mä-22 (98 cm above the Flowery Sheet)
The total number of elements in the sample is 1210, representing 12 species. In this sample *Microzarkodina parva* first appears, co-occurring with *Triangulodus brevibasis*, and the sample is therefore referred to Phase 3. A relative frequency of more than 30% for *Paroistodus originalis* in Phase 3 is not fulfilled, however, as there is only 15.4% of that taxon. According to the subdivision by Bagnoli & Stouge (1997), this sample belongs to the *Microzarkodina parva* Zone, which corresponds to Phase 3 of the *Paroistodus originalis* Zone (Löfgren 1995).

Mä-23 (111 cm above the Flowery Sheet)
The sample contains 5555 elements representing 13 different species. This sample is assigned to Phase 3, but as in the previous sample the abundance of the zonal fossil still does not exceed 30%, being 11.1%. The most common taxa are *Baltoniodus navis* (38.3%) and *Drepanoistodus basiovalis* (26.8%).

Mä-24 (143 cm above the Flowery Sheet)
The 6390 elements in this sample represent 13 different species. The most abundant taxa are *Baltoniodus navis* (28.8%), *Paroistodus originalis* (25.8%) and *Drepanoistodus basiovalis* (25.7%). This sample presumably also belongs to Phase 3.

Mä-25 (167 cm above the Flowery Sheet)
The 2867 elements in this sample represent 12 different species. The most common species are *Baltoniodus navis* (28.6%), *Drepanoistodus basiovalis* (27.5%) and *Paroistodus originalis* (23.5%), and consequently this sample also belongs to Phase 3.

Mä-26 (189 cm above the Flowery Sheet)
The number of elements in this sample is 670, representing 10 different species, and it yielded conodonts indicative of Phase 3 within the upper part of the *P. originalis* Zone. The most frequent taxa are *Baltoniodus navis* (34.9%), *Paroistodus originalis* (24.2%) and *Drepanoistodus basiovalis* (16.4%). *Microzarkodina parva* has increased compared to the previous sample, and is rather common (14.6%).

Mä-27 (199 cm above the Flowery Sheet)
The 824 elements in this sample represent 9 different species. The dominating taxon in this sample is *B. navis* (55.3%), and *M. parva* has continued to increase (18.1%). The zonal fossil, *P. originalis*, has decreased to 6.2%. The sample is suggested to belong to Phase 4 within the *P. originalis* Zone, since the criteria for this phase are fulfilled.

Mä-28 (215 cm above the Flowery Sheet)
Total number of elements in this sample is 2470, representing 14 different species. The most abundant taxa are *B. navis* (49.7%), *D. basiovalis* (19.1%) and *M. parva* (15.4%). *Paroistodus originalis* is quite rare with a relative frequency of 2.7%. '*Semiacontiodus*' aff. *cornuformis* has increased, and reached 2.4% in relative numbers. The sample is representative of Phase 4 within the *P. originalis* Zone.

Mä-29 (234 cm above the Flowery Sheet)
The 1446 elements in this sample represent 13 different species. This sample is also proposed to belong to Phase 4, since the most abundant taxa are *D. basiovalis* (25.6%), *M. parva* (24.7%) and *B. navis* (20.8%), and since the zonal fossil is only represented by one specimen among the 1446 elements in total. The frequency of '*Semiacontiodus*' aff. *cornuformis* is quite ample (6.8%), which also indicates Phase 4. *Scalpellodus latus* has increased to 8.0%. *Protopanderodus calceatus* occurs in low frequency (0.14%), and is included among '*Others*' in the range chart (Fig. 7).

Baltoniodus norrlandicus Zone

The *Baltoniodus norrlandicus* Zone, introduced by Bagnoli & Stouge (1997), can be correlated with the lower part of the *Microzarkodina parva* Zone proposed by Lindström (1971), and the lower boundary of the *B. norrlandicus* Zone is marked by the same criteria as the that of the *M. parva* Zone. Indicative for the base of the zone is the first appearance of *B. norrlandicus* (see Bagnoli & Stouge 1997), along with an increase in numbers of '*Semiacontiodus*' aff. *cornuformis*. Bagnoli & Stouge (1997) described the upper part of the *M. parva* Zone of Lindström (1971) as the *Lenodus antivariabilis* Zone. As Bagnoli & Stouge (1997) used a zone named *M. parva*, corresponding to the uppermost part of the *P. originalis* Zone (Phase 3-5), the *B. norrlandicus* Zone is used herein instead of the *M. parva* Zone of Lindström (1971).

Mä-30 (238 cm above the Flowery Sheet)
This sample consists of two combined samples, which are taken from the same horizon, but are laterally separated. The 1421 elements represent 16 different species. The most abundant taxon is *B. navis* (33.6%). Other common taxa are *D. basiovalis* (21.4%) and *M. parva* (11.9%). A few specimens of *B. norrlandicus* have been included amongst the *B. navis* elements. As the relative frequency of *P. originalis* is very low (2.0%), and *B. norrlandicus* is present in the sample, the sample is suggested to represent the base of the *B. norrlandicus* Zone, and not belonging to Phase 5 of the *P. originalis* Zone as might be assumed. *Scalpellodus latus* reaches its highest values at Mäekalda (8.7%) in this sample. '*Semiacontiodus*' aff. *cornuformis* is quite numerous (8.4%), and since that taxon is considered a typical shallow water species, its increase may correspond to a major regression. Included in *'Others'* in the range chart is another shallow water indicator; *Parapanderodus quietus* (0.7%).

Mä-31 (242 cm above the Flowery Sheet)
The 532 elements in this sample represent 12 different species. The sample is considered to belong to the *B. norrlandicus Zone,* since *B. norrlandicus* is present, although not in great numbers, and *P. originalis* is lacking. The most common taxon is *B. navis* with a relative frequency of 34.0% (rare *B. norrlandicus* elements have been included within *B. navis*). Other numerous taxa are *D. basiovalis* (29.2%) and *T. brevibasis* (13.9%). The number of '*Semiacontiodus*' aff. *cornuformis* elements is less than in Mä-30, but the taxon is still rather abundant (3.9%). Included in *'Others'* is *Protopanderodus calceatus* (0.8%).

Discussion

The conodont faunas derived from the investigated outcrop are in many ways similar to those of equivalent sequences in Sweden. Comparisons were made between the fauna from Mäekalda section and the faunas from the following Swedish localities: the Gillberga and Sandvik sections on Öland (Löfgren 1995), the Orreholmen quarry in Västergötland (Löfgren 1996), the Lanna quarry in Närke (Löfgren 1995), the Finngrundet drillcore in the south Bothnian Bay (Löfgren 1985), and Kloxåsen and Kalkberget in Jämtland (Löfgren 1978, 1995). The resemblances and differences between the Mäekalda section and the Swedish sections, and their possible causes are outlined below.

The two lowermost Mäekalda samples, Mä-14 and Mä-15, are referred to the upper part of the *B. navis* Zone. The relative frequency of *D. forceps* is 37.2% in Mä-14 and 42.4% in Mä-15. Löfgren (1993, 1995) described a drop in frequency of *D. forceps* in the upper part of this zone, which has been reported in e.g. the Finngrundet drillcore (Löfgren 1993). In lower parts of the zone *D. forceps* has very high relative frequencies, sometimes reaching more than 60% in samples from Jämtland (Löfgren 1993). Low numbers of *T. brevibasis* (0.1%) characterises Mä-14 and Mä-15, and according to Löfgren (1995) the presence of this taxon is acceptable within the *B. navis* Zone as long as the relative frequency is less than 0.3%, since the species has occasionally been reported in strata older than those belonging to the *P. originalis* Zone (Löfgren 1995).

The five phases within the *P. originalis* Zone proposed by Löfgren (1995), and suggested to be representing faunal changes due to physical events in the depositional environment, are distinguishable in the investigated outcrop. Samples from the Mäekalda section belonging to Phase 1 of the *P. originalis* Zone include Mä-16 and Mä-17, even though they lack the zonal fossil. *Triangulodus brevibasis* has reached 0.6% and 2.1%, respectively, and its co-occurrence with *M. flabellum* and *D. forceps*, is indicative for the phase. A decrease in the number of *M. flabellum* and *D. forceps* within this interval was noted by Löfgren (1995). In Mä-16 and Mä-17 *M. flabellum* decreases, but not *D. forceps*. One sample from Sandvik, Öland, Öl94-2, and two from Kloxåsen, Jämtland, J74-30 and J69-63, were referred to Phase 1, even though they had high frequencies of latter two taxa, and less than 5% of *P. originalis* (Löfgren 1995). These samples were considered to be from intervals close to the lower boundary (Löfgren 1995). This is probably also the case with the Mäekalda samples.

Samples Mä-18, Mä-19, Mä-20 and Mä-21 from the Mäekalda section are referred to Phase 2 within the *P. originalis* Zone. The lowermost of these samples, Mä-18, is probably taken near the boundary between Phase 1 and 2, since *D. forceps*, *M. flabellum* and *T. brevibasis* co-occur with *P. flabellum* and *D.* cf. *basiovalis*. In Mä-18, *D. forceps* is still abundant (45.0%), and *D.* cf. *basiovalis* occurs only in low numbers (2.8%). In Mä-19 *D. basiovalis* (38.5%) has replaced *D. forceps* (0.4%). *Periodon flabellum* only occurs in the two lowermost samples from Mäekalda (0.1% in each of them), distinguishing the

Mäekalda samples from the Swedish samples, which are believed to have been deposited in deeper water. Of all investigated Swedish samples from this interval, it is only in one sample from Kalkberget, Jämtland, that *P. flabellum* is absent (Löfgren 1995). At some localities, e.g. in Öland, the relative frequency of *P. flabellum* is less than 1% , and in some, e.g. in Jämtland, the frequency is more than 15%. *Drepanodus arcuatus* is rare in the samples from Mäekalda (Mä-18 - 21), with relative frequencies between 0.1-1.6% within Phase 2. This is similar to samples from Öland, where low values of the taxon have been reported (Löfgren 1995). In Jämtland *D. arcuatus* is more abundant (up to 7.4%) (Löfgren 1995). The Mäekalda samples also yield very low numbers of the zonal taxon compared to those from the Swedish localities. The relative frequency of *P. originalis* varies in Mä-18 - 21 between 4.3 and 16.1%. Similar abundances have only been reported in samples from Gillberga on Öland, with relative frequencies below 20% (Löfgren 1995). *Triangulodus brevibasis* is more abundant in the Mäekalda samples (2.2%-11.7%) than in the ones described by Löfgren (1995) (0.7-6.5%). *Protopanderodus rectus* is a quite common taxon with relative frequencies between 1.9-10.0% in the Mäekalda samples, but higher values were reported from e.g. Lanna (19-26%) (Löfgren 1995).

The samples from Mäekalda assigned to Phase 3 within the *P. originalis* Zone are Mä-22, Mä-23, Mä-24, Mä-25 and Mä-26. In Mä-22 *M. parva* first appears (11.9%), replacing its predecessor *M. flabellum*. *Protopanderodus rectus* is less common than in the previous interval, with values between 0.7-1.7%, and a similar decrease has also been reported from the Gillberga and Lanna samples (Löfgren 1995). The Mäekalda samples contain *T. brevibasis* to a greater extent (5.2-10.9%) than the Swedish samples do. The number of *P. originalis* in the Swedish samples is much higher than in the Mäekalda samples (11.1-25.8%). In samples from the Lanna section the relative frequency is greater than 40%, and in several other samples the zonal species makes up at least 30% (Löfgren 1995). Samples from Gillberga, Kloxåsen and Finngrundet have less than 30% of the zonal taxon (Löfgren 1995).

The *P. originalis* Zone, Phase 4, is distinguished in Mä-27, Mä-28 and Mä-29. The number of elements of *Scalpellodus latus* (Fig. H-I) increases within this interval (from 0.6 to 8.0%). In Mä-28 and Mä-29 an increase of '*S.*' aff. *cornuformis* occurs, and in all three Mäekalda samples also an increase of *M. parva* (15.4-24.7%) can be observed. Löfgren (1995) only reported '*S.*' aff. *cornuformis* within this phase in samples from Öland. *Paroistodus originalis* shows a sharp decrease in most of the Swedish samples, generally to between 0 and 0.4% (Löfgren 1995). The drop has been suggested to be a response to a regression (Löfgren 1995). In the Mäekalda samples the frequency varies between 0.07-6.2%, which is quite similar to the frequency fluctuations in Öland (up to 5.3%) (Löfgren 1995).

Phase 5 within the *P. originalis* Zone cannot be distinguished in the Mäekalda samples, since *P. originalis* never increases in numbers before the first appearance of *B. norrlandicus*. Generally the numbers of the zonal fossil are very low in the Mäekalda samples compared to the Swedish ones, since the Estonian sequence presumably represents a shallower environment than the Swedish sequences do. The thickness of the *P. originalis* Zone at Mäekalda is approximately 2 m, which is relatively thin compared to the Swedish sections, also due to shallower conditions. The zone is of varying thickness in the Swedish sections, e.g.; Kalkberget 8.0-9.0 m, Finngrundet between 5.5 and 6.4 m, Dalarna between 1 and 2 m, northern Öland about 1 m (Löfgren 1995).

The two uppermost samples from Mäekalda, Mä-30 and Mä-31, are referred to the *B. norrlandicus* Zone, since *B. norrlandicus* has its first appearance in the lower of these samples, and '*Semiacontiodus*' aff. *cornuformis* increases. The co-occurrence of *Baltoniodus navis* and *B. norrlandicus* has also been reported from lower parts of the zone, e.g. in Närke and Öland (Löfgren 1995). *Baltoniodus navis* is dominating and *B. norrlandicus* is rare in the samples from Mäekalda, whereas *B. norrlandicus* is dominating in Swedish samples.

Taxa with sporadic occurrences in the investigated samples from Mäekalda include *Cornuodus longibasis* (Fig. 8J), *Scolopodus rex*, *Decoriconus* cf. *mercurius*, *Trapezognathus* sp. and *Drepanodus arcuatus*. Their relative frequencies are quite similar to those in the Swedish samples, and most of them never or rarely reach more than a few percent.

Regional summary and conclusions

Seddon & Sweet (1971) proposed an ecological model for conodonts. According to this, different species are segregated by vertical stratification and all conodonts had a pelagic mode of life. Another ecological model, proposed by Barnes & Fåhraeus (1975), is based on lateral segregation, which forms laterally segregated conodont communities (Fåhraeus & Barnes 1975). This indicates that most Ordovician conodonts were benthic or nektobenthic (Barnes & Fåhraeus 1975). Some taxa, e.g. coniform taxa, are considered pelagic (Barnes & Fåhraeus 1975) in this model.

The investigated outcrop at Mäekalda represents a sequence deposited in a shallower part of the palaeobasin than coeval sediments from the Swedish sections do, due to an increased water depth gradient westwards. The eastern parts of Baltoscandia are thus representing the shallowest parts of the basin, and the deepest biofacies in Estonia is most probably similar in depth to the shallowest biofacies in the more western parts of Baltoscandia. Presumably this led to an environment more sensitive to sea level fluctuations than those in the deeper environments within the palaeobasin. This is reflected in the conodont fauna, which contains fewer typical deep water or open oceanic taxa, such as for instance *Periodon flabellum*, than the Swedish samples do. These taxa would increase only at the peak of a transgression in the lower parts of the ramp zone in contrast to its middle-upper parts. This is probably the reason why *Paroistodus originalis* in the samples from Mäekalda is generally less numerous than in central Sweden. The taxon is known to increase in intervals considered representing transgressive events (Löfgren 1995). The consequences of a regression in a shallow water environment could result in an increase of shallow water taxa, e.g. '*Semiacontiodus*' aff. *cornuformis* and *Microzarkodina*, which generally have higher relative frequencies at Mäekalda than in the Swedish faunas. '*Semiacontiodus*' aff. *cornuformis* occurs, albeit in low numbers, in almost all of the Mäekalda samples. In the two uppermost samples from the *P. originalis* Zone, the taxon increases in numbers. In the Swedish samples the taxon only occurs in very low numbers in Phase 4 and 5 within the *P. originalis* Zone, and only at Lanna (Närke) and Gillberga (Öland). The similarities between the Mäekalda samples and especially Öland samples are obvious, and could be explained by a shorter distance between the localities, leading to similar depth and depositional conditions.

Acknowledgements.- I thank my supervisor Anita Löfgren for all her help with questions and literature, a lot of good ideas and suggestions, and of course for introducing me to the subject. I am also grateful to her, Sofie Lindström and Mikael Siverson for constructive comments on the manuscript, and to Sven Stridsberg for help with the layout work. My colleagues and teachers at the department have patiently answered my questions and given me good advice during this study. My friends and my family have given me support through thick and thin. I am deeply thankful to all of you!

References

Bagnoli, Gabriella & Stouge, S., 1997: Lower Ordovician (Billingenian - Kunda) conodont zonation and provinces based on sections from Horns Udde, north Öland, Sweden. *Bollettino della Società Paleontologica Italiana 35(2)*, 109-163.

Barnes, C.R. & Fåhraeus, L.E., 1975: Provinces, communities, and the proposed nektobenthic habit of Ordovician conodontophorids. *Lethaia 8*, 133-149.

Briggs, D.E.G., Clarkson, E.N.K. & Aldridge, R.J., 1983: The conodont animal. *Lethaia 16,* 1-14.

Dzik, J., 1983: Relationships between Ordovician Baltic and North American Midcontinent conodont Faunas. *Fossils and Strata 15*, 59-86.

Einasto, R., Puura, I. & Viira, Viive, 1996: Mäekalda section. *In* T. Meidla, I. Puura, J. Nemliher, A. Raukas & L. Saarse, (eds.): *The Third Baltic Stratigraphical Conference. Abstracts. Field Guide*, 100-105, Tartu.

Epstein, Anita G., Epstein, J.B. & Harris, L.D., 1977: Conodont Color Alteration - an Index to regional metamorphism. *United States Geological Survey Professional Paper 995*, 1-27.

Fåhraeus, L.E. & Barnes, C.R., 1975: Conodonts as indicators of palaeogeographic regimes. *Nature 258*, 515-518.

Heinsalu, Helje & Viira, Viive, 1997a: Pakerort Stage. *In* A. Raukas & A. Teedumäe (eds.): *Geology and mineral resources of Estonia*, 52-57. Estonian Academy Publishers, Tallinn 1997.

Heinsalu, Helje & Viira, Viive, 1997b: Varangu Stage. *In* A. Raukas & A. Teedumäe (eds.): *Geology and mineral resources of Estonia*, 58-58. Estonian Academy Publishers, Tallinn 1997.

Jaanusson, V., 1976: Faunal dynamics in the Middle Ordovician (Viruan) of Baltoscandia. *In* M.G. Bassett (ed.): *The Ordovician System: Proceedings of a Palaeontological Association Symposium, Birmingham, September 1974*, 301-326.

Jeppsson, L., Fredholm, Doris & Mattiasson, B., 1985: Acetic acid and phosphatic fossils - a warning. *Journal of Paleontology 59*, 952-956.

Lindström, M., 1971: Lower Ordovician conodonts of Europe. *Geological Society of America, Memoir 127*, 21-61.

Lindström, M., 1984: Baltoscandic conodont life environments in the Ordovician: Sedimentologic and paleogeographic evidence. *Geological Society of America Special Paper 196*, 33-42.

Löfgren, Anita, 1978: Arenigian and Llanvirnian conodonts from Jämtland, northern Sweden. *Fossils and Strata 13*, 1-129.

Löfgren, Anita, 1985: Early Ordovician conodont biozonation at Finngrundet, south Bothnian Bay, Sweden. *Bulletin of the Geological Institutions of the University of Uppsala 10*, 135-148.
Löfgren, Anita, 1993: Arenig conodont successions from central Sweden. *Geologiska Föreningens i Stockholm Förhandlingar 115*, 193-208.
Löfgren, Anita, 1995: The middle Lanna/Volkhov Stage (middle Arenig) of Sweden and its conodont fauna. *Geological Magazine 132*, 693-711.
Löfgren, Anita, 1996: Lower Ordovician conodonts, reworking, and biostratigraphy of the Orreholmen quarry, Västergötland, south-central Sweden. *Geologiska Föreningens i Stockholm Förhandlingar 118*, 169-183.
Mac Niocaill, C., van der Pluijm B. A. & Van der Voo, R., 1997: Ordovician paleogeography and the evolution of the Iapetus ocean. *Geology 25*, 159-162.
Meidla, T., 1997a: Volkhov Stage. *In* A. Raukas & A. Teedumäe (eds.): *Geology and mineral resources of Estonia*, 61-63. Estonian Academy Publishers, Tallinn 1997.
Meidla, T., 1997b: Hunneberg Stage. *In* A. Raukas & A. Teedumäe (eds.): *Geology and mineral resources of Estonia*, 58-59. Estonian Academy Publishers, Tallinn 1997.
Meidla, T., 1997c: Billingen Stage. *In* A. Raukas & A. Teedumäe (eds.): *Geology and mineral resources of Estonia*, 60-61. Estonian Academy Publishers, Tallinn 1997.
Meidla, T., 1997d: Kunda Stage. *In* A. Raukas & A. Teedumäe (eds.): *Geology and mineral resources of Estonia*, 64-66. Estonian Academy Publishers, Tallinn 1997.
Meidla, T., Ainsaar, L. & Tinn, O., 1998: Volkhov Stage in northern Estonia and sea level changes. *Proceedings of the Academy of Sciences of the Estonian SSR, Geology, 47*, 141-157.
Mens, Kajsa, Viira, Viive, Paalits, I. & Puura, I., 1989: Cambrian-Ordovician boundary beds at Mäekalda, Tallinn, north Estonia. *Proceedings of the Academy of Sciences of the Estonian SSR, Geology, 38*, 101-111.
Pander, C.H., 1856: *Monographie der Fossilen Fische des silurischen Systems der russisch-baltischen Gouvernements*. 92 pp. Kaiserlichen Akademie der Wissenschaft, S:t Petersburg.
Seddon, G. & Sweet, W.C., 1971: An ecological model for conodonts. *Journal of Paleontology 45*, 869-880.
Torsvik, T.H., Smethurst, M.A., Meert, J.G., van der Voo, R., Mc Kerrow, W.S., Brasier, M.D., Sturt, B.A. & Walderhaug, H.J., 1996: Continental break-up and collision in the Neoproterozoic and Paleozoic - A tale of Baltica and Laurentia. *Earth-Science Reviews 40*, 229-258.

Tidigare skrifter i serien "Examensarbeten i Geologi vid Lunds Universitet":

45. Jacobsson, Mikael, 1993: Depositional and petrographic response of climatic changes in the Triassic of Höllviken-II, southern Sweden.
46. Christodoulou, Gina, 1993: Agglutinated foraminifera from the Campanian of the Kristianstad basin, southern Sweden.
47. Söderlund, Ulf, 1993: Structural and U-Pb isotopic age constraints on the tectonothermal evolution at Glassvik, Halland.
48. Remelin, Mika, 1993: En revision av Hedströms *Phragmoceras*-arter från Gotlands Silur.
49. Gedda, Björn, 1993: Trace fossils and Palaeoenvironments in the Middle Cambrian at Äleklinta, Öland, Sweden.
50. Månsson, Kristina, 1993: Trilobites and stratigraphy of the Middle Ordovician Killeröd Formation, Scania.
51. Carlsson, Patric, 1993: A Petrographic and Geochemical Study of the Early Proterozoic, Bangenhuk Granitoid Rocks of Ny Friesland, Svalbard.
52. Holmqvist, Björn.H., 1993: Stratigrafiska undersökningar i sjön Vuolep Njakajaure, Abisko.
53. Zander, Mia, 1993: Sedimentologisk undersökning av en kvartär deltaavlagring vid övre Jyllandselv, Jameson Land, Östgrönland.
54. Albrecht, Joachim, 1993: Sedimentological and lithostratigraphical investigations in the gravel pit "Hinterste Mühle" at Neubrandenburg, northeastern Germany.
55. Magnusson, Martin, 1994: Sedimentologisk och morfologisk undersökning av Gyllebo-Baskemöllafältet, östra Skåne.
56. Holmqvist, Johan, 1994: Vittring i en moränjord vid Farabol, NV Blekinge.
57. Andersson, Torbjörn, 1994: A sedimentological study of glacial deposits in the upper Sjællandselv area, Jameson Land, East Greenland.
58. Hellman, Fredrik, 1994: Basement - cover relationships in the Harkerbreen Group of the northern Ny Friesland Caledonides, Svalbard.
59. Friberg, Magnus, 1994: Structures and PT determination of the Caledonian metamorphism of the lower part of the Planetfjella Group in the area around Mosseldalen, northern Ny Friesland, Svalbard.
60. Remelin, Mika, 1994: Palaeogeographic and sedimentation models for the Whitehill-Irati sea during the Permian of South America and southern Africa.
61. Hagman, Mats, 1994: Bevattning med avloppsvatten - en hydrogeologisk studie.
62. Sandström, Olof, 1994: Petrology and depositional history of the Campanian strata at Maltesholm, Scania, southern Sweden.
63. Pålsson, Christian, 1995: Middle-Upper Ordovician trilobites and stratigraphy along the Kyrkbäcken rivulet in the Röstånga area, southern Sweden.
64. Gustafson, Lars, 1995: Senkvartär stratigrafi och utveckling i Örseryd, mellersta Blekinge.
65. Gichina, Boniface M., 1995: Early Holocene water level changes as recorded on the island of Senoren, eastern Blekinge, southeastern Sweden.
66. Nilson, Tomas, 1996: Process- och miljötolkning av sedimentationen i en subglacial läsideskavitet, Järnavik, S. Blekinge.
67. Andersson, Jenny, 1996: Sveconorwegian influence on the ca. 1.36 Ga old Tjärnesjö granite, and associated pyroxene bearing quartz-monzonites in southwestern Sweden.
68. Olsson, Ingela, 1996: Sedimentology of the Bajocian Fuglunda Member at Eriksdal, Scania, southern Sweden.
69. Calner, Hanna, 1996: Trace fossils from the Paleocene-Middle Eocene Monte Sporno flysch complex, Northern Apennines, Italy.
70. Calner, Mikael, 1996: Sedimentary structures and facies of fine grained deep-water carbonate turbidites in a Paleocene-Middle Eocene flysch complex, Monte Sporno, Northern Apennines, Italy.
71. Hesbøl, Ros-Mari, 1996: Retrograded eclogites of the Richarddalen Complex, NW Svalbard - Petrology and P/T-contitions.
72. Eriksson, Mats, 1996: Lower Silurian polychaetaspid and ramphoprionid polychaetes from Gotland: aspects on taxonomy and palaeoecology.
73. Larsson, Daniel, 1996: Proterozoic hydrothermal alteration and mineralization along the Protogine Zone in southern Sweden.
74. Rees, Jan, 1996: A new hybodont shark fauna from the Upper Jurassic Vitabäck Clays at Eriksdal, Scania, southern Sweden.
75. Bengtsson, Fredrik, 1996: Paleomagnetisk undersökning av senpaleozoiska gångbergarter i Skåne; Kongadiabas, melafyr och kullait.
76. Björngreen, Maria, 1996: Kontrollprogram vid avfallsupplag - en utvärdering.
77. Hansson, Anders, 1996: Adaptations and evolution in terrestrial carnivores.
78. Book, Jenny, 1996: A Light Microscopy and Scanning Electron Microscopy study of coccoliths from two bore holes along the City Tunnel Line in Malmö, Sweden.
79. Broström, Anna, 1996: The openess of the present-day landscape reflected in pollen assem-blages from surface sediments in lakes -

a first step towards a quantitative approach for the reconstruction of ancient cultural landscapes in south Sweden.

80. Paulsson, Oskar, 1996: Sevekomplexets utbredning i norra Kebnekaise, Skandinaviska Kaledoniderna.
81. Sandelin, Stefan, 1997: Tektonostratigrafi och protoliter i Mårma-Vistasområdet, Kebnekaise, Skandinaviska Kaledoniderna.
82. Meyerson, Jacob, 1997: Uppermost Lower Cambrian - Middle Cambrian stratigraphy and sedimentary petrography of the Almbacken drill-core, Scania, southern Sweden.
83. Åkesson, Mats, 1997: Moränsedimentologisk undersökning och bestämning av postglacialt bildade järn- och manganmineral i en drumlinformad rygg.
84. Ahlgren, Charlotte, 1997: Late Ordovician communities from North America.
85. Strömberg, Caroline, 1997: The conodont genus *Ctenognathodus* in the Silurian of Gotland, Sweden.
86. Borgenlöv, Camilla, 1997: Vätskeinklusioner som ledtrådar till bildningsmiljön för Bölets manganmalm, Västergötland, södra Sverige.
87. Mårtensson, Thomas, 1997: En petrografisk och geokemisk undersökning av inneslutningar i Nordingrågraniten.
88. Gunnemyr, Lisa, 1997: Spårämnesförsök i konstgjort infiltrerat vatten - en geologisk och hydrogeologisk studie av Strömsholmsåsen, Hallstahammar, Västmanland.
89. Antonsson, Christina, 1997: Inventering, hydrologisk klassificering samt bedömning av hydrogeologisk påverkan av våtmarksområden i samband med järnvägstunnelbyggnation genom Hallandsåsen, NV Skåne.
90. Nordborg, Fredrik, 1997: Granens markpåverkan - en studie av markkemi, jordmånsbildning och lermineralogi i gran- och lövskogsbestånd i södra Småland.
91. Dobos, Felicia, 1997: Pollen-stratigraphic position of the last Baltic Ice Lake drainage.
92. Nilsson, Johan, 1997: The Brennvinsfjorden Group of southern Botniahalvøya, Nordaustlandet, Svalbard - structure, stratigraphy and depositional environment.
93. Tagesson, Esbjörn, 1998: Hydrogeologisk studie av grundvattnets kloridhalter på östra Listerlandet, Blekinge.
94. Eriksson, Saskia, 1998: Morängenetiska undersökningar i klintar vid Greifswalder Boddens södra kust, NÖ Tyskland.
95. Lindgren, Johan, 1998: Early Campanian mosasaurs (Reptilia; Mosasauridae) from the Kristianstad Basin, southern Sweden.
96. Ahnesjö, Jonas, B., 1998: Lower Ordovician conodonts from Köpings klint, central Öland, and the feeding apparatuses of *Oistodus lanceolatus* Pander and *Acodus deltatus* Lindström.
97. Rehnström, Emma, 1998: Tectonic stratigraphy and structural geology of the Ålkatj-Tielma massif, northern Swedish Caledonides.
98. Modin, Anna-Karin, 1998: Distributionen av kadmium i moränmark kring St. Olof, SÖ Skåne.
99. Stockfors, Martin, 1998: High-resolution methods for study of carbonate rock: a tool for correlating the sedimentary record.
100. Zillén, Lovisa, 1998: Late Holocene dune activity at Sandhammaren, southern Sweden-chronology and the role of climate, vegetation, and human impact.
101. Bernhard, Maria, 1998: En paleoekologisk-paleohydrologisk undersökning av våtmarkskomplexet Rolands hav, Blekinge.
102. Carlemalm,Gunnar, 1999: En glacialgeologisk studie av morän och moränfyllda sprickor i underliggande sandursediment, Örsjö, Skåne.
103. Blomstrand, Malou, 1999: 1992-1998 Seismicity and Deformation at Mt.Eyjafjallajökull volcano,South Iceland.
104. Dahlqvist, Peter, 1999: A Lower Silurian (Llandoverian) halysitid fauna from the Berge Limestone Formation, Norderön, Jämtland, central Sweden.
105. Svensson, Magnus A., 1999:Phosphatized echinoderm remains from upper Lower Ordovician strata of northern Öland, Sweden - preservation, taxonomy and evolution.
106. Bengtsson, Anders, 1999: Trilobites and bradoriid arthropods from the Middle and Upper Cambrian at Gudhem in Västergötland, Sweden
107. Persson, Christian, 1999: Silurian graptolites from Bohemia, Czech Rebublic
108. Jacobson, Mattias, 1999: Five new cephalopod species from the Silurian of Gotland
109. Augustsson, Carita, 1999: Lapillituff som bevis för underjurassisk vulkanism av strombolikaraktär i Skåne
110. Jensen, Sigfinn J., 1999: En silurisk transgressiv karbonatlagerföljd vid S:t Olofsholms stenbrott, Gotland
111. Lund, Mats G., 1999: En strukturgeologisk modell för berggrunden i Sarvesvagge-Luottalako-området, Sareks Nationalpark, Lappland
112. Magnusson, Jakob, 1999: Exploration of submarine fans along the Coffee Soil Fault in the Danish Central Graben
113. Wickström, Jenny, 1999: Conodont biostratigraphy in Volkhovian sediments from the Mäekalda section, north-central Estonia.