RECONSTRUCTION AND USE OF THE SUCCESSION OF EAST BALTIC SILURIAN OSTRACODES

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Abstract. On the basis of distributions of East Baltic Silurian ostracodes (205 species of 43 core sections) a succession of 80 selected species is constructed. The succession is considered as an ordinal timescale and compared with the available biozonal scheme based on the same ostracodes. The succession is subdivided into ages by the index species of regional stages as defined in the zonal scheme.

Key words: ostracodes, palaeontological timescales, biozones, geochronology, East Baltic Silurian.

INTRODUCTION

Numerous studies on the ostracodes of the East Baltic Silurian carried out by A. Neckaja, L. Gailite, A. Pranskevičius, N. Sidaravičiene, L. Sarv, and others have revealed about 300 species from nearly 100 sections (see Meidla & Sarv, 1990). The most valuable data were obtained from core sections drilled in the course of geological mapping of the area. Distributions of these ostracodes in a great number of sections comprise a unique data set for any kind of studies based on palaeontological records, predominantly for the stratigraphy of the Silurian in the East Baltic and adjacent areas.

The aim of this paper has been to reconstruct a temporal succession of the studied species which are not affected by sedimentological or environmental factors, as in particular sections, and whose composition is free of any kind of previously determined stratigraphical correlation, such as range charts plotted against prescribed chronostratigraphic units. It has been shown that such a succession of species can be built by estimating and arranging their total ranges in relation to a reference section (Shaw,

1964) or by means of their mutual positions (see Guex, 1989; Agterberg, 1990). The successions achieved so have been taken as palaeontological timescales, which can be ordinal or interval scales, and used as tools to date rocks in terms of any kind of geochronological units, including those defined by boundary stratotypes (Rubel & Pak, 1984; Cooper, 1992; Kleffner, 1995). The ordinal succession of the East Baltic Silurian ostracodes given below will be compared with their available biozones established by L. Gailite, D. Kaljo, and L. Sarv (Meidla & Sarv, 1990) and tied to the regional stages of the Silurian of Estonia.

THE DATA SET

The data set, based on taxonomic identifications by L. Sarv, includes the ranges of 295 species from 43 East Baltic core sections (Fig. 1, Table 1).

Table 1

List of core sections and their stratigraphy.
LL, Llandovery; WN, Wenlock; LU, Ludlow; PR, Přidoli; E, Estonia; La, Latvia;
Li, Lithuania; R, Russia

Section	LL	WN	LU	PR	Section	LL	WN	LU	PR
Abja, E	+	–	–	–	Nässuma, E	+	+	+	+
Aknīste, La	+	+	–	–	Ohesaare, E	+	+	+	+
Alūksne, La	+	–	–	–	Ohesaare-2, E	–	–	–	+
Asuküla, E	+	–	–	–	Ohesaare, cliff, E	–	–	–	+
Dubovskoe, R	–	–	+	+	Palamuse, E	+	–	–	–
Ezere, La	–	–	+	+	Pāvilosta, La	–	–	+	+
Holdre, E	+	–	–	–	Piltene-1, La	–	–	+	+
Kabala, E	+	–	–	–	Piltene-32, La	–	–	+	+
Kalvarija, Li	+	+	–	–	Priekule, La	–	–	+	+
Karja-Pärsamaa, E	+	+	–	–	Pärnu, E	+	+	–	–
Kaugatuma, E	–	–	+	+	Pärnu-VI, E	+	+	–	–
Kihnu, E	+	+	–	–	Stoniškiai, Li	–	–	+	+
Kingissepa, E	–	+	–	–	Tauragė, Li	–	–	–	+
Kipi, E	+	–	–	–	Tinuri, E	+	+	–	–
Kolka, La	–	–	+	+	Tori, E	+	–	–	–
Koonga, E	+	–	–	–	Valjala, E	+	+	–	–
Krekenava, Li	+	+	+	–	Ventspils, La	–	–	+	+
Kunkojai, Li	–	+	+	+	Vesiku, E	+	–	–	–
Meedla, E	–	–	+	+	Viesīte, La	+	–	–	–
Mežciems, La	–	+	–	–	Virbalis, Li	–	+	+	+
Märjamaa-I, E	+	–	–	–	Äiamaa, E	+	+	–	–
Märjamaa-II, E	+	–	–	–					
					Total	23	17	18	17

It was organized as a computer database including the following three files:

(1) the accepted species list;

(2) the list of sections and their stratigraphy;

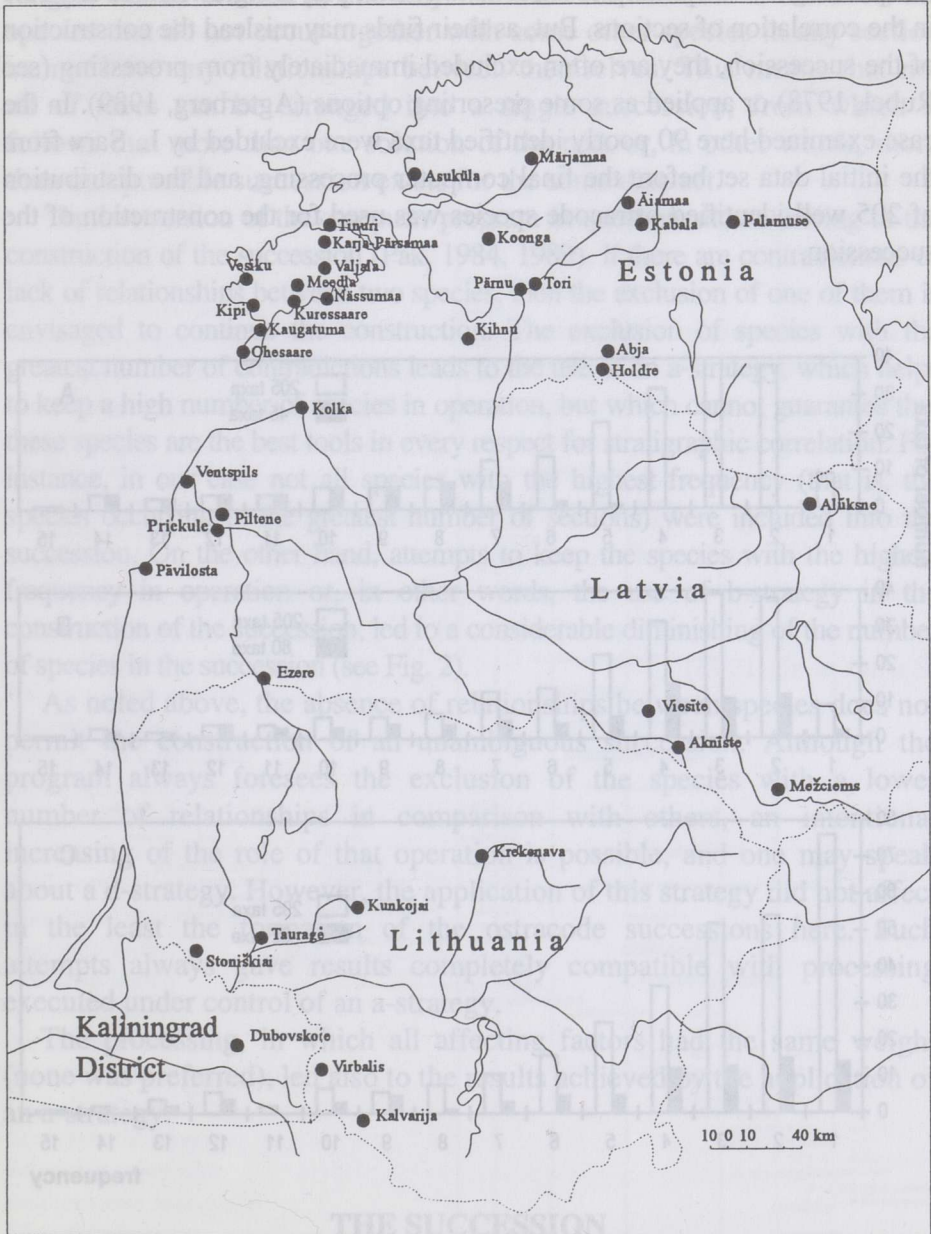(3) the distribution of species: the first and last appearances according to the corresponding depths in each section.

Fig. 1. Location of the borings.

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There were nearly a thousand local intervals of these 295 species from 43 sections. The sections are mostly distributed in Estonia (25), Latvia (10), Lithuania (6), and Kaliningrad District of Russia (1) (Fig. 1). Two borings penetrated the whole Silurian sequence (Table 1).

The full list of East Baltic Silurian ostracodes includes many taxa with open nomenclature (identifications with *aff.*, *cf.*, *ex gr.*, *sp.*). Most of these have a very restricted distribution, usually only in one section or even one sample (Fig. 2). In principle, these taxa cannot play a significant or any role in the correlation of sections. But, as their finds may mislead the construction of the succession, they are often excluded immediately from processing (see Rubel, 1978) or applied as some presorting options (Agterberg, 1989). In the case examined here 90 poorly identified taxa were excluded by L. Sarv from the initial data set before the final computer processing, and the distribution of 205 well-identified ostracode species was used for the construction of the succession.
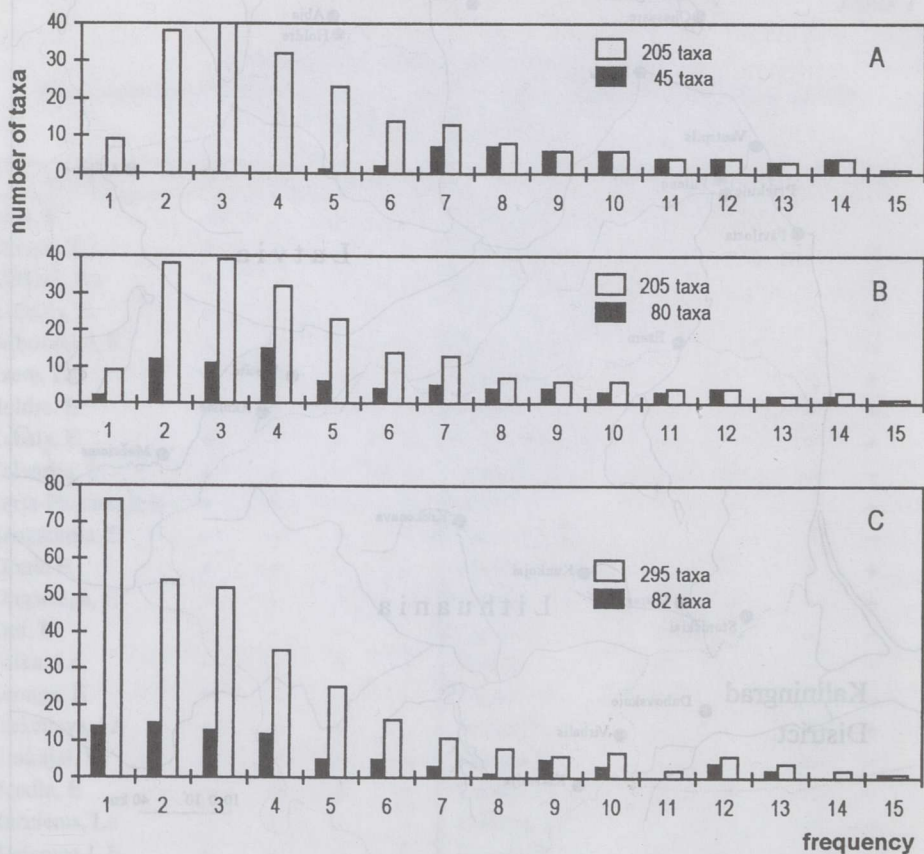

Fig. 2. Distribution of taxa in frequency classes (1–15): A, B, selected taxa; C, all taxa. The black area indicates the number of taxa included into the succession according to a-strategy (B, C) and b-strategy (A).

METHOD AND STRATEGIES

To construct the required succession of species, the algorithm by Rubel & Pak (1984) was used here. This algorithm finds the succession spanning the local ranges of each species by its observed coexistence with other species, arranged in turn by their persistent order in all sections. Unfortunately, not all species, even by their estimated total ranges, can be ordered in this way without contradictions. Moreover, the species that do not occur together with some other species in any section cannot have any relationships between themselves. This means that not all of them can be arranged into a single succession, from which it follows that more than one solution of the task or, in other words, more than one possible succession exists for the same data set.

The last version of the computer program in question allows driving of the construction of the succession (Pak, 1984, 1989). If there are contradictions or lack of relationships between two species, then the exclusion of one of them is envisaged to continue the construction. The exclusion of species with the greatest number of contradictions leads to the use of an a-strategy, which helps to keep a high number of species in operation, but which cannot guarantee that these species are the best tools in every respect for stratigraphic correlation. For instance, in our case not all species with the highest frequency (that is, the species occurring in the greatest number of sections) were included into the succession. On the other hand, attempts to keep the species with the highest frequency in operation or, in other words, the use of b-strategy in the construction of the succession, led to a considerable diminishing of the number of species in the succession (see Fig. 2).

As noted above, the absence of relationships between species does not permit the construction of an unambiguous succession. Although the program always foresees the exclusion of the species with a lower number of relationships in comparison with others, an intentional increasing of the role of that operation is possible, and one may speak about a d-strategy. However, the application of this strategy did not affect in the least the formation of the ostracode successions here. Such attempts always gave results completely compatible with processing executed under control of an a-strategy.

The processing, in which all affecting factors had the same weight (none was preferred), led also to the results achieved by the application of an a-strategy.

THE SUCCESSION

The use of the a-strategy within the program arranged the 80 species from the 205 presorted Baltic Silurian ostracodes into a timescale. This

scale was one of the richest in the number of species and had a relatively high average frequency of its species if compared with other possible scales (see Table 2). The order of appearances and disappearances of these 80 species in the accepted succession defines 28 datum planes.

Processing strategies and results

No. of species processed	Strategy	Species in succession	Datum plane	Average frequency
295	a	82	27	4.854
205	b	45	9	9.844
205	a	80	28	6.038

The species included into the succession have various ranges, although most of them tend to be quite short-ranging. There exists a noticeable break in the middle of the succession, where only a small number of short-ranging species occurs, from which in turn only one, *Signetopsis semicircularis,* is common to the lower and upper halves of the succession (Fig. 3, Table 3). Such a break indicates clearly the uneven temporal distribution of the studied ostracodes. It is very likely that the break reflects the widely expressed late Wenlock regression of the Baltic sedimentary basin and may be related to the Middle Homerian Event (Barnes et al., 1995).
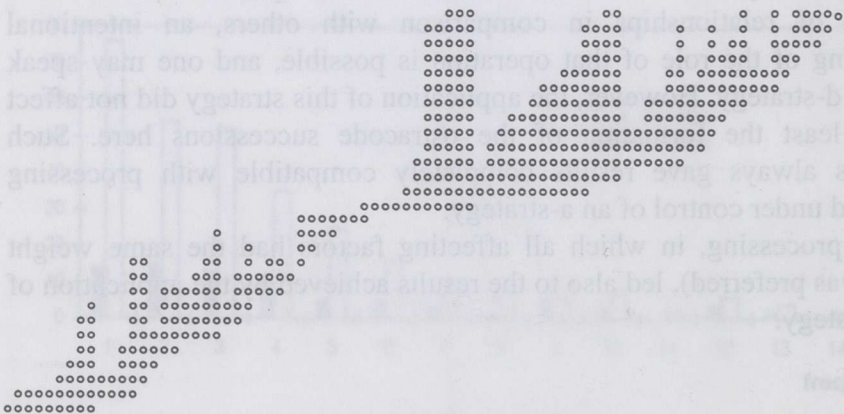

Fig. 3. Pure succession (compare with Table 3) to show the uneven distribution (break) of the studied ostracodes.

The main part of the succession consists of species with a relatively high frequency and can be considered as a fairly uniform base for the dating (correlation) of the sections studied. If one takes into consideration the number of species defining the datum planes, then the most easily detectable datum plane is located in the middle of the succession and related to the above-mentioned break in the succession.

Table 3

Succession of 80 taxa as a timescale showing the regional ages. Stage abbreviations are according to Table 4. a, appearances and d, disappearances used by Kaljo (1990) to define stages by their lower boundaries
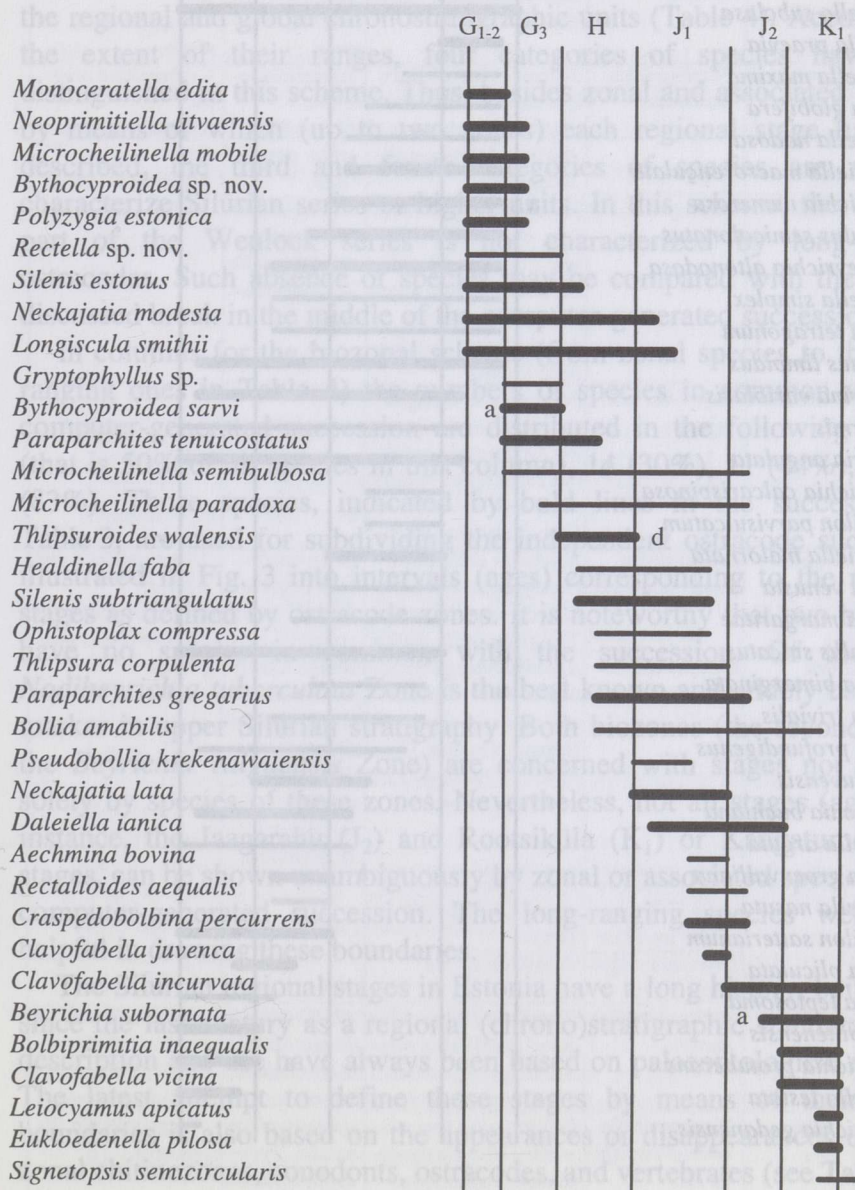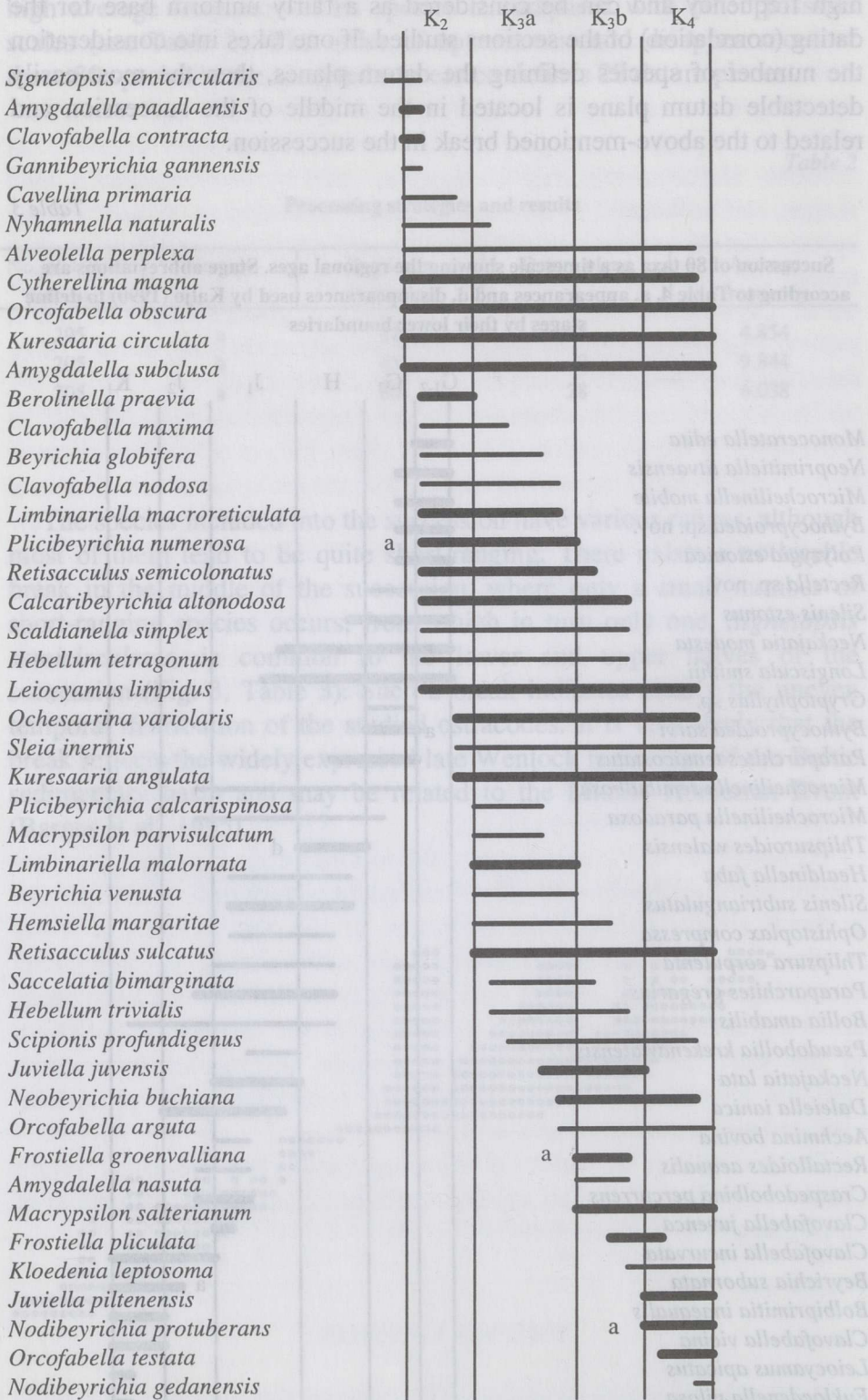
	G$_{1-2}$	G$_3$	H	J$_1$	J$_2$	K$_1$
Monoceratella edita						
Neoprimitiella litvaensis						
Microcheilinella mobile						
Bythocyproidea sp. nov.						
Polyzygia estonica						
Rectella sp. nov.						
Silenis estonus						
Neckajatia modesta						
Longiscula smithii						
Gryptophyllus sp.						
Bythocyproidea sarvi	a					
Paraparchites tenuicostatus						
Microcheilinella semibulbosa						
Microcheilinella paradoxa						
Thlipsuroides walensis			d			
Healdinella faba						
Silenis subtriangulatus						
Ophistoplax compressa						
Thlipsura corpulenta						
Paraparchites gregarius						
Bollia amabilis						
Pseudobollia krekenawaiensis						
Neckajatia lata						
Daleiella ianica						
Aechmina bovina						
Rectalloides aequalis						
Craspedobolbina percurrens						
Clavofabella juvenca						
Clavofabella incurvata						
Beyrichia subornata					a	
Bolbiprimitia inaequalis						
Clavofabella vicina						
Leiocyamus apicatus						
Eukloedenella pilosa						
Signetopsis semicircularis						

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Table 3 continued

K₂ K₃a K₃b K₄

Signetopsis semicircularis
Amygdalella paadlaensis
Clavofabella contracta
Gannibeyrichia gannensis
Cavellina primaria
Nyhamnella naturalis
Alveolella perplexa
Cytherellina magna
Orcofabella obscura
Kuresaaria circulata
Amygdalella subclusa
Berolinella praevia
Clavofabella maxima
Beyrichia globifera
Clavofabella nodosa
Limbinariella macroreticulata
Plicibeyrichia numerosa
Retisacculus semicolonatus
Calcaribeyrichia altonodosa
Scaldianella simplex
Hebellum tetragonum
Leiocyamus limpidus
Ochesaarina variolaris
Sleia inermis
Kuresaaria angulata
Plicibeyrichia calcarispinosa
Macrypsilon parvisulcatum
Limbinariella malornata
Beyrichia venusta
Hemsiella margaritae
Retisacculus sulcatus
Saccelatia bimarginata
Hebellum trivialis
Scipionis profundigenus
Juviella juvensis
Neobeyrichia buchiana
Orcofabella arguta
Frostiella groenvalliana
Amygdalella nasuta
Macrypsilon salterianum
Frostiella pliculata
Kloedenia leptosoma
Juviella piltenensis
Nodibeyrichia protuberans
Orcofabella testata
Nodibeyrichia gedanensis

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USE

As with the Baltic ostracode biozones, the succession discussed here is a tool to date the rocks or geological events. However, only the succession can be considered as a strictly operating but ordinal timescale and, therefore, used in a proper way (see Rubel & Pak, 1984), while the biozones are stratigraphic units defined by occurrences of some fossils and can be used firstly as time markers. In spite of differences in technology of their formation as well as use, a succession and a zonal scheme can be compared against each other because they are both based on the evolutional order of species, which is used for the same goal.

The ostracode zones discussed here are clearly directed to characterize the regional and global chronostratigraphic units (Table 4). According to the extent of their ranges, four categories of species have been distinguished in this scheme. Thus, besides zonal and associated species, by means of which (up to two zones) each regional stage has been described, the third and fourth categories of species are used to characterize Silurian series or higher units. In this scheme, the topmost part of the Wenlock series is not characterized by long-ranging ostracodes. Such absence of species may be compared with the above-discussed break in the middle of the computer-generated succession.

In columns for the biozonal scheme (from zonal species to the long-ranging ones in Table 4) the numbers of species in common with the computer-generated succession are distributed in the following way: 7 (that is 50% of all species in this column), 14 (30%), 11 (44%), and 15 (83%). Those species, indicated by bold lines in the succession of Table 3, are used for subdividing the independent ostracode succession illustrated in Fig. 3 into intervals (ages) corresponding to the regional stages as defined by ostracode zones. It is noteworthy that two biozones have no species in common with the succession. Of these the *Nodibeyrichia tuberculata* Zone is the best known and widely used time marker in upper Silurian stratigraphy. Both biozones (the second one is the *Beyrichia valguensis* Zone) are concerned with stages not defined solely by species of these zones. Nevertheless, not all stages (ages), for instance, the Jaagarahu (J_2) and Rootsiküla (K_1) or Kaugatuma (K_3b) stages, can be shown unambiguously by zonal or associated species in the computer-generated succession. The long-ranging species were then helpful in drawing these boundaries.

The Silurian regional stages in Estonia have a long history, being used since the last century as a regional (chrono)stratigraphic standard. Their description and use have always been based on palaeontological records. The latest attempt to define these stages by means of their lower boundaries is also based on the appearances or disappearances of some zonal chitinozoans, conodonts, ostracodes, and vertebrates (see Table 2 in

Table 4

Zonal scheme by Sarv (according to Meidla & Sarv, 1990)

SERIES	REGIONAL STAGE	OSTRACODE ZONES	CHARACTERISTIC SPECIES FOR STAGE OR ZONE	FOR SERIES	LONG-RANGING SPECIES
Pridoli	Ohesaare K₄	*Nodibeyrichia protuberans*	*Berolinella steusloffi, Juviella piltenensis, Frostiella loodensis, Orcofabella testata*	*Hemsiella maccoyiana, Macrypsilon salterianum, Neobeyrichia buchiana, Frostiella pliculata, Orcofabella araneosa, Venzavella, multicostata, V. costata*	*Retisacculus semicolonatus, Juviella juvensis, Ochesaarina variolaris, Amygdalella subclusa, Nemuniella solida, Leiocyamus limpidus, Orcofabella obscura, Cytherellina magna, Kuresaaria angulata, Kuresaaria circulata*
	Kaugatuma K₃b	*Nodibeyrichia tuberculata*	*Frostiella cornuta, Aechmina molengraaffii*		
		Frostiella groenvalliana	*Sleia equestris, Nodibeyrichia bifida, Signetopsis decorata*		
Ludlow	Kuressaare K₃a	*Plicibeyrichia numerosa*	*Retisacculus sulcatus, Calcaribeyrichia altonodosa, Primitiopsis minima, Limbinariella malornata*	*Hemsiella loensis, Calcaribeyrichia simplicior, Clavofabella contracta, Limbinariella macroreticulata*	
	Paadla K₂	*Neobeyrichia nutans*	*Hammariella pulchrivelata, Berolinella praevia, Hemsiella hemsiensis, Neobeyrichia ctenophora, Amygdalella paadlaensis, Clavofabella diffusa*		
Wenlock	Rootsiküla K₁	*Beyrichia subornata*	*Bolbiprimitia inaequalis, Ochesaarina lunaris, Leiocyamus apicatus, Signetopsis malornata, Eukloedenella pilosa, Lichvinia silurica*		
	Jaagarahu J₂	*Leptobolbina quadricuspidata*	*Beyrichia hellviensis, Clavofabella extenata, C. incurvata, C. vicina, Triemilomatella prisca*	*Craspedobolbina cuspidulata, C. percurrens, C. insulicola, Clavofabella reticristata, Gotlandella cornuta, Silenis subtriangulatus, Daleiella ianica, D. acutafinis*	*Neoprimitiella versipella, Bollia amabilis, Paraparchites gregarius, Neckajatia lata*
	Jaani J₁	*Craspedobolbina mucronulata*	*Apatobolbina gutnica, Beyrichia bicuspis, B. suurikuensis, Craspedobolbina ornulata, Clavofabella juvenca, Venzavella germana*		
Llandovery	Adavere H	*Longiscella caudalis-Thlipsuroiroides walensis*	*Apatobolbina simplicidorsata, Noviportia silurica*		
		Beyrichia valguensis	*Beyrichia ultima*		
	Raikküla G₃	*Bythocyproidea sarvi*	*Craspedobolbina permira, Bolbibollia estona, Bingeria pristina, Herrmannina hisingeri*	*Aitilia senecta, Silenis estonus, Microcheilinella mobile, Paraprimitia bipunctata, Polyzygia estonica*	*Neckajatia modesta, Longiscula* cf. *smithi, Paraparchites tenuicostatus, Neoprimitiella litvaensis*
	Juuru G₁₋₂	*Monoceratella edita-Steusloffina eris*	*Bolbiprimitia tamsaluensis, Kiltsiella rosensteinae, Bythocyproidea* sp.		

Kaljo, 1990). The ostracode index events coincide well with others; only two to three of them indicate a boundary a little higher than that proposed by chitinozoan or conodont markers (ibid.). If one wants now to use these ostracode events for recognition of the ages (stages) in their succession as presented here, then compatible intervals can be achieved. Only two of such marker species, *Plicibeyrichia numerosa* and *Beyrichia subornata,* indicate an earlier boundary position than drawn by means of the biozonal and associated ostracodes in the succession.

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IDA-BALTIKUMI SILURI OSTRAKOODIDE AJALISE JÄRGNEVUSE REKONSTRUEERIMINE JA RAKENDUS

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Ida-Baltikumi siluri 205 ostrakoodiliigi (saadud 43 puuraugust) levik oli aluseks nende ajalise järgnevuse rekonstrueerimisele. Kasutatud algoritm reastas neist 80 liiki, mille ilmumine ja kadumine, järjestatuna nende täisintervallide järgi, defineeris 28 korrelatiivset taset. Niisugust järgnevust vaadeldi iseseisva ajaskaalana, mille võrdlus samade ostrakoodide biotsonaalse skeemiga näitas head kokkulangevust ja võimaldas saadud skaalat kalibreerida regionaalseile lademeile vastavaiks lõikudeks (igadeks). Skaala on kasutatav regionaalses kronostratigraafias.

РЕКОНСТРУКЦИЯ И ПРИМЕНЕНИЕ ПОСЛЕДОВАТЕЛЬНОСТИ СИЛУРИЙСКИХ ОСТРАКОД В ПРИБАЛТИКЕ

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На основе данных распространения 205 видов силурийских остракод из 43 буровых скважин рассматриваемого региона восстановлена последовательность полных интервалов их существования. Использованный для этого алгоритм расставил 80 видов из упомянутого числа в порядке их появления и вымирания. Эта последовательность представила 28 корреляционных уровней, а сам порядок видов – шкалу относительного времени. Сравнение этой шкалы с имеющейся биозональной схемой тех же остракод показало их хорошее совпадение, что, в свою очередь, позволило подразделить полученную последовательность на соответствующие региональным горизонтам временные интервалы.